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Financial reforms and innovation: A micro-macro perspective

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Financial reforms and innovation: a micro-macro perspective

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Abstract

We develop a horizontal R&D growth model that allows us to investigate the different channels through which financial reforms affect R&D investment and patent activity. First, a “micro” reform that abolishes barriers to entry in the banking sector produces a straightforward result: a decrease in lending rates which stimulates R&D investment and economic growth. Second, a “macro” reform that removes restrictions on banks’ reserves and credit controls. While this reform increases liquidity, it also increases the risk of default, potentially raising the cost of borrowing. This we dub the “reserves paradox” – this makes banks offset the rise in the default rate with a higher spread between loans and deposit rates. Thus our model suggests that whilst micro reforms boost innovation, macro reforms may appear negative. We test and find empirical support for these propositions using a sample of 21 OECD countries.

JEL classification: G2, C23, E44, O43.

Keywords Finance; Growth; Patents; Monitoring; Reserves Paradox; Estimation.

Non-Technical Summary

The link between the size and nature of the financial sector and developments in the real economy is a common if unresolved issue in the literature. In this paper, we develop an endogenous growth model where the long run per capita growth rate of the economy is related to innovation activity, R&D investments, and patenting. We assume that the R&D expenditure is financed through loans from the banking system.

The theory model allows us to examine both micro and macro changes and reforms in the financial system that may arise and may have consequences for innovation activity. The former change is associated with reduced barriers to entry in the banking system which increase competition and lowers borrowing costs. The macro reform translates into the removal of reserve requirements and credit control restrictions. This increases liquidity but, on the other hand, increases the induced risks of default and insolvency. Higher risks in the banking sector force banks to implement an extra premium between interest rate for loans and deposits which increases the spread further and therefore the borrowing cost for R&D firms.

We map the predicted channels of the model to an estimated form. Examining a panel of 21 OECD countries over 1981-2005, we find that micro financial reforms have a positive impact on patenting activity whilst macro reforms have a negative effect. These empirical predictions line up with the theory model.

1 Introduction

The link between finance and economic growth is one of the most enduring controversies in economics (e.g., Tobin and Brainard, 1963; King and Levine, 1993; Rajan and Zingales, 1998; Beck et al. 2000; Christopoulos and Tsionas, 2004; Ang, 2008; Laeven, et al., 2015; Popov, 2018; Aghion et al., 2018; Papadopoulos, 2019). Much of this literature posits that a well-developed financial system enhances resource allocation: financial intermediaries monitor risks and the distribution of funds across investment projects. This helps coordinate transactions and lowers information costs and the cost of external finance (Greenwood and Jovanovic, 1990; Bencivenga and Smith, 1991). A well-functioning financial market can not only potentially help incumbent firms to grow but also facilitates the emergence of new entrants (Bekaert et al. 2005; Hsu et al. 2014, Faria, 2016).

Although the literature provides ample evidence for a connection between financial development and growth,¹ the mechanisms underlying some of those links remain unclear. Although innovation boosts living standards over time, little is known on how innovation-intensive sectors respond to financial reforms (such as to “liberalize” the financial system). Likewise, it is unclear whether all financial reforms aid growth.

To address this question, we develop an endogenous growth model in which funding investment in Research and Development (R&D) is affected by financial markets. Those effects, however, are allowed to differ depending on the financial channel involved and the associated policy reform. The scarce empirical evidence up to now (Ang, 2011) suggests a negative link between financial policy reforms and innovation.² Notably, these findings rely on *aggregate* indices of financial reforms, without investigating the *individual* effect of each reform. Additional research is therefore needed to unveil whether there are aspects of policy reforms that cause adverse effects in the external funding of R&D, and others which facilitate innovation.

Through the lens of our model, policies that promote competition through the reduction of barriers to entry into financial markets (hereafter called a “micro reform”) appear compatible with the needs of an innovation-oriented economy that seeks to provide firms with access to competitive rates of credit for R&D activity. However, an element of financial reforms with a potentially ambiguous effect on innovation funding is through the removal of credit controls (“macro reform”, hereafter).

¹ Specifically, cross-country evidence for the positive role of financial development on economic growth can be found in Atje and Jovanovic (1993), McCaig and Stengos (2005), while firm-level evidence that emphasizes the positive role of financial development on growth can be found in Levine (2002) and Demirgüç-Kunt and Maksimovic (2002). Finally, for a recent review of models with financial frictions, see Duncan and Nolan (2018).

² Bandiera et al. (2000) find a similar negative effect of financial liberalization on savings. More generally, Stiglitz (2010) provides a highly critical role of the financial sector in imparting macroeconomic risks. Laeven, McAdam and Popov (2019) by contrast analyze the effect of labor-market reforms on the functioning of financial markets.

At a first glance, such a macro reform increases liquidity as banks maintain lower reserve requirements but it might also induce higher default risks that lead to higher financial instability realized through lower repayable loans (Demirgüç-Kunt and Detragiache, 1998; Kaminsky and Reinhart, 1999; Stiglitz, 2000). Despite increased liquidity, the (potentially) higher default rate reduces banks' profits and prompts (or may prompt) an increase in lending costs, which can be a principal source of under investment in R&D, especially for new and small firms (Hall and Lerner, 2010).³ This type of outcome we dub the “reserves paradox”. Indeed, the US R&D boom in the 1990s is largely attributed to beneficial funding for young and small high technology firms (Brown et al. 2009), indicating that policy makers would do well to distinguish between financial reforms that favor R&D investment and reforms that simply shift funds towards less risky activities with more tangible and secure returns in the short-term.⁴

Our theoretical framework seeks to confront this (macro-micro) ambiguity head on. The model captures the effects of financial (micro, and macro) reforms on innovation (patents) through R&D investment. The paper puts forward two main hypotheses:

1. The *micro* reform of abolishing barriers to entry promotes competition among banking rivals, which decreases the cost of lending for R&D investment, and;
2. The *macro* reform of lower reserve requirements impacts R&D investment through the spread between loan and deposit interest rates. Lower reserve requirements can lead either to a higher supply of R&D loans if the spread falls or to a lower supply if it increases as a bank's reaction to cover the higher default rate.

Figure 1 provides a simple overview of our intended framework. Micro and Macro reforms are set outside of the system (respectively indicated as red and blue). Both affect the spread and this endogenously affects innovation activity through patents. If the innovation is successful this generates a new (intermediate) variety which increases patenting activity and per-capita economic growth. In the case of the macro reform, there is an additional channel (indicated by the dual lines) indicating the possibility of a reserves paradox.

Figure 1 Here

³ Venture capital cannot cover in full the financial needs of small R&D firms contrary to large established firms, e.g., Hall and Lerner (2010).

⁴ The external creditor of R&D encounters additional risks that do not usually exist in the finance of other ordinary projects. Fifty percent of R&D cost is salaries of workers that produce an intangible and non-codifiable good. This type of “tacit” knowledge is lost when R&D employees leave the firm. This feature increases the risk of the investment and causes moral hazard issues for the external creditor. Additionally, the time needed from conceptualisation to commercialisation of a new idea is usually long, which certainly increases the time gap between investment and returns.

At this point it is important to provide some clarifications regarding our two main hypotheses. Higher competition in the banking sector means more banks but the amount of loans provided is the same since the quantity of savings is the same, and it derives from the equalization of the deposit interest rate with the return from the intermediate firms (see the analysis in the next section). By contrast, a reduction in reserve requirements implies more loans given the same amount of savings, but the more loans – given the fixed monitoring capacity we assume – generate higher default probabilities. In both cases, however, banking profits suffer. For micro reforms, more intense competition implies less profits per bank; for macro reforms (due to higher default rate) banking profits diminish if the monitoring process is less efficient than it might otherwise be.

A final clarification is that we isolate the specific role of the banking system in the innovation process. The literature often makes specific differences of the financial system between stock markets and banking sector. Levine (1991) creates an endogenous growth model where stock markets promote growth because it is easier for investors to change ownership of firms and to diversify portfolios. Levine and Zervos (1998) find in a cross-sectional empirical study that both stock market liquidity and banking development promote growth (see also Beck and Levine, 2004). Benfratello et al. (2008) and Chava et al. (2015) find empirically that banking development and innovation are correlated positively. On the contrary, Brown et al. (2013, 2017), and Hsu et al. (2014) find empirically that it is the venture capital which enhances more the innovation activities in comparison to the official banking sector. However, Hellmann et al. (2008) in an empirical set up for the US venture capital market, find that banks invest in venture capital for strategic reasons, namely to build relationships early (in some sense, banks are also behind venture capital schemes). Therefore in the current paper we are largely interested in investigating the impact of the banking system in the innovation process. Although an interesting extension of the model would be to consider multiple sources of R&D funding.

We test some predictions of the theoretical propositions of the model among a sample of 21 OECD countries over 1981-2005 using the internationally comparable dataset of financial reforms of Abiad et al. (2010). Our findings support the positive role of the micro reform on patents, while evidence for the role of the macro reform is negative.⁵

The paper is organized as follows. [Section 2](#) describes the endogenous growth model with financial elements, and its main propositions. [Section 3](#) is the empirical exercise, including specification set-up, preliminary evidence, and estimation. Given the chronic endogeneity between

⁵ Regarding our sample dimensions, the Abiad et al database finishes at 2005 (by which time the bulk of the financial liberalization had been enacted). See our later [Figure 3](#).

the variables underlying patent growth, we use a variety of estimation methods. In so doing, we present an interesting application of copula regression. Copulas model the joint distribution of endogenous regressors with the error term and the information obtained is used to restore consistent and unbiased estimates avoiding (potentially weak) instruments. [Section 4](#) concludes. Additional material is provided in appendices.

2 The Model

We develop an endogenous growth model à la Romer (1990) and Jones (1995) with expanding varieties of intermediate inputs and with a banking sector which competes à la Cournot for providing loans. The reason for banks competing for loans is that the deposit interest rate is fixed to the rate of return of intermediate firms and therefore the deposits are also a fixed amount. The determination of the interest rate for loans allows banks to always control the spread in response to the behavior of their competitors.⁶ A key element to the endogenous growth literature moreover is the presence of costs paid upfront, e.g., Acemoglu (2009). Accordingly, our framework assumes that R&D investment, which is a necessary investment to cover sunk costs⁷ of operating in the R&D sector, is financed by loans.

The economy consists of five sectors: final output, intermediate, R&D, financial and education sector. The households are homogeneous of mass one (without population growth) and the economy is closed. The households have one unit of unskilled labor which is provided inelastically in the production of the final output, and human capital (skilled labor) which is accumulated over time following Lucas (1988) and is used as an input in the production of new patents in the R&D sector. The households are both the owners of intermediate firms and the owners of banks.

The final goods sector produces a consumption good with the use of intermediate inputs and unskilled labor. The intermediate input is produced with one unit of foregone output. Both final output and R&D sectors are competitive with zero long-run profits, while firms in the intermediate sector receive profits from monopolistic rents. Importantly, the R&D sector produces new ideas with human capital but, in order to operate in that sector, requires a sunk cost to be paid upfront.

⁶ Papers which model the banking sector in an oligopolistic set up are those of Berthelemy and Varoudakis (1996), Allen and Gale (2004) and Ghossoub and Reed (2015, 2019). Cournot competition in the banking sector is the most general way in order to capture any degree of competition in the banking sector (perfect competition and monopoly). Moreover, our policy reforms (micro reforms) affect the barriers to entry and therefore the degree of competition in the banking sector.

⁷ For simplicity, we consider these as (unrecoverable) sunk costs which pertains to the specific R&D project undertaken. Otherwise, if some fraction of the equipment could be resold or rented to other firms, or retrieved by the bank in case of default, then this would require the modelling of a secondary market for such transactions which is beyond our current motivation.

This is financed by loans from banks.⁸

Given the uncertainty in the innovation process, some fraction of R&D loans is expected to default as new ideas will not be realized in production. Since R&D projects are risky by their nature, banks find them difficult to monitor and accordingly the monitoring process follows convex increasing costs. Therefore, the probability of default loans is increasing in cases that banks provide more loans to R&D firms.⁹ Indeed, this is a critical channel through which macro reforms impact R&D financing.¹⁰

Finally, the following assumptions hold in the model. First, if the cost of borrowing to finance sunk cost in R&D is ‘too high’, there is a reduction of profitability in the R&D sector which results in a lower quantity of new patents. Second, whilst the number of ideas is endogenously determined, the financial reforms are assumed exogenous. They comprise (i) the micro reform of abolishing entry barriers to entry which increases competition in the banking sector and (ii) the macro reform which lowers restrictions in capital controls and also decreases reserve requirements.¹¹

2.1 Production

There is a competitive sector for producing final output. The production of final output by a representative firm is produced with unskilled labor L and specialized inputs x_{it} . The price of final goods is normalized to one. We follow a standard aggregate production technology (Ethier 1982):

$$Y_t = L^{1-\alpha} \int_0^{\Omega_t} x_{it}^\alpha di, \quad (1)$$

where Y_t denotes aggregate output at time t , Ω_t is the number of intermediate-input varieties discovered until time t ; in variables which do not vary over time, we suppress the time subscript

⁸ Financial resources are necessary for R&D activity to cover expenditures in equipment, machinery and access to scientific publications and manuals (Aghion and Howitt, 1998). These financial resources include agents’ savings not used for consumption of the final good.

⁹ For simplicity, we do not explicitly model banks’ monitoring process. The assumption is that there is an increasing monitoring cost function for loans provided to risky R&D projects.

¹⁰ The financial system plays a crucial role in maturity transformation: redirecting savings to loans to firms (over some risk spectrum). In our model, this is key since otherwise R&D firms would be unable to finance their sunk costs. However, banks in reality invest directly by themselves to assets and have endogenous monitoring process in order to reduce the potential risks from the provided loans (see Laeven et al. (2015) for a discussion of the endogenous monitoring process).

¹¹ As Christopoulos and McAdam (2017) argue, the global trend toward less regulated finance reflected a mixture of historical happen-stance and evolving institutional preferences: e.g., the reduction of existing financial arrangements (e.g., the breakdown of Bretton Woods, the suspension of dollar-gold convertibility, the establishment of the Eurodollar market); the electoral success of “pro-market” governments; the spontaneous development of financial services etc. If such reforms were uniformly endogenous and tailored directly towards R&D needs we might have expected to have seen more variability and even reversals in policy reforms reflecting the uneven pattern of innovation in the OECD; in the Abiad et al. (2010) database financial reforms were rarely reversed (significant policy reversals constitute only 5% of the country sample). In our empirical exercises, though, we *do* foresee an endogeneity between human capital, R&D expenditures and the growth rate of patents.

for compactness. Parameter $\alpha \in (0, 1)$ represent the elasticity of the final good with respect to intermediate inputs. The maximization problem of final output firms is:

$$\max_{L, x_i} \pi_Y = L^{1-\alpha} \int_0^{\Omega_t} x_i^\alpha di - w_Y L - \int_0^{\Omega_t} P_i x_i di, \quad (2)$$

where P_i is the price of each intermediate input i . The first order conditions are:

$$w_Y = (1 - \alpha) L^{-\alpha} \int_0^{\Omega_t} x_i^\alpha di \quad (3)$$

$$P_i = \alpha L^{1-\alpha} x_i^{\alpha-1} \quad (4)$$

Equation (3) is the demand for labor from the final output firms and (4) is the inverse demand for the intermediate input i . By re-writing (4) we derive the demand for the intermediate input i :

$$x_i = \left(\frac{\alpha}{P_i} \right)^{\frac{1}{1-\alpha}} L \quad (5)$$

2.2 Intermediate Producers

The intermediate firms are monopolistic competitors since every intermediate input in the production function of final output is an imperfect substitute for that of any other intermediate good. The cost of producing one unit of any intermediate input i is one unit of foregone final output. A representative intermediate firm solves the following maximization problem:

$$\max_{P_i} \pi_i = P_i x_i - x_i \quad (6)$$

subject to equation (5). The solution gives us the price mark up:

$$P_i = \alpha^{-1} > 1 \quad (7)$$

2.3 R&D Sector

There are a large number of R&D competitive firms that produce new ideas, with Ω denoting the total stock of knowledge in the economy and g_Ω its growth rate. In our empirical application below, we make the usual assumption that the empirical counterpart of ideas is registered patents. In order for an individual firm to operate in the R&D sector the following conditions hold for the

invention of a patent j at any specific moment of time t :

$$\Omega_j : \begin{cases} > 0 \text{ with probability } \psi \in (0, 1) \text{ iff } \mathcal{F} > 0 \\ = 0 \text{ with probability } 1 \text{ iff } \mathcal{F} = 0 \end{cases} \quad (8)$$

In other words knowledge accumulation through the research sector can happen with probability $\psi \in (0, 1)$ iff the R&D firm covers a fixed amount of R&D expenditure $\mathcal{F} > 0$. The probability of gaining a patent is exogenous and constant over time and it can be seen as an average probability of producing new ideas in the innovation sector. We assume that the R&D expenditure \mathcal{F} is financed through loans from the banking system which requires the repayment with an interest rate for loans r^L . Therefore, the total sunk cost for operating in the R&D sector is $r^L \mathcal{F}$. Under the above assumptions, R&D expenditure is a cost but at the same time is a necessary investment in order for a firm to be able to operate in the R&D sector. Financial resources \mathcal{F} are expressed in units of final output since loans are households' savings which are not used for consumption. At the aggregate, the accumulation of the stock of ideas evolves as follows (e.g., Jones, 1995):

$$\dot{\Omega} = \phi \left(H_{\Omega}^{1-\beta} \Omega^{\beta} \right) \quad (9)$$

The necessary inputs are human capital (or the number of researchers working in the R&D sector, H_{Ω}) and the term Ω^{β} which captures the potential impact of the spillover effects of the existing stock of knowledge.¹² The assumption of $\beta \in [0, 1)$ satisfies the empirical regularity that the production of new ideas falls as the number of researchers increases (Kortum, 1993). The term $\phi > 0$ is the average total factor productivity in the R&D sector. Finally, that equation (9) has constant returns implies that the growth rate of ideas g_{Ω} is constant in the Balanced Growth Path (BGP).

Since knowledge accumulation in production also requires the prior existence of R&D expenditures we include such a term in the estimation, interacting these terms with policy reform indicators. It is worth noting that human capital is not only an indispensable element in the literature of endogenous growth models but also in a practical way because higher levels of human capital increases the success of the innovation process. One possible development of the model would therefore be the extension of bank finance to households to finance human capital.

¹² In the limit $\beta \rightarrow 1$, the rate of innovation increases one to one with the existing stock of ideas; if $\beta < 1$ there are positive spillover effects but with diminishing returns; and if $\beta = 0$, the rate of current innovation is independent from the stock of knowledge (no spillover effects).

The price of selling the patent of the intermediate good is the present value of the perpetual profits of intermediate firms:

$$V_{\Omega} = \int_t^{\infty} \pi_{\tau}^i e^{-\int_t^{\tau} r^x(s) ds} d\tau, \tau > t \quad (10)$$

where V_{Ω} is the price of the i^{th} patent at time t , π_{τ}^i is the instantaneous profit of the i^{th} intermediate input and r^x is the return for a household of investing part of its asset holdings in an intermediate firm. Therefore the profit maximization of the representative R&D firm is:

$$\max_{H_{\Omega}} \pi^{\Omega} = \phi(H_{\Omega}^{1-\beta} \Omega^{\beta}) V_{\Omega} - w_{\Omega} H_{\Omega} - r^L \mathcal{F} \quad (11)$$

With free entry and perfect competition in the R&D sector, the zero profit condition in the R&D sector implies the following wage for the human capital employed in the R&D sector in the BGP equilibrium¹³:

$$w_{\Omega} = \phi u^{-\beta} \left(\frac{\Omega}{H} \right)^{\beta} V_{\Omega} \quad (12)$$

Since there is uncertainty in the production of new ideas in the R&D sector together with perfect competition, we assume that the market value of the i^{th} patent needed for the production of an intermediate input equals the total sunk cost of operating in the R&D sector:

$$r^L \mathcal{F} = V_{\Omega} \quad (13)$$

2.4 Households

Households are assumed to maximize utility of the constant relative risk aversion form:

$$\int_0^{\infty} \frac{C_t^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt \quad (14)$$

where $\theta > 1$ is the inverse of the intertemporal elasticity of substitution of consumption¹⁴ and $\rho > 0$ is the rate of time preference. We also assume that the representative household accumulates human capital (Lucas, 1988) as:

$$\dot{H}_t = \sigma (1 - u_t) H_t, \quad (15)$$

where $\dot{H} = dH/dt$ and $\sigma > 0$ represents the efficiency of the education sector.

¹³ See [Appendix A](#) (part 1) for the proof.

¹⁴ Blundell et al. (1994) and Attanasio and Browning (1995) find θ to be close to 1 at the country level while Evans (2004) and Percoco (2008), after allowing for market demand preferences, suggest that it is around 1.5.

The share of human capital u_t which does not enter into the education sector is endogenously allocated in the R&D sector (i.e. H_Ω), while $1 - u_t \in (0, 1)$ is the share of human capital entering into the education sector for further human capital accumulation. The households inelastically supply the full amount of unskilled labor they possess into final output and receive wage w_Y , and the fraction of skilled labor they possess is employed in the R&D sector with wage w_Ω . However, households will receive their wage from the R&D sector with probability $\psi \in (0, 1)$ depending on the successful invention of the R&D sector.¹⁵ The saving of assets is defined as households' income not used for consumption. Their assets are used either as deposits in the banking sector or as dividends in the intermediate firms.¹⁶ Thus, the equation of asset accumulation for the representative households is defined as:

$$\dot{A}_t = r_t^D A_t + \psi w_Y L + w_\Omega u_t H_t - C_t \quad (16)$$

Henceforth, the time subscript will be suppressed unless strictly needed.

2.5 Financial Sector

We assume that the default of some loans does not raise any issue regarding the safety of deposits and thus we can abstract from a deposit insurance sector. More precisely, banks by knowing in advance the probability of default for an R&D project can take it into account in their maximization problem by setting such a spread in the interest rates in order to be able to pay back the deposits increased with the deposit interest rate.

The previous mechanism requires that banks provide loans to more than one R&D firm. For simplicity we can assume that the reserve requirements $1 - \eta$ are sufficient to cover the defaulted loans. However, the more defaulted loans, the lower will be the potential banking profitability which in turn encourages banks to assign an excess premium in the spread of the interest rates.^{17, 18}

The micro reform is a policy instrument that controls barriers to entry in the banking sector,

¹⁵ Households do not know what will be the real probability of default which is the result of the bank's monitoring efforts but they perform their maximization problem by taking into account the average probability of default in the R&D sector. In the next section we give details regarding the probability of default of an R&D project.

¹⁶ In equilibrium, the rate of return from equity holdings in intermediate good firms equals the bank deposit interest rate, $r^D = r^x$.

¹⁷ It is a simplistic assumption since our concern lies not in investigating the insurance sector and also – according to our knowledge – an appropriate cross-country time series dataset for deposit insurance is not available. Papers in the literature on deposit insurance include Amable et al. (2002) and Boyd and De Nicolò (2005).

¹⁸ Even if the risk of default is zero, banks in an oligopolistic environment will have positive profits by implementing a spread between the interest rates. If in addition there is positive amount of default then the spread will be even higher in order banks to recover potential losses. This is the idea of an extra premium between the spread of the interest rates.

which in turn determines the level of competition in the banking sector.¹⁹ The macro reform in turn is a policy instrument that affects the control of reserve requirements. Accordingly, each bank j can only lend a fraction $\eta \in (0, 1)$ of its deposits D_j with the remainder $1 - \eta$ used for reserve requirements. Therefore, the amount of deposits given for loans is ηD_j . Moreover, in our model for simplicity, we assume an exogenous monitoring process (cf. Laeven et al., 2015). Particularly, we assume that if the exogenous monitoring process of R&D projects which demand loans, is efficient, then the probability of default for an R&D project $z(\eta)$ will be lower than the exogenous given probability $1 - \psi$ which represents the average default rate of any R&D project.²⁰ Because of our static dimension regarding the monitoring process, if the banks provide more loans to R&D projects then it is higher the probability of default,

$$z'(\eta) > 0$$

given the fixed monitoring capacity. However, it is also possible that technological advances make production processes more complex and thus harder for investors to monitor, see Laeven et al. (2015) and Growiec (2015). It would be interesting to extend the framework by distinguishing the success to innovate from the success to make a commercial gain from the innovation. Therefore, possible extensions of the current paper will be to create an endogenous dynamic in nature monitoring process which will depend more ambiguously from the technological progress and from the success of an innovation relative to commercial success. Therefore, the amount $1 - z(\eta)$ is the percentage of loans which will be repayable.

Since, as mentioned above, the equilibrium interest rate of deposits equals the rate of return of intermediate firms, the deposit interest rate r^D is given, thus banks compete à la Cournot in providing loans to R&D firms determining the level of the loan interest rate r^L . Therefore, banks set up a spread between the interest rate for loans and deposits: $r^L / r^D = 1 + \xi$. For simplicity we assume this spread is constant, a function of some exogenous parameters. If any of the parameters (some of them being the financial reforms) change, then and only then the spread will change as well. The higher that spread, the higher the cost of borrowing, thus the lower the R&D firm's profitability. Cross-bank symmetry implies that the loans provided to R&D firms from bank j are: $L_j = \mathcal{F}/n$, where n is the number of banks. Equilibrium in the loans market is determined

¹⁹ Before implementing the micro financial reform, the number of banks is finite. After the reform, increases in competition erode banking profits.

²⁰ In case of no monitoring the default rate $z(\eta)$ will be on average equal to the exogenous probability of default $1 - \psi$, which leads to lower profits for banks.

as follows:

$$\eta D_j = L_j \equiv \mathcal{F}/n \quad (17)$$

The present value of j 's bank profit is:

$$\pi_j^B = \frac{[1 - z(\eta)] r^L L_j - r^D D_j}{r^D} \quad (18)$$

where $[1 - z(\eta)] r^L L_j$ is the revenue from repayments of successful R&D projects. Bank j maximizes profit given the demand for loans and the interest rate elasticity of loans, ε_L with respect to loans L_j .²¹ Substituting (17) into (18) the discounted profit function for bank j becomes:

$$\pi_j^B = L_j \left(\frac{r^L [1 - z(\eta)]}{r^D} - \frac{1}{\eta} \right) \quad (19)$$

Differentiating (19) wrt loans provides the equilibrium spread between the interest rate associated to loans and deposits D :²²

$$\frac{r^L}{r^D} = 1 + \xi = \left[\left(\eta - \eta z(\eta) \right) \left(1 - \frac{1}{n} \right) \right]^{-1} > 0 \quad (20)$$

As we demonstrate below, we can determine the equilibrium interest rate for deposits which, if it is used inside equation (20), also provides us with the equilibrium interest rate for loans. The effects of micro and macro reforms are derived from differentiating (20) wrt parameters n and η , respectively.

As we know, the implementation of the *micro* reform depends on n the number of banks, but we can now also see that it affects the equilibrium value of the spread. On the other hand, the implementation of the *macro* reform depends on

$$\text{sgn} \left\{ 1 - z(\eta) - \eta z'(\eta) \right\}$$

If $\text{sgn}\{\cdot\} > 0$ then the positive liquidity effect of macro reforms dominates the higher default rate of loans which leads to a reduction in the spread between interest rate of loans and deposits. The opposite result holds if $\text{sgn}\{\cdot\} < 0$.²³

²¹ From the condition (13) $r^L \mathcal{F} = V_\Omega$ it can be proved that the elasticity for loans is $\varepsilon = \frac{dL}{dr^L} \frac{r^L}{L} = \frac{d\mathcal{F}}{dr^L} \frac{r^L}{\mathcal{F}} = -1 < 0$. According to Calza et al. (2006) the elasticity with respect to (wrt) the short term interest rate varies from 0.4 to 1 in absolute values and the elasticity wrt the long term interest rates varies from 1.8 to 3.1 in absolute value.

²² The proof of the result in (20) is available upon request. Moreover, Appendix A.2 provides the condition under which $r^L \geq r^D$, which ensures non-negative profits for banks.

²³ The magnitude of $z'(\eta)$ depends on the monitoring efficiency, which is part of the characteristics of the banking-financial system in each country.

2.6 General Equilibrium and BGP Analysis

The definition, characterization and derivation of the BGP equilibrium are shown in [Appendix A.1](#) and [Appendix A.2](#). Our current interest though is the effect of the financial reforms on the growth rate of patents (and by implication that of the whole economy) which is shown below in equation (22). Accordingly, we can proceed directly to the equilibrium conditions of the model, which define the equilibrium interest rate for deposits and the BGP equilibrium for the growth rate of innovation, for the share of human capital employed in the R&D sector and the optimal ratio of human capital to the stock of ideas. These are respectively given by:²⁴

$$r^D = r^x = \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) [\eta - \eta z(\eta)] [1 - \frac{1}{n}]}{\mathcal{F}}} \quad (21)$$

$$g^* = \frac{r^D - \rho}{\theta} \quad (22)$$

$$u^* = \frac{\sigma\theta + \rho - r^D}{\sigma\theta} = 1 - \frac{g^*}{\sigma} \quad (23)$$

$$\left(\frac{H}{\Omega}\right)^* = \left[\frac{r^D - \rho}{\theta\phi}\right]^{\frac{1}{1-\beta}} \left[\frac{\sigma\theta}{\sigma\theta + \rho - r^D}\right] \quad (24)$$

where $*$ denotes equilibrium values compatible with the BGP.

Condition (21) equates the deposit rate and the return from investing in an intermediate firm. This return is proportional to n (the size of the banking sector), η (the fraction of deposits lent), \mathcal{F} (the sunk-cost, also defined as R&D expenditure), and defaulted loans $z(\eta)$. Condition (22) is the standard euler or Keynes-Ramsey rule, showing how the growth in real variables fluctuates over time in responses to changes in the interest rate (relative to time preference), for a given substitution elasticity. This rate of growth, g^* , is the rate at which all real variables grow in the BGP: $g_Y = g_C = g_A = g_H = g_\Omega = g^*$.²⁵ Finally, (24) defines the equilibrium ratio between the level of human capital and intermediate-input varieties (innovations).

Since our main focus is on the effect of financial reforms on the growth rate of patents, we omit the comparative statics of equations (23) and (24).²⁶ Given this derivation, we can formulate the model's necessary Propositions (and key predictions):

²⁴ Recall that x is the name of intermediate inputs whereas j denotes one specific intermediate input.

²⁵ The growth rate of the economy is affected by r^D , equation (22). From equation (21) we observe that the financial reforms have different effect on r^D in comparison to both r^L and the spread. As the spread decreases, the cost for R&D expenditure falls which increases the return of the R&D firms ($r^D = r^x$). Therefore, the financial reforms have opposite impact on the spread and on the growth rate of the economy.

²⁶ They are, though, available from authors upon request.

Proposition 1 *The micro reform increases the numbers of banks n which in turn increases competition in the banking sector leading to a lower spread between the interest rates of loans and deposits.*

Proof Differentiate (20) wrt n . \square

Proposition 2 *The macro reform decreases the reserve requirements $1 - \eta$, but it has an ambiguous effect on the spread between the interest rates for loans and deposits. The following cases exist:*

- i) *a decrease in reserve requirements leads to a higher spread due to a higher default rate for loans (iff $1 - z(\eta) < \eta z'(\eta)$);*
- ii) *a decrease in reserve requirements leads to a lower spread if the default rate of loans does not increase sharply relatively to the supply of loans (iff $1 - z(\eta) > \eta z'(\eta)$), and;*
- iii) *if $1 - z(\eta) - \eta z'(\eta) = 0$, there is no effect from credit controls on the spread between the interest rates for loans and deposits.*

Proof Differentiate (20) wrt η . \square

Proposition 3 *The effect of micro reform on the growth rate of the economy is positive. Since, higher banking competition increases the number of banks n , the spread between the interest rates of loans and deposits becomes lower, which reduces the cost of operating in the R&D sector. Therefore more patents will be produced.*

Proof Differentiate (22) wrt n . \square ²⁷

Intuitively, if the total sunk cost is lower due to a low spread between the interest rates, then the price of a patent is lower and the demand for patents from intermediate firms is higher. The high demand for patents increases the available quantity of intermediate inputs in the economy which increases economic growth, since the ultimate source of increased living standards in this class of endogenous growth model precisely depends on the number of the intermediate inputs.

Proposition 4 *The effect of macro reform $1 - \eta$ on the growth rate of the economy is ambiguous. The following three cases arise:*

- i) *a decrease in reserve requirements leads to a higher spread due to a higher default rate of loans (iff $1 - z(\eta) < \eta z'(\eta)$), which increases the cost of operating in the R&D sector and therefore less patents will be produced;*
- ii) *a decrease in reserve requirements leads to a lower spread due to a lower default rate of loans (iff $1 - z(\eta) > \eta z'(\eta)$), which reduces the cost of operating in the R&D sector and therefore more patents will be produced, and;*
- iii) *in case of $1 - z(\eta) - \eta z'(\eta) = 0$, there is no effect from credit controls on the spread between the interest rates for loans and deposits, therefore the produced number of patents will not be affected.*

Proof Differentiate (22) wrt η . \square

The intuition behind **Proposition 4** is similar to that of **Proposition 3**. In case the interest-rate spread increases because the lower reserve requirements increase by much the default rate of loans, banks react by increasing the interest rate for loans which results in higher total sunk cost

²⁷ Note, n is contained within r^D in (21) and r^D is contained within (22).

for operating in the R&D sector. In that case, the price of a patent is higher as well and the demand for patents from the intermediate firms is lower. The low demand for patents reduces the available quantity of intermediate inputs in the economy and thus reduces economic growth.

3 An Empirical Examination

Propositions 3 & 4 are important elements of our analysis and provide testable hypotheses regarding the mechanisms discussed in the previous sections. In brief, the growth rate of per capita income is driven by the growth rate of new ideas. The latter are generated through R&D investment, which is essentially financed through bank loans. The terms and conditions for the provision of these loans depends on the institutional environment that exists within the financial sector. Precisely, policy reforms towards a more market oriented environment affects potentially the credit available for R&D firms. The objective of the empirical section is to test the mechanisms through which micro and macro reforms drive the accumulation of patents.

3.1 Data Sources and Preliminary Data Analysis

We start by making a preliminary analysis of the data regarding the evolution of patents before and after financial reforms. We construct the stock of patents applying the perpetual inventory method assuming a depreciation rate δ^P of 10% (Ang, 2011), where the initial stock of patents is given by,

$$P_{it=0} \equiv \frac{PAT_{i0}}{\delta^P + \bar{g}_i^{PAT}},$$

where \bar{g}_i^{PAT} is the sample average growth rate of the stock of patents in country i over the sample and PAT_0 is the number (or flow) of patents in the initial year of the sample. Data on patents granted²⁸ are taken from OECD Patent statistics. Raw data on patents report the country of residence of each inventor following the International Patent Classification (IPC).²⁹ We consider only patents registered in the USA patents office (USPTO) to capture “high quality” innovation conducted in each country.³⁰ The technological domains covered in the USPTO include ICT,

²⁸ Note the distinction between patent granted and patent applied for with the former capturing better the inventive performance. Accordingly, a patent application refers only to the filing process of a patent to a specific patent office, while patent granted refers to the conferment of patent rights by the authorized body.

²⁹ The World Industrial Property Office (WIPO) provides only the location of company’s headquarters of each patent without specifying the country of innovation activity. For our analysis the country of residence is a crucial piece of information showing where the inventor is located and how the financial system in the country of residence supports the innovation effort (Jaffe and Trajtenberg, 2002).

³⁰ Patent data is the most common proxy for the production of a new idea (Kortum, 1993; Madsen, 2008; Ang, 2011) but there are caveats: (i) they do not specify the economic value of the patent, and, (ii) the inventor might not use the patent system to protect a new idea preferring others methods (e.g., secrecy, lead time and franchising).

nano-technology, bio-technology, environment and health.

RD_{it} is the share of Business Enterprise R&D (BERD) stock to GDP for country i at time t . R&D stock is computed from the accumulation of R&D expenditure as follows:

$$RD_{it} = (1 - \delta^{RD})RD_{it-1} + RDE_{it-1}$$

Expenditures are expressed in 2005 US\$ PPP prices and are also taken from OECD R&D statistics. Data for R&D expenditure are available from 1981 onwards for all 21 countries in the sample except Portugal (which begins in 1982). We use linear interpolation for non-reporting R&D expenditure values. The R&D stock series are also initiated by the formula, $RD_{it=0} = RDE_{i0}/(\delta^{RD} + \bar{g}_i^{RD})$, where the depreciation of R&D stock, δ^{RD} is also assumed to be 10% following the common literature norm (see Bournakis et al. 2018, and the references therein), \bar{g}_i^{RD} is the average growth rate of R&D expenditure over 1981-2005. The positive link between R&D expenditure and patents granted can be gauged by [Figure 2](#). This depicts the positive pattern between R&D intensity and innovation output. This is a well-documented empirical relationship discussed before.

[Figure 2 Here](#)

The two indices of financial reforms, *entry* and *credit* are assigned values from 0 (indicating fully repressed) to 3 (fully liberalized). A micro policy reform withdraws government restrictions on entry of new competitors (including foreign banks) in the domestic market, while a macro policy reform abolishes restrictions on reserve requirements.³¹ [Figure 3](#) documents that OECD countries have implemented financial reforms towards a progressively more liberalized system. In early 1980s both entry and credit show a partially repressed environment, which was essentially fully liberalized by the first half of the 2000s. The pattern indicates essentially no policy reversals (see below). Exceptionally, the Netherlands reversed its policy on credit controls in 1976 and 1986 (the former event not included in the current time span). There are only small reversals from a partially liberalized to a partially repressed credit controls regime.

[Figure 3 Here](#)

Moreover, [Table 1](#) shows the average growth rate of patents for the pre and post reform periods. For expositional purposes in this table, we define a dummy variable with “0” when the country is either fully or partially repressed (i.e., corresponding to values 0 and 1 in the original Abiad et al, 2010 dataset) and “1” when the country is either partially or fully liberalized (i.e. corresponding to

³¹ It may also curb expansion and government finance towards ‘priority sectors’.

values 2 and 3 in that same dataset). The switch year in the first column is the year when country transitions to a different regime. In the post micro reform period, countries experience a much higher growth rate of patents, on average 7.07% (from 3.26). The equivalent transform for the macro reforms is apparently more modest increase: 7.57% (from 5.49%). This provides suggestive (though by no means conclusive) evidence that financial reforms have supported innovation activities.

[Table 1 Here](#)

3.2 Empirical Specification

This section describes the equation used as an empirical device essentially for testing **Propositions 3 & 4**.³² Following the assumptions of our theoretical model, reforms are expected to affect the growth rate of patents through the channel of R&D investment: the greater the size of R&D investment, the more likely the development of patents. As mentioned, data on financial reforms come from the influential Abiad et al. (2010) dataset, which covers the sample 1973–2005.³³ The database comes with several indices relating to specific financial reforms: these indices lie in a 0, 3 support, with the higher the value of the reform index, the higher degree of financial liberalization. The two reforms pertinent to our analysis contained in that database are:

1. *Credit controls* (restrictiveness of reserve requirements; extent to which credit is channeled to certain sectors, and subsidized), and;
2. *Entry barriers/pro-competition measures* (various measures to capture entry of domestic and foreign banks into home economy and regulate their activities).

We abbreviate these two reforms over time as $credit_{it}$ and $entry_{it}$ reflecting, respectively, micro and macro financial reforms (for country i at time t).³⁴ Specifically, the interaction of micro reform with R&D expenditure and the macro reform are defined as: $micro_{it} = entry_{it} \times RD_{it}$; $macro_{it} = credit_{it} \times RD_{it}$.

By transforming (9) into growth rates, we can conclude that the higher the level of human capital, the higher will be the growth rate of patents, whereas the contrary exists for the already invented stock of patents. Moreover, we know that R&D investment is a necessary element for operating in the R&D sector and from **Propositions 3 & 4** we know that the effects of the financial

³² The dataset and the R codes to replicate our results are available on request.

³³ We restrict our time span to 1981 onwards reflecting the starting availability of R&D data.

³⁴ The other indices for reference include measures to capture the flexibility and openness of interest rate controls, banking supervision, state ownership of banks, international capital flows, and securities Markets.

reforms on the growth rate of patents appears through the R&D investment. Finally, from (21) and (22) we observe that the risk of default for the R&D firms is negatively related to the growth rate of patents. With the above considerations in mind, we estimate the following log-linear specification:

$$\begin{aligned}\Delta \log p_{it} = & \beta_0 + \beta_1 \log p_{i0} + \beta_2 \log H_{it} + \beta_3 \log RD_{it} + \beta_4 \log Risk_{it} \\ & + \beta_5 \underbrace{\text{entry}_{it} \times \log RD_{it}}_{\text{micro}} + \beta_6 \underbrace{\text{credit}_{it} \times \log RD_{it}}_{\text{macro}} \\ & + X' \beta + e_{it}\end{aligned}\quad (25)$$

The first line of (25) is the basic empirical analogue of (9), the second incorporates interaction terms in the financial reforms and R&D activity and the final line adds relevant controls.

The symbol $\Delta \log p_{it}$ is the difference in logs of the stock of patents P (lower case p denotes per capita) in country $i = 1, 2, \dots, N$ at year $t = 1, 2, \dots, T$.³⁵ We include $\log p_{i0}$ to capture initial conditions in the innovation status of each country. This is consistent with equation (9) whereby the evolution of the stock of ideas (patents) is a function of the past accumulation of ideas (this term can also be a proxy for unobserved heterogeneity between countries). H_{it} is human capital measured by the average years of schooling in tertiary (or post secondary) education for population aged at or above 25 years (Barro and Lee, 2013). Higher risk means lower probability for inventing a new patent and therefore a lower patent growth rate. Our measure of the risk associated to R&D processes, $Risk_{it}$, is modelled as an *EGARCH*(1, 1) (exponential generalized autoregressive conditional heteroscedastic) process.³⁶ Term β_0 is an overall regression constant³⁷ and $e_{it} \stackrel{iid}{\sim} (0, \sigma_e)$ is the error term. We estimate (25) on an unbalanced panel of 21 OECD countries over 1981-2005; Table 2 provides summary statistics of the variables of interest pooled across countries.³⁸

Table 2 Here

Now we discuss regression controls. According to the literature (inter alia, Torvik (2002), Papyrakis and Gerlagh (2007) and the references therein) if a country has high rents from resources is focusing on rent seeking behavior and there is no motivation for investors to invest in companies.

³⁵ Since our model does not include population growth (of mass one), the per capita and aggregate variables coincide. However, the per capita growth rate of patents is the best suited variable to perform cross-national research.

³⁶ The conventional risk measures of variance and standard deviation are unconditional and inappropriate to capture the time series dimension in the data. We use the EGARCH version (Nelson, 1991) which is generally considered to outperform the original model of Engle (1982).

³⁷ There are no country fixed effects since their inclusion creates collinearity with the financial reform variables, as well as with the starting value of log patents by country.

³⁸ The 21 countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK, and USA.

If on the contrary the rents are small there is interest to invest in other assets.³⁹ Therefore, in this way we can capture the idea of “angel financing”. A proxy for this at the aggregate level is the log total natural resources rents to gdp, *Angel*. To account for the possibility that R&D can also be financed using equity (known as venture capital) other than external borrowing, we augment (25) with the log of the total value of stocks traded to GDP, *Stock_{it}*. We assume that the availability of venture capital for R&D activities is analogous to the expansion of equity markets; data for *Stock_{it}* are taken from World Bank Development Indicators (2018) (denoted WBDI).⁴⁰ Security markets contain stock markets, bond markets and derivatives markets. Moreover, high yield of long run bonds means high confidence of the investors to invest in alternative assets and not in the riskless government bond. Therefore, *Secmark* (security markets) can be captured by the long time bond yields as a percent per year, where high values of it provide an indication that the R&D firms can find alternative funding to the official banking system.

3.3 Econometric Estimations and Results

OLS estimates for (25) are problematic due to the likelihood of endogeneity bias that arises from omitted variables, feedback effects between patents, R&D and Human capital. In such a case OLS will yield biased and inconsistent estimates. Instrumental variable (IV) techniques are commonly used to address this type of problem: i.e., identifying instruments highly correlated with the endogenous regressors but uncorrelated with the error term. This is known to be an extremely challenging task in country-level regressions, often leading to finite sample bias of the IV results similar to the one produced by OLS (Bound et al. 1995).

To overcome limitations associated with instrument identification, we use an alternative econometric approach to control for endogeneity. The method to correct for endogeneity uses the copula technique within a time series-cross sectional context as per Patton (2006) and Christopoulos et al. (2021) (see also the discussion in Kourtellis, Stengos and Tan, 2016).⁴¹ Copulas model the joint distribution of the endogenous regressors with the error term and the information obtained

³⁹ Torvik (2002) in a theoretical model of rent seeking shows that if an economy is abundant in natural resources there are incentives for rent-seeking behavior and investment in less productive firms. Papyrakis and Gerlagh (2007) find empirically that abundance in natural resources leads into lower investment, R&D expenditure and economic growth.

⁴⁰ The variable *Stock_{it}* is the best proxy available to account for the amount of R&D that is not financed through external debt. We have also used different measures to represent the development of equity markets (market capitalization, total value at current US\$ for stocks traded and turnover ratio of domestic shares), which all provide very similar results to those shown in our estimation tables. These extra results are available on request. Note also time fixed effects proved insignificant as did an overall time trend.

⁴¹ See also Growiec (2013) for an application of copula theory to technology modelling and Fan and Patton (2014) for a review of the use of copulas in economic contexts.

is used to restore consistent and unbiased estimates avoiding (potentially weak) instruments.⁴²

Appendix C describes the key steps of the copulas transformation and estimation.

Notwithstanding, for robustness, we estimate using all three econometric methodologies, and in doing so we introduce the controls in a sequential manner. The full set of results are shown in Appendix D, whilst Figure 4 groups the parameter values in a more digestible manner. It shows the central parameter estimate for the *macro* and *micro* parameter across three estimation cases within three econometric methods (Copula, OLS and IV). In the left side, we can see that the macro reform parameter is generally negative, implying that the introduction of macro reforms (as defined here) in the banking sector does – across countries and in the long run – tend to dampen R&D activity and patent growth. The Copula and IV results are relatively similar. This is to be expected since they both make attempts to control for endogeneity. The OLS results are ostensibly less reliable. The effect of the macro reform can roughly be attributed as $-0.007 \times \log RD_{it}$ where the $\log RD_{it}$ term can be evaluated at its (country-specific) mean or median value. For the micro reform, we have positive and generally significant parameters suggesting that greater competition in the banking sector across time and countries has generally supported R&D and patenting activity. The positive central parameters are consistent with the model.

Figure 4 Here

4 Conclusions

Our approach highlighted that financial reforms can drive R&D investment in different ways. To better understand the specific channels through which financial liberalization can affect how banks finance R&D investment, we developed an endogenous growth model with Cournot competition in the banking sector.

We distinguished between two main effects. First, a micro reform that abolishes barriers to entry in the banking sector. Enhancement of competition and an expansion of market size produces a straightforward result: a decrease in lending rates. This policy potentially stimulates R&D investment and thus the accumulation of new ideas. The second effect is a macro reform that removes restrictions on banks' reserves and credit controls. While this policy change increases liquidity, it also increases the risk of default, potentially raising the cost of borrowing. This scenario we dubbed the "reserves paradox" – this makes banks offset the rise in the default rate with a higher spread between loans and deposit rates.

⁴² Christopoulos et al. (2021) analyze the power and size properties of this type of estimator in various contexts.

Testing these two propositions among a sample of OECD countries, suggests that it is the micro reform that generates gains for innovation. The effect of macro reform on innovation activity is mostly negative (depending on the specification under consideration). That, in turn, provides some credibility to the presence of a “reserves paradox”. In effect, the financial sector overstretches itself.

What policy lessons might be drawn from our analysis? First, it should not be taken as granted that all types of financial reforms boost sectors that are drivers of technological progress. Easy access to credit at a competitive rate is important for R&D firms but it can be more straightforwardly achieved with fostering competition in the banking sector rather than necessarily deregulating the control of credit or providing higher degrees of liquidity. A broader policy implication is that financial reforms should be designed in a way that prevents adverse effects in the way activities vital for long-term growth are funded. Both our theoretical and empirical findings raise some scepticism as to whether removal of credit ceilings can work unambiguously well for sectors that embody high risks. Finally, although we have held the monitoring mechanism constant for simplicity (and comparative static purposes), a narrative interpretation of our results is that a necessary complement to macro reforms might be better monitoring technologies by banks.

Future research might extend our analysis to other financial reforms not considered here, namely interest rate controls, international capital flows, banking supervision and state ownership. It may also consider which types of financial reforms better stabilize the R&D sector in response to business-cycle fluctuations and shocks. Finally, the additional integration of funding for agents’ human capital accumulation and allowing for multiple sources of R&D funding (beyond the banking sector) would be interesting.

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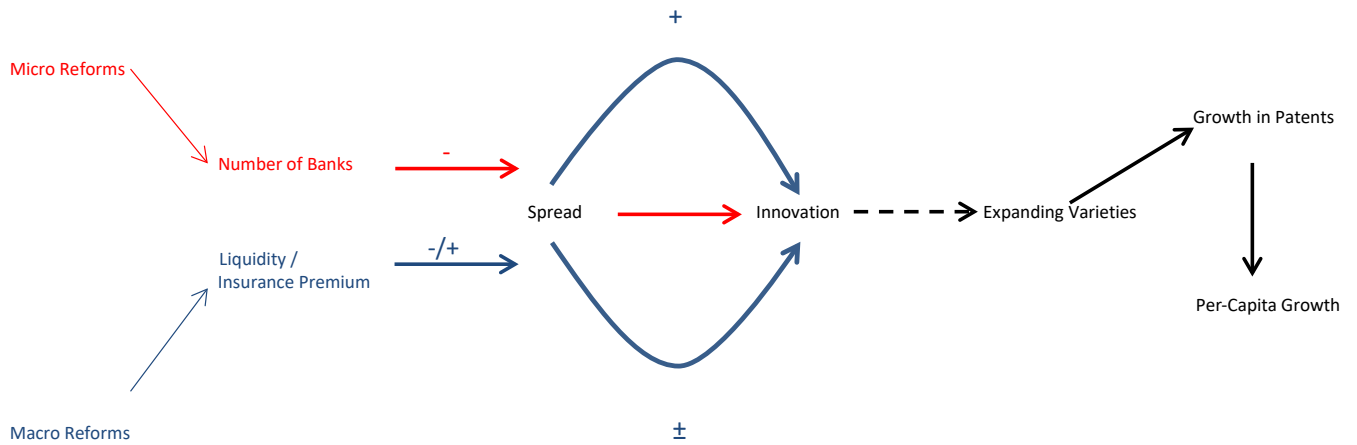
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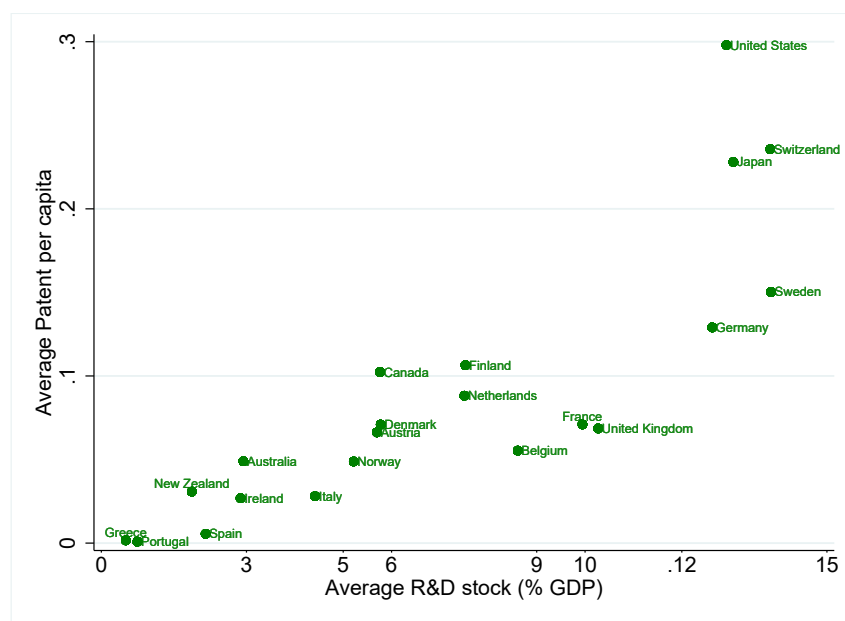
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FIGURE 1: SIMPLE TAXONOMY OF MODEL CHANNELS



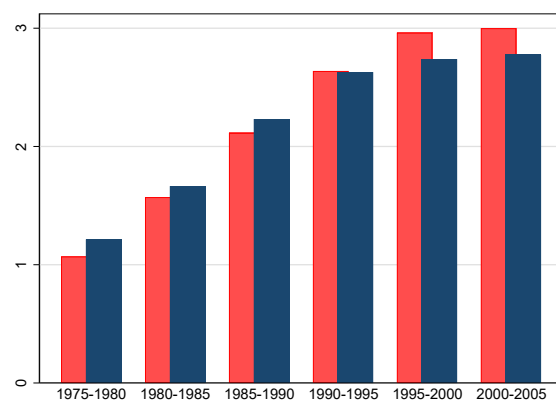
Notes: This figure shows the broad model framework. Macro and micro reforms are set outside of the system (respectively indicated as red and blue). Both affect the spread and this endogenously affects innovation activity through patents. If the innovation is successful this generates a new (intermediate) variety which increases per-capita economic growth. In the case of the macro reform, there is an additional channel (indicated by the bidirectional lines) indicating the possibility of a reserves paradox.

FIGURE 2: THE RELATIONSHIP BETWEEN R&D STOCK AND PATENTS PER CAPITA



Notes: This figure plots the country averages over the same of R&D Stock as a % of GDP against patents per capita, by country.

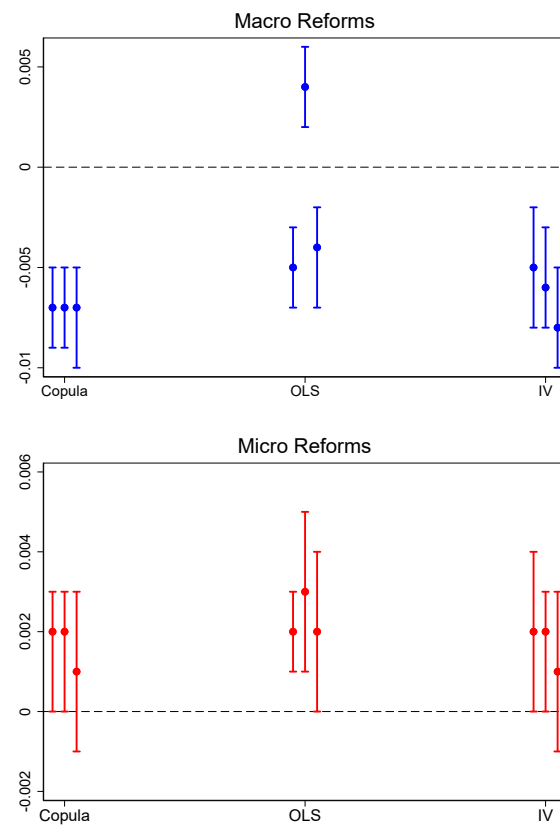
FIGURE 3: INDEX OF ENTRY BARRIERS (Micro) AND CREDIT CONTROLS (Macro) FOR 21 OECD COUNTRIES



Notes: Values close to 3 indicates a fully liberalized regime in the respective categories.

Source: Abiad et al. (2010).

FIGURE 4: PARAMETER VALUES AND BOOTSTRAPPED CONFIDENCE INTERVALS FOR MICRO AND MACRO TERMS



Notes: These figures plot the estimation results from the *macro* and *micro* parameter values in equation (25). The circle is the central parameter estimates and the lines above and below represent the respective bootstrapped 95% and 5% confidence intervals. The first estimation shows when there are no controls (i.e., X is the null matrix). The second is the case when the controls include $\log Angel$ and $SecMark$ and the final case when the controls also include $\log Stock$. For visual convenience, zero is marked by a dashed horizontal line.

TABLE 1: GROWTH RATES OF PATENTS BEFORE AND AFTER FINANCIAL REFORMS

	Micro Reform (entry barriers)				Macro Reform (credit controls)				
	Switch [†]	Before	After	Always	Switch	Before	After	Always	Never
	Liberalized [‡]				Liberalized Liberalized				
Australia	1985	1.97	9.37		1981	−0.98	8.85		
Austria	1991	2.73	6.87					4.07	
Belgium	1992	2.90	8.46					5.23	
Canada	1992	3.92	6.39					4.74	
Denmark	1988	2.86	10.29						7.20
Finland				8.87	1984	7.41	9.22		
France	1984	−0.19	4.43		1985	0.91	4.43		
Germany	1985	1.69	4.19					3.66	
Greece				19.62	1993	24.59	15.03		
Ireland				12.10					12.10
Italy	1993	4.00	5.54		1993	4.00	5.54		
Japan	1991	9.20	5.77		1991	9.20	5.77		
Netherlands			5.31				5.31		
New Zealand	1984	−1.40	9.39		1984	−1.40	7.25		
Norway				7.33	1988	4.28	9.58		
Portugal	1983	9.51	18.40						33.86
Spain				7.47	1992	4.10	8.25		
Sweden	1986	−0.78	5.36		1986	−0.78	5.36		
Switzerland			1.34				1.34		
United Kingdom				2.60				2.60	
United States	1996	3.81	2.77					3.19	
Average [§]		3.26	7.07	7.99		5.49	7.57	3.80	16.58

Notes: [†] Switch is the year that the country moves from a repressed to a liberalized regime. [‡] For the micro reforms, there are no "Never Liberalized" cases. [§] unweighted average

TABLE 2: SUMMARY STATISTICS

Variable	Definition	Mean	Std. Dev.	Min	Max	Source
H	Human Capital (Average Tertiary)	0.575	0.275	0.100	1.440	Barro and Lee (2013)
	Population (100,000)	31463.590	47157.950	2316	236267	Barro and Lee (2013)
p	Patent Grants Per head	716.404	693.642	1.838	3.532	OECD Patent Statistics
	R&D stock share	7.182	4.582	0.200	18.810	OECD Patent Statistics
P_0	Initial Patent Grants Stock	493.842	518.013	1.839	1886.520	OECD Patent Statistics
$Stock$	Stocks Traded (% of GDP)	51.060	45.517	0.041	30.980	WBDI
$entry$	Barriers to Entry	2.460	0.830	0	3	Abiad et al. (2010)
$credit$	Credit Controls	2.410	0.850	0	3	Abiad et al. (2010)
$SecMark$	Government Bond Yields	16.147	176.858	1.012	4013.000	United Nations
$Angel$	Total Natural Resource Rents (% GDP)	0.957	1.620	0.011	11.745	WBDI

Notes: This table shows descriptive statistics for variables used in the empirical analysis. Refer to the main text for more information on the variables. WBDI stands for World Bank Development Indicators. References to the data source can be found in more detail in [Appendix B](#).

[†]: R&D is in 2005 US Dollars PPP million.

ONLINE APPENDICES

A BGP, Selected Proofs, Lemmas and Conditions

A.1 Balanced Growth Path (BGP) Equilibrium and Proofs of Selected Equations

The BGP equilibrium is defined as a situation where: (i) all time depending variables grow at constant exponential rates and (ii) the share of human capital allocated to the R&D sector is constant ($u_t = u, \forall t \geq 0$). The solution of the model requires markets clearing for: (i) the intermediate input market, (ii) the loans market and (iii) the human capital market. Overall, the following conditions must hold:

$$u_t H_t = H_{\Omega_t} \quad (\text{A.1})$$

$$r^D = r^x \quad (\text{A.2})$$

By aggregating for all firms the demand for the intermediate input i equation (5) and using the intermediate price from equation (7) and the assumption that the total amount of unskilled labour is one (normalized), we find the total demand for input i :

$$x_i = \alpha^{\frac{2}{1-\alpha}} \quad (\text{A.3})$$

By replacing in equation (10) the profit function for intermediate firms from equation (6) together with the price of intermediate input from equation (7) and equation (A.3) we have the following condition for the price of a patent:

$$V_{\Omega} = \alpha^{\frac{2}{1-\alpha}} \left(\frac{1-\alpha}{\alpha} \right) \int_t^{\infty} e^{-r^x(\tau-t)} d\tau \quad (\text{A.4})$$

The solution of (A.4) with r^x constant and equal to r^D from (A.2) is:

$$V_{\Omega} = \frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha)}{r^D} \quad (\text{A.5})$$

By replacing in equation (13) V_{Ω} from equation (A.5), r^L from the condition $r^L = (1+\xi) r^D$ and $1+\xi$ from equation (20) we derive:

$$r^D = r^x = \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) [\eta - \eta z(\eta)] \left[1 - \frac{1}{n}\right]}{\mathcal{F}}} \quad (\text{A.6})$$

This is the same as (21). The total assets of the households are distributed exogenously as deposits A_{Bt} in the banking sector and as dividends in the intermediate firms A_{ft} . If the banks have positive profits π_t^B , those are also distributed to the depositors since we assume that they are owners of the banks. Therefore the equation which describes total assets is: $A = A_{ft} + A_{Bt} = \Omega_t V_{\Omega t} + D_t + \pi_{Bt}$.

The representative household maximizes the following Hamiltonian:

$$\max_{C,u,A,H} \mathcal{H} = \frac{C^{1-\theta} - 1}{1-\theta} + \mu_1 [r^D A + w_Y L + \psi w_\Omega u H - C] + \mu_2 [\sigma (1-u) H]$$

The necessary first order conditions are:

$$C^{-\theta} = \mu_1 \quad (\text{A.7})$$

$$\mu_1 \psi w_\Omega = \mu_2 \sigma \quad (\text{A.8})$$

$$\dot{\mu}_1 = \rho \mu_1 - \mathcal{H}_A \Rightarrow g_{\mu_1} = \rho - r^D \quad (\text{A.9})$$

$$\dot{\mu}_2 = \rho \mu_2 - \mathcal{H}_H \Rightarrow \dot{\mu}_2 = \rho \mu_2 - \mu_1 \psi w_\Omega u - \mu_2 \sigma (1-u) \quad (\text{A.10})$$

where μ_1, μ_2 are the costate variables associated to the respective constraints (16) and (15). The following transversality: $\lim_{t \rightarrow \infty} \mu_{1t} A_t = 0$, $\lim_{t \rightarrow \infty} \mu_{2t} H_t = 0$ and initial conditions: $A(0) > 0$ and $H(0) > 0$ also hold. By using μ_1/μ_2 from (A.8) into (A.10) we arrive at:

$$g_{\mu_2} = \rho - \sigma \quad (\text{A.11})$$

By log-differentiating (A.7) with respect to time we derive the usual Euler equation:

$$g_C = \frac{r^D - \rho}{\theta} \quad (\text{A.12})$$

This is the same as (22). From equation (9) in order to have constant growth rate in BGP for patents, we have:

$$g_\Omega = g_H \quad (\text{A.13})$$

The accumulation of assets from equation (16) can be written as:

$$g_A = r^D + \frac{w_Y L}{A} + \frac{\psi w_\Omega u H}{A} - \frac{C}{A}.$$

In order for g_A to be constant in BGP together with the assumption of $L = 1$ the following conditions should hold:

$$g_A = g_{w_Y} = g_H = g_C \quad (\text{A.14})$$

Due to the perfect competition in the R&D sector, there is free entry which results into zero profits in the R&D sector. Therefore, from equation (11) by using equation (13), the following condition for the wages in the R&D sector must hold in the long run BGP equilibrium: $w_\Omega = \lim_{t \rightarrow \infty} \left[\phi u^{-\beta} \left(\frac{\Omega}{H} \right)^\beta - \frac{1}{uH} \right] V_\Omega \Rightarrow w_\Omega = \phi u^{-\beta} \left(\frac{\Omega}{H} \right)^\beta V_\Omega$. Moreover, since u , V_Ω and Ω/H are constant along the BGP then the following result holds regarding the growth rate of wages in the R&D sector:

$$g_{w_\Omega} = 0 \quad (\text{A.15})$$

Finally, from equation (1) we have:

$$Y_t = \Omega_t x_{it}^\alpha \quad (\text{A.16})$$

But since x_{it} is constant according to (A.3), then the following condition holds:

$$g_Y = g_\Omega \quad (\text{A.17})$$

From (A.13), (A.14) and (A.17) we have the following conditions to hold along the BGP equilibrium:

$$g_Y = g_\Omega = g_A = g_{w_Y} = g_H = g_C = g^* \quad (\text{A.18})$$

By substituting (A.6) into (A.12) and using the condition (A.18) we derive the common growth rate along the BGP:

$$g_Y = g_C = g_A = g_H = g_\Omega = g^* = \frac{1}{\theta} \left[\sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) [\eta - \eta z(\eta)] \left[1 - \frac{1}{n}\right]}{\mathcal{F}}} - \rho \right] \quad (\text{A.19})$$

The equation of human capital accumulation can be written as: $g_H = \sigma(1 - u)$, where if set equal to (A.19) allows us to derive the endogenous value for u :

$$u^* = \frac{\sigma\theta + \rho - \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) [\eta - \eta z(\eta)] \left[1 - \frac{1}{n}\right]}{\mathcal{F}}}}{\sigma\theta} \quad (\text{A.20})$$

This, suitably transformed, is the same as (23). Equation (9) can be written as: $g_\Omega = \phi(uH)^{1-\beta} \Omega^{\beta-1} \Rightarrow g_\Omega = \phi u^{1-\beta} \left(\frac{H}{\Omega}\right)^{1-\beta}$ and if we use (A.19) and (A.20) we derive the optimal ratio of H/Ω along the BGP:

$$\left(\frac{H}{\Omega}\right)^* = \left[\frac{\sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) [\eta - \eta z(\eta)] \left[1 - \frac{1}{n}\right]}{\mathcal{F}}} - \rho}{\theta\phi} \right]^{\frac{1}{1-\beta}} \times \left[\left(\frac{\sigma\theta}{\sigma\theta + \rho - \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) [\eta - \eta z(\eta)] \left[1 - \frac{1}{n}\right]}{\mathcal{F}}}} \right) \right] \quad (\text{A.21})$$

This, suitably transformed, is the same as (24). \square

A.2 Conditions for a well-behaved BGP and for non-negative Banking profits

Lemma 1 For $r^D > \rho$; $\sigma\theta + \rho > r^D$ and $g^* < \sigma - \rho$, the following results hold: $g_Y = g_C = g_A = g_H = g_\Omega = g^* > 0$, $u \in (0, 1)$ and the two transversality conditions $\lim_{t \rightarrow \infty} \mu_{1t} A_t = 0$, $\lim_{t \rightarrow \infty} \mu_{2t} H_t = 0$.

Proof: From (A.20) $u > 0$ iff $\sigma\theta + \rho > r^D$ and $u < 1$ iff $r^D > \rho$. By adding by part the previous conditions we have that $u \in (0, 1)$ iff $\sigma\theta > 0$ for the parameter values described in the model. Moreover, from (A.12) $g^* > 0$ iff $r^D > \rho$. By using (A.9) and (A.12) the necessary condition for satisfying $\lim_{t \rightarrow \infty} \mu_{1t} A_t = 0$ is $r^D > \rho$. Finally, by using (A.11) together with (A.12) in order to satisfy $\lim_{t \rightarrow \infty} \mu_{2t} H_t = 0$, we require as a necessary condition $g^* < \sigma - \rho$. \square

Lemma 2 In order for the profits in the banking sector to be non-negative the following condition must hold: $r^L \geq \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha)}{\mathcal{F}[\eta - \eta z(\eta)] [1 - \frac{1}{n}]}}$.

Proof: From equation (19) in order for the banks to have non-negative profits it is necessary the following condition holds

$$r^L \geq \frac{r^D}{\eta - \eta z(\eta)} \quad (\text{A.22})$$

From condition (20), which shows the optimum interest rate spread (which gives the maximum profits), we require for non-negative profits to exist

$$r^L \geq \frac{r^D}{[\eta - \eta z(\eta)] [1 - \frac{1}{n}]} \quad (\text{A.23})$$

For $n \geq 2$ (A.23) is larger than (A.22) which implies that, if (A.23) holds, (A.22) holds as well.

Finally, by substituting r^D from (A.6) into (A.23) we require $r^L \geq \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha)}{\mathcal{F}[\eta - \eta z(\eta)] [1 - \frac{1}{n}]}}$. \square

B Additional Information on Data Sources

The sites pertaining to the collection of the data used are given below:

- Barro-Lee dataset:
<http://www.barrolee.com/>
- Entry and Credit reform indices:
https://www.imf.org/-/media/Websites/IMF/imported-datasets/external/pubs/ft/wp/2008/Data/_wp08266.ashx
- Venture capital at aggregate level can be captured by the total value of stocks traded to GDP, as taken from the World Bank Development Indicators:
<https://data.worldbank.org/indicator/CM.MKT.TRAD.GD.ZS>
- Secmark (security markets) which can be captured by the long time bond yields as a percent per year. High bond yield of long run bonds means high confidence of the investors to invest in alternative assets and not in the riskless government bond. These are taken from:
<http://data.un.org/Data.aspx?d=IFS&f=SeriesCode3A613BCountryCode3A163> and <http://data.un.org/Data.aspx?d=IFS&f=SeriesCode%3A61%3BCountryCode%3A163>
- Total natural resources rents: <https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS>
- Patents Granted: https://stats2.digitalresources.jisc.ac.uk/Index.aspx?DataSetCode=PATS_IPC#
- R&D Expenditure and R&D Stocks:
http://stats.oecd.org/Index.aspx?DataSetCode=GERD_FUNDS_PRE1981

C The Copula Method

Consider the following generic model:

$$y_{it} = \mathbf{x}_{it}'\beta + e_{it} \quad (\text{C.1})$$

where y is the dependent variable, \mathbf{x} is a $k \times 1$ vector of potentially endogenous regressors with the first element set at one and β is a $k \times 1$ vector of parameters to be estimated. The vector \mathbf{x} of endogenous variables can be potentially identified by a $p \times 1$ vector of instrumental variables \mathbf{z}_t :

$$\mathbf{x}_{it}\beta = \mathbf{z}_{it}'\gamma + v_{it} \quad (\text{C.2})$$

where v is an error term. IV estimates are consistent under the following conditions:

$$\mathbb{E}(e_{it}|\mathbf{x}_{it}) \neq 0, \mathbb{E}(v_{it}|\mathbf{z}_{it}) = 0, \text{cov}(e_{it}, v_{it}) \neq 0 \quad (\text{C.3})$$

where \mathbb{E} denotes the expectation operator.

In the presence of weak instruments, the conditions in (C.3) no longer hold and IV estimates are no longer consistent. Copulas however restore consistency of the estimates of β in (C.1) by modelling the joint distribution of endogenous regressors \mathbf{x}_{it} with the error term e_{it} .

Initially, this joint distribution is unknown. Following Park and Gupta (2012), we build continuous marginal distribution function F_x and F_e of $\vec{\mathbf{x}}_{it} = \Phi^{-1}[F_x(X_{it})]$ and $\vec{e}_{it} = \Phi^{-1}[F_e(e_{it})]$, respectively. Φ^{-1} stands for the standard normal cumulative distributive function (CDF). In our application, the marginal distribution of $\vec{\mathbf{x}}_{it}$ is derived from a non-parametric density estimation, which allows the observed data to determine the marginal distribution without imposing any restriction on the data generation process. Then, copulas model the distribution of $[\vec{\mathbf{x}}_{it}, \vec{e}_{it}]$ as a bivariate standard normal distribution, which can be written as:

$$\begin{bmatrix} \vec{\mathbf{x}}_{it} \\ \vec{e}_{it} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \varphi & \sqrt{1-\varphi^2} \end{bmatrix} \begin{bmatrix} \mu_{it}^1 \\ \mu_{it}^2 \end{bmatrix} \quad (\text{C.4})$$

where μ_{it}^1, μ_{it}^2 are independent random normal variables and φ denotes the correlation coefficient between endogenous regressors $\vec{\mathbf{x}}_{it}$ and the error term \vec{e}_{it} . After some manipulation, (C.4) can be written as:

$$\vec{e}_{it} = \varphi\mu_{it}^1 + \sqrt{1-\varphi^2}\mu_{it}^2 = \varphi\vec{\mathbf{x}}_{it} + \sqrt{1-\varphi^2}\mu_{it}^2 \quad (\text{C.5})$$

Assuming that e_{it} is a normally distributed error term we have:

$$e_{it} = F_e^{-1}[\Phi(\vec{e}_{it})] = \Phi_{\sigma_e^2}^{-1}[\Phi(\vec{e}_{it})] = \sigma_e \vec{e}_{it} \quad (\text{C.6})$$

with $\vec{e}_{it} = \Phi^{-1}[F_e(\vec{e}_{it})]$. By substituting (C.6) into (C.1) we derive:

$$y_{it} = \mathbf{x}_{it}'\beta + \sigma_e \left[\varphi\vec{\mathbf{x}}_{it} + \sqrt{1-\varphi^2}\mu_{it}^2 \right] \quad (\text{C.7})$$

Specification (C.7) is an estimating representation of (C.1) with vector $\vec{\mathbf{x}}_{it}$ to include additional copula transformed regressors and to be uncorrelated with any other right-hand side term. Parameters β in (C.7) can be then consistently estimated with OLS. The transformed regressors $\vec{\mathbf{x}}_{it}$

correct for endogeneity in a manner similar to the approach of control functions suggested in Heckman (1979) and Hausman (1978) (see also Kourtellis et al., 2016).¹

A drawback of the Gaussian copula is that as the true distribution of the endogenous regressor X approaches a normal distribution, the correlation between the endogenous regressor X and its transform variant lead to serious multicollinearity problems, see Park and Gupta (2012). To avoid collinearity problems between the Gaussian copula and the endogenous l regressors we use a Student's T copula with four degrees of freedom. Furthermore, an additional attractive feature of the Student's t copula is that it allows for tail dependence between the error term and the endogenous regressor X unlike the Gaussian copula that assumes zero tail dependence, see Christopoulos et al. (2021). Finally, model estimates are robust to violations of the distributional assumption of the error term, see Park and Gupta (2012).

D Full Set of Empirical Results: Copula, IV and OLS Estimation

Full estimations results are reported in tables, Table D.1 to Table D.3. The different number of observations between the Copula and the IV approach is due to the loss of observations in the copula case. In particular the additional transformed variables (copula transformations) require the use of the quintile function where for probabilities $(0, 1)$ this function tends to $(-\infty, \infty)$.

Although our main interest is in the significance and sign of the *micro* and *macro* parameters, the other parameters are worth commenting upon. The regressor of the initial value of patent stock $\log p_{i0}$ is negative, indicating convergence; countries that are initially scarce in patents stock per capita tend to accumulate ideas faster than countries already well-endowed with stock of ideas. Human capital $\log H$ is a positive determinant of the growth rate of patents stock per capita consistent with the literature that stresses the importance of education in facilitating the production of new ideas (Eaton and Kortum, 1996).

Moreover, $\log RD$ is positive and statistically significant reinforcing the strong relationship between R&D stock and patents as emphasized in models of endogenous growth theory and which we earlier saw to be a feature of the data. The estimated coefficient of $\log Risk$ is negative representing the likelihood that the higher the risk the lower probability for inventing a new patent and therefore the growth rate of patent is lower if the risk is high.

The sign of angel might be expected to be negative. But in our cases it is generally insignificant.

The control variable of stock (venture capital) has the expected positive sign but it is insignificant. The final control variable *SecMark* (security markets), the effect of which can be captured by the long time bond yields as a percent per year. High bond yield of long run bonds means high confidence, has the expected positive sign but is it also insignificant.

D.1 Copula Results

Column A presents the most parsimonious case, without controls. The remaining columns incrementally add controls. All cases incorporate the *micro* and *macro* reforms as well as the copula transformation to correct for endogeneity in human capital and R&D expenditures (indicated, respectively, by $(\log \vec{R})$ and $(\log \vec{H})$). Although these parameters have no economic interpreta-

¹ As the true distribution of \mathbf{x}_{it} approaches a normal distribution, the inclusion of \vec{x}_{it} – a linear transformation of \mathbf{x}_{it} – increases multicollinearity in the model. This does not cause bias but inefficiency, which can be easily overcome in panel data with relatively large number of observations.

tion, they are statistically significant in most of the specifications, confirming that the copula transformed variables in our estimations have effectively removed endogeneity bias. Since the specifications are nested, we also report the Akaike Information Criterion (AIC). Moreover, least square estimates behave badly when the error distribution is non normal (in our case tests reject the null of residual normality), we employ an M-estimator with the Huber weight function that is robust to this class of errors, see Huber (2009).

D.2 IV

We now briefly describe the regression results when using instrumental variables for the endogenous variables, namely R&D expenditures and human capital. We run separate instrumenting regressions for these. For the former we estimate a fixed effect model including time variables plus Foreign Direct Investment, net inflows (% of GDP) and Merchandise trade (% of GDP). For the Human capital auxiliary equation we estimate a fixed effect model including time variables plus FDI, net inflows (% of GDP), Merchandise trade (% of GDP) and Urban population (% of total). The corresponding equation residuals, respectively $ResR$ and $ResH$ are then inserted into the main estimating equation (see for example Wooldridge, 2010).

Finally, for the OLS case by definition no correction for covariate endogeneity is made.

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TABLE D.1: ESTIMATES OF PATENT STOCK PER CAPITA, EQUATION (25): COPULA ESTIMATES

coef./case	A	B	C
β_0	0.105 [0.085,0.129]	0.105 [0.082,0.104]	0.096 [0.075,0.123]
$\log p_0$	-0.016 [-0.021,-0.012]	-0.016 [-0.021,-0.012]	-0.015 [-0.02,-0.011]
$\log H$	0.023 [0.007,0.042]	0.023 [0.007,0.043]	0.024 [0.008,0.042]
$\log RD$	0.036 [0.022,0.051]	0.036 [0.021,0.051]	0.036 [0.021,0.050]
$\log Risk$	-0.003 [-0.005,0.000]	-0.002 [-0.005,0.000]	-0.002 [-0.005,0.001]
<i>micro</i>	0.002 [0.000,0.003]	0.002 [0.000,0.003]	0.001 [-0.001,0.003]
<i>macro</i>	-0.007 [-0.009,-0.005]	-0.007 [-0.009,-0.005]	-0.007 [-0.0010,-0.005]
$\log Angel$		0.000 [-0.002,0.002]	0.000 [-0.003,0.001]
<i>SecMark</i>		0.000 [-0.001,0.001]	0.000 [-0.001,0.001]
$\log Stock$			0.003 [-0.000,0.006]
$\overrightarrow{\log \hat{H}}$	0.000 [-0.007, 0.006]	0.000 [-0.006,0.006]	0.000 [-0.007,0.005]
$\overrightarrow{\log RD}$	-0.007 [-0.012,-0.002]	-0.007 [-0.012,-0.002]	-0.008 [-0.013,-0.003]
σ_e	0.025	0.025	0.024
<i>AIC</i>	-1491.35	-1488.191	-1488.96
<i>N</i>	367	367	367

Notes: Coefficients marked in bold are significantly different from zero at the 5% level of significance or below. Numbers in square brackets show 95% confidence intervals based on 2,000 bootstrapped replications. *micro* and *macro* are respectively defined as $entry \times RD$ and $credit \times RD$. $\overrightarrow{\log \hat{R}}$ and $\overrightarrow{\log \hat{H}}$ are coefficients of the copula transformed variables to control for endogeneity. σ_e is the standard error of the residuals, *AIC* is the Akaike Information Criterion and *N* is the number of observations. Time fixed effects were found to be insignificant. Estimation with a general time trend had a negligible impact on the remaining parameters and was suppressed for parsimony.

TABLE D.2: ESTIMATES OF PATENT STOCK PER CAPITA, EQUATION (25): IV ESTIMATES

coef./case	A	B	C
β_0	0.128 [0.11,0.146]	0.129 [0.111,0.147]	0.121 [0.101,0.141]
$\log p_{i0}$	-0.017 [-0.028,-0.006]	-0.018 [-0.022,-0.013]	-0.018 [-0.023,-0.012]
$\log H$	0.02 [0.013,0.028]	0.021 [0.013,0.03]	0.025 [0.016,0.033]
$\log RD$	0.021 [0.011,0.031]	0.023 [0.012,0.035]	0.036 [0.022,0.051]
$\log Risk$	0.000 [-0.003,0.004]	0.000 [0.000,0.003]	-0.002 [-0.007,0.004]
<i>micro</i>	0.002 [0.000,0.004]	0.002 [0.000,0.003]	0.001 [-0.001,0.003]
<i>macro</i>	-0.005 [-0.008,-0.002]	-0.006 [-0.008,-0.003]	-0.008 [-0.01,-0.005]
$\log Angel$		0.000 [-0.002,0.002]	0.001 [-0.001,0.004]
<i>SecMark</i>		0.000 [0.000,0.000]	0.000 [0.000,0.000]
$\log Stock$			0.0005 [-0.003,0.005]
<i>RESRD</i>	-0.004 [-0.006,-0.001]	-0.003 [-0.006,0.000]	-0.003 [-0.054,0.048]
<i>RESH</i>	-0.082 [-0.13,-0.034]	-0.079 [-0.128,-0.03]	-0.09 [-0.141,-0.039]
σ_e	0.032	0.315	0.306
<i>AIC</i>	-892.361	-883.223	-707.045
<i>N</i>	440	440	345

Notes: See notes to Table D.1.

TABLE D.3: ESTIMATES OF PATENT STOCK PER CAPITA, EQUATION (25): OLS ESTIMATES

coef./case	A	B	C
β_0	0.126 [0.108,0.144]	0.106 [0.081,0.131]	0.098 [0.067,0.129]
$\log p_0$	-0.016 [-0.018,-0.014]	-0.014 [-0.018,-0.01]	-0.013 [-0.017,-0.009]
$\log H$	0.018 [0.014,0.022]	0.018 [0.012,0.024]	0.016 [0.01,0.022]
$\log RD$	0.02 [0.009,0.031]	0.019 [0.011,0.026]	0.019 [0.011,0.027]
$\log Risk$	0.003 [0.001,0.005]	-0.002 [-0.005,0.001]	-0.001 [-0.003,0.001]
<i>micro</i>	0.002 [0.001,0.003]	0.003 [0.001,0.005]	0.002 [0.000,0.004]
<i>macro</i>	-0.005 [-0.007,-0.003]	0.004 [0.002,0.006]	-0.004 [-0.007,-0.002]
$\log Angel$		-0.002 [-0.004,0.000]	-0.002 [-0.004,0.000]
<i>SecMark</i>		0.000 [-0.000,0.002]	0.000 [-0.000,0.002]
$\log Stock$			0.002 [-0.000,0.004]
σ_e	0.033	0.033	0.033
<i>AIC</i>	-2061.025	-2060.048	-2058.571
<i>N</i>	523	523	523

Notes: See notes to Table D.1.

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