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Financial reforms and innovation: A micro–macro perspective

Spyridon Boikos [a], Ioannis Bournakis [b], Dimitris Christopoulos [c], Peter McAdam [d,*]

[a] University of Macedonia, Greece
[b] SKEMA Business School, Lille and Université Côte d'Azur, France
[c] Athens University of Economics and Business, Greece
[d] Research Department, Federal Reserve Bank of Kansas City, USA

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ABSTRACT

We develop a horizontal R&D growth model 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 leads to a decrease in lending rates which stimulates R&D investment and 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 find empirical support for these propositions using a sample of 21 OECD countries.

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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 the connection between financial development and growth,[1] the mechanisms underlying some of those links remain unclear. Despite the widespread agreement that innovation enhances

* Corresponding author.
E-mail address: peter.mcadam@kc.frb.org (P. McAdam).

[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).

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the standard of living, 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 and through the reduction of reserve requirements ("macro reform", hereafter).[3]

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). In fact, bank crises in recent history are initiated by the excess of cash liquidity and the existence of heavy asymmetric information on bank's default risk (Calomiris et al., 2015). As banks' liabilities are usually in the form of money market instruments with short duration, they tend to respond with severe credit rationing even with small increases in default risk (Calomiris and Gorton, 1991). Therefore, high liquidity is recognized as a source of increased default risk that prudential regulation mitigates with the insurance of deposits. Berger and Bouwman (2017) found that banking crises from the mid-1980s to the late 2010s are associated with abnormal liquidity creation. The subprime crisis of 2007–2009 and the malfunction of the inter-bank market were typical examples of excess liquidity crises that led to the loosening of lending standards. In the context of our analysis, increased liquidity and the (potentially) higher default risk reduce banks' profits and prompt (or may prompt) an increase in lending costs, which adversely affects the financing of activities crucial for growth. The outcome of this macro reform leads to the paradox, which is labeled as the "reserves paradox"[4] and argues that increases in banks' cash holdings do not necessarily benefit the financing of new investment projects, in particular R&D, of young and small firms (Hall and Lerner, 2010).[5] On the contrary, excess liquidity increases the cost of insurance that is passed on to the borrower creating a less competitive banking environment for firms that seek external financing for their investment projects. 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 toward less risky activities with more tangible and secure returns in the short-term. Therefore, higher liquidity enhances the default risk which is associated with the prudential regulatory response of higher insurance premiums that discourage the financing of innovation activities that are inherently long term projects and highly uncertain by nature.[6] We dub this process as the "reserves paradox" and develop a framework that allows to examines its empirical validity.

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. We put 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.

[2] Bandiera et al. (2000) find a similar negative effect of financial liberalization on savings. Boikos et al. (2022) find empirically through the use of quantile regression techniques that financial reforms are more important than financial development especially for less developed countries and that different types of financial reforms affect differently the GDP per capita growth. More generally, Stiglitz (2010) provides a highly critical role of the financial sector in imparting macroeconomic risks. Laeven et al. (2019) by contrast analyze the effect of labor-market reforms on the functioning of financial markets.

[3] As far as we know, we are the first to make this distinction between macro and micro financial reforms in a modeling context. Moreover, to keep the analysis tractable, in the theoretical model we indeed model the reserve requirements and not the capital controls. In the empirical part the index for capturing reserve requirements includes as well the capital controls. In terms of intuition however, both reserve requirements and capital controls reduce liquidity (even from different paths). Moreover, after 1980's for the most of the countries in our sample capital controls do not exist, whereas reserve requirements are still an important policy tool for Central Banks. These are the reasons for calling this type of reform as macro reform and not as reserve requirements.

[4] The contextual meaning of "reserves paradox" in our paper differs from "Goodhart's reserves paradox" (Goodhart, 2008), which argues that due to cash requirements that banks are forced to hold, they have limited capacity in terms of cash availability to resolve liquidity problems.

[5] 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).

[6] 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 conceptualization to commercialization of a new idea is usually long, which certainly increases the time gap between investment and returns.

Fig. 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.

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.

It is also important to mention the vast literature on the effects of banking competition on financing more or less risky projects. The seminal papers of Keeley (1990), Hellmann et al. (2000) and Demirgüç-Kunt and Detragiache (2002) provide theoretical and/or empirical justification on the competition-fragility nexus. Their main argument is that lower bank profitability due to fierce competition leads banks to finance firms with more risky projects. In the same line of argument, Berger et al. (2005), Dell'Ariccia and Marquez (2006) indicate that lower banking profitability weakens the incentive of monitoring funded projects. Bushman et al. (2016) and Jiang et al. (2022) support empirically the competition-fragility scenario, while contributions in favor of the competition-stability scenario indicate that banking competition reduces the cost of borrowing which makes firm not undertake risky investments (Boyd and De Nicolo, 2005; Martinez-Miera and Repullo, 2010; Schaeck et al., 2009; Houston et al., 2010; Anginer et al., 2014; Akins et al., 2016; Goetz, 2018).

In the current paper however, for analytical tractability there is provision of loans only to the risky-by-nature R&D projects and we do not assume the coexistence of loans to less risky projects. Therefore, we do not show that higher competition in the banking sector leads banks to provide loans to the more risky R&D firms in comparison to loans to the less risky investments. We actually capture indirectly (without modeling risk directly, but having controlled risk through an endogenous monitoring process) both the competition-stability result (as suggested in Boyd and De Nicolo (2005)), i.e. the higher competition leads to lower interest rate of loans and therefore to more loans provided to the risky-by-nature R&D firms – and the competition-fragility result i.e. that higher competition reduces the interest rate of loans, thus implying higher loan supply to R&D firms. In order to capture the connection of risk taking by banks when they provide loans with the micro reform policy in the same theoretical framework without directly adding risk, we arrive at the transformed model in the endogenous monitoring set up, provided in Appendix A2 online appendix. We have then the following two results: i) when competition largely reduces monitoring incentives with high default rates, banks will increase the spread of interest rates which will result in lower demand for loans from R&D firms and ii) when competition does not largely reduce monitoring incentives with low default rates, banks will reduce the spread of interest rates which will result in higher demand for loans from R&D firms. The former result captures the competition-fragility scenario, while the latter captures the competition-stability scenario. Despite our anticipation that the competition-stability scenario dominates, we carefully scrutinize the validity of both hypotheses in our empirical analysis.

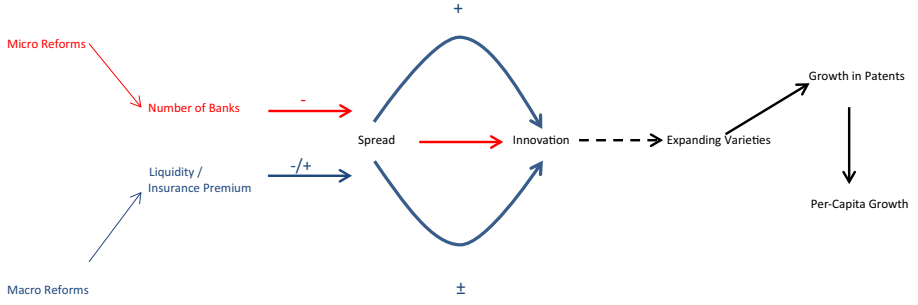

Fig. 1. Simple taxonomy of model channels. *Notes:* This figure shows the broad model framework. Macro and micro reforms are set outside of the system (respectively indicated as red and blue). Both affect the spread and this endogenously affects innovation activity through patents. If the innovation 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. In the empirical part we check how the different types of financial reforms affect through the R&D expenditure the growth rate of the stock of patents.

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 diversify portfolios. Levine and Zervos (1998) and Beck and Levine (2004) confirm empirically that both stock market liquidity and banking development promote growth, while Benfratello et al. (2008) and Chava et al. (2013) also find that banking development is highly correlated with innovation. Our paper contributes to that literature by investigating how changes in the banking system impact innovation outcomes.

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.[7]

Organization. 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 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 at any instant point of time. The determination of the interest rate for loans allows banks to always control the spread in response to the behavior of their competitors.[8] 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 costs[9] 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 baseline model of variety expansion (see, Barro and Sala-i-Martin (2003, ch. 6)) uses raw labor only in the production of the final output and the invention of a new idea requires only units of foregone output. In the literature (both theoretical and empirical) there is plenty of evidence that human capital is a necessary input for the production of new ideas. Romer (1990) uses both unskilled and skilled labor in the production of final output and in the R&D sector he uses only skilled labor. Moreover, an important paper in the literature among others where households possess both unskilled labor (used only in the production of final output) and skilled augmenting labor used as an input only in the R&D sector is the paper of Grossmann and Steger (2013).[10] 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. This is financed by loans from banks.[11]

[7] 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 Fig. 3.

[8] 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), Ghossoub and Reed (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.

[9] 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 modeling of a secondary market for such transactions which is beyond our current motivation.

[10] Moreover, we've solved a version (available upon request) where we have only human capital (skilled labor) inside the production of all the three sectors (final output, intermediate inputs and R&D). This version of the model provides the same qualitative results but there is considerably more algebra and the analysis of the results is much more complicated. Therefore, in order to keep the analysis as simple as possible and at the same time to have human capital inside the R&D sector, we made the assumption that a household possess inelastically one unit of unskilled labor used as an input only in the final output and human capital (skilled labor) which is augmented endogenously through time and which is used in the R&D sector only.

[11] 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.

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 increased difficulty to monitor a higher amount of loans. Therefore, the probability of default loans is increasing in cases that banks provide more loans to R&D firms.[12] Indeed, this is a critical channel through which macro reforms impact R&D financing.[13]

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.[14] In the main text we will analyze mainly the R&D and financial sector. In Appendix B1 apart from the solution of the model we describe the final output and intermediate sectors and the households' problem as well.

At this point before we proceed to the analytical description of the R&D and financial sector, and even if there is scarce literature in investigating this topic, we make a comparison of the theoretical model with three papers which somehow are more closely related to ours. First, Blackburn and Hung (1998) use external funding as an important element for risky R&D firms. They consider the existence of asymmetric information, and they consider that the development of the banking sector can reduce the impact of the use a costly monitoring process and therefore promote economic growth. They use a horizontal differentiation product variety as in our model by following Romer (1990), but they do model the market structure of the banking sector and the possible effects of reserve requirements on the spread of interest rates and therefore on the promotion or not of innovation. The second paper which is closely related to ours is of Romero-Ávila (2011). In this paper in an R&D set up as in Arnold (1998), it is shown that if there is information disclosure in the banking sector, then the size of the banking sector can be increased in a profitable manner and it is more efficient the provision of loans to R&D firms, which promotes economic growth. In this paper contrary to ours, human capital is not considered as a crucial input of the innovation process and more importantly, there is monopolistically competitive banking sector without considering the possible different effect of different types of financial reforms on innovation activity. Finally, the paper of Laeven et al. (2015) which follows a Schumpeterian framework as in Aghion et al. (2005), shows that financial innovation can improve the screening ability of financiers and therefore this will lead to the promotion of the risky innovation sector. Apart of the main difference which has to do with Romerian vs Schumpeterian R&D framework and the absence of human capital in their analysis, they do not consider the role of different types of financial reforms on the provision of loans to the risky R&D firms.

2.1. R&D sector

There are a large number of R&D competitive firms that produce new ideas, with Ωdenoting 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:

$$\Omega_j \quad : \quad \begin{cases} > 0 \text{with probability} & \psi \in (0,1) \quad \textit{iff } \mathscr{F} > 0 \\ = 0 \text{with probability} & 1 \qquad\quad \textit{iff } \mathscr{F} = 0 \end{cases} \tag{1}$$

Eq. (8) describes what happens for any random R&D firm which wants to operate in the R&D sector. We do not try to model uncertainty in the model for simplicity. That's why we consider that if a firm covers the sunk cost for entering into the R&D sector can have the exogenous possibility to invent a successful idea. 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 $\mathscr{F} > 0$. 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 $\mathscr{F}$ 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 $r^L\mathscr{F}$. Under the above assumptions, R&D expenditure is a cost but at the same time is a necessary invest-

[12] For simplicity, we do not explicitly model banks' monitoring process in the main text. The assumption is that there is a monitoring capacity for loans provided to risky R&D projects. However, we have endogenized the monitoring process in a supplementary material and the analysis of the financial sector is more complicated but the main results remain the same. The exposition and solution of endogenous monitoring process is available in Appendix A.1.

[13] 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 in a dynamic set up).

[14] 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; Fig. 3 verifies the stability of financial reforms over time). In our empirical exercises, though, we *do*foresee an endogeneity between human capital, R&D expenditures, and the growth rate of patents. However, for future research it can be important in a theoretical set up to analyze how Central banks can determine endogenously specific policy measures after taking into account their impact on different areas of the economy.

ment in order for a firm to be able to operate in the R&D sector. Financial resources $\mathscr{F}$ 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):

$$\dot{\Omega} = \phi H_{\Omega}^{1-\beta}\Omega^{\beta} \tag{2}$$

It is important to clarify that Eq. (2) shows the aggregate accumulation of ideas that has happened only from the successful innovator-firms. 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.[15] 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 Eq. (2) 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.The price of selling the patent of the intermediate good is the present value of the perpetual profits of intermediate firms:

$$V_{\Omega} = \int_{t}^{\infty} \pi_{\tau}^{i} e^{-\int_{t}^{\tau} r^{x}(s)ds} d\tau, \tau > t \tag{3}$$

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:

$$\max_{H_{\Omega}} \pi^{\Omega} = \phi H_{\Omega}^{1-\beta}\Omega^{\beta}V_{\Omega} - w_{\Omega}H_{\Omega} - r^{L}\mathscr{F} \tag{4}$$

The profit function in the above equation represents the profit maximization problem of the representative successful R&D firm. This is the reason why the probability of success ψ does not appear in the profit function above. 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 equilibrium[16]:

$$w_{\Omega} = \phi u^{-\beta}\left(\frac{\Omega}{H}\right)^{\beta} V_{\Omega} \tag{5}$$

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:

$$r^{L}\mathscr{F} = V_{\Omega} \tag{6}$$

2.2. 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.[17] 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 baking profitability which in turn encourages banks to assign an excess premium in the spread of the interest rates.[18,19]The micro reform is a policy instrument

[15] In the limit $\beta \to 1$, 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).

[16] See Appendix B (part 1) for the proof. In this proof it is shown that the wages in the R&D sector w_{Ω}, which satisfy the zero entry condition of zero profits, are positive.

[17] A simple and realistic assumption for avoiding any complicated inclusion of deposit insurance sector, which holds for the most technological advanced economies, is that the government can guarantee the safety of the deposits.

[18] 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 data set for deposit insurance is not available. Papers in the literature on deposit insurance include Amable et al. (2002) and Boyd and De Nicolo (2005).

[19] 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.

that controls barriers to entry in the banking sector, which in turn determines the level of competition in the banking sector.[20] 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, 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.[21,22] 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. We have not assumed the probability of default to depend on banking competition for simplicity. In a version of the financial sector where monitoring intensity is endogenous we have considered that higher banking competition means less loans provided by the average bank which makes the monitoring process more efficient.[23] 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. The interest rate of deposits in an oligopolistic environment is not constant but actually it shows the inverse demand for loans $r^L(L)$ which depends negatively on the total amount of the provided loans. The total amount of loans in the economy are $L = \sum_{j=1}^{n} L_j$. Therefore, banks set up a spread between the interest rate for loans and deposits: $r^L/r^D = 1+\xi$. It is proved that the equilibrium level of spread is constant and a function of the exogenous financial reform parameters (See, Eq. (20)). If any of the parameters 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: $L_j = \Omega\mathscr{F}/n$, where $\mathscr{F}$ is the sunk cost per R&D firm which results into an equivalent amount of loans and $\Omega\mathscr{F}$ is the total amount of loans requested by all the R&D firms in the economy. Of course n is the number of banks. Equilibrium in the loans market is determined as follows:

$$\eta D_j = L_j \equiv \Omega\mathscr{F}/n \tag{7}$$

The present value of j's bank profit is:

$$\pi_j^B = \frac{[1-z(\eta)]r^L L_j - r^D D_j}{r^D} \tag{8}$$

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.[24] Substituting (7) into (8) the discounted profit function for bank j becomes:

$$\pi_j^B = L_j\left(\frac{r^L[1-z(\eta)]}{r^D} - \frac{1}{\eta}\right) \tag{9}$$

Differentiating (9) wrt loans provides the equilibrium spread between the interest rate associated to loans and deposits D:[25]

$$\frac{r^L}{r^D} = 1+\xi = \left[(\eta - \eta z(\eta))\left(1-\frac{1}{n}\right)\right]^{-1} > 0 \tag{10}$$

As we demonstrate below, we can determine the equilibrium interest rate for deposits which, if it is used inside Eq. (10), also provides us with the equilibrium interest rate for loans. The effects of micro and macro reforms are derived from differentiating (10) 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

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

[20] In the absence of any specific assumption-restriction regarding the maximum size of demand for loans, it cannot be determined a finite number of banks in the perfect competition regime (zero banking profits). On the contrary, if there is perfect competition the number of banks tends to infinity. The proof is in Appendix B.5.

[21] In case of no monitoring the default rate $z(\eta)$ will be on average equal to the exogenous probability of default $1-\psi$, but if there is monitoring process the defaulted loans from the R&D recipient firms will be lower. The more efficient is the monitoring process the lower the defaulted loans in comparison to the average probability of default that exist in the R&D sector.

[22] In the case of exogenous monitoring process we have assumed implicitly that the monitoring does not have any burden for the banks - it is like assuming that the banks with the same resources they can implement without any extra cost the monitoring process. In the endogenous monitoring process version of the paper which is presented in Appendix A.1, the monitoring implements a cost for the banks. The results qualitatively remain however the same.

[23] 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).

[24] The elasticity for loans is according to the following formula: $\varepsilon_L = \frac{dL}{dr^L}\frac{r^L}{L}$. The total amount of loans equal to $L = \Omega\mathscr{F}$. By multiplying with Ω both parts of condition (6) $r^L\mathscr{F} = V_\Omega$, we have $r^L\Omega\mathscr{F} = \Omega V_\Omega \Rightarrow r^L L = \Omega V_\Omega$. By implementing implicit differentiation in the previous condition, we can prove that $\varepsilon_L = \frac{dL}{dr^L}\frac{r^L}{L} = -1 < 0$. 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.

[25] The proof of the result in (10) is provided in Appendix B.4. Moreover, Lemma 3 in Appendix B.2 provides the condition under which $r^L \geqslant r^D$, which ensures non-negative profits for banks.

If $sgn\{\cdot\} > 0$ 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 $sgn\{\cdot\} < 0$.[26]

2.3. General equilibrium and BGP analysis

The definition, characterization and derivation of the BGP equilibrium are shown in Appendix B.1 and Appendix B.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 Eq. (12). 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:[27]

$$r^D = r^x = \sqrt{\frac{\alpha^{\frac{1+\alpha}{1-\alpha}}(1-\alpha)[\eta - \eta z(\eta)]\left[1-\frac{1}{n}\right]}{\mathscr{F}}} \tag{11}$$

$$g^* = \frac{r^D - \rho}{\theta} \tag{12}$$

$$u^* = \frac{\sigma\theta + \rho - r^D}{\sigma\theta} = 1 - \frac{g^*}{\sigma} \tag{13}$$

$$\left(\frac{H}{\Omega}\right)^* = \left[\frac{r^D - \rho}{\theta\phi}\right]^{\frac{1}{1-\beta}}\left[\frac{\sigma\theta}{\sigma\theta + \rho - r^D}\right] \tag{14}$$

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

Condition (11) 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), $\mathscr{F}$ (the sunk-cost, also defined as R&D expenditure), and defaulted loans $z(\eta)$. Condition (12) 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: $g_Y = g_C = g_A = g_H = g_\Omega = g^*$.[28] Finally, (14) 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 Eqs. (13) and (14) from the main text.[29] Given this derivation, we can formulate the model's necessary Propositions (and key predictions):

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 (10) wrt n. □

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 (10) wrt η. □

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.*

[26] The magnitude of $z'(\eta)$ depends on the monitoring efficiency, which is part of the characteristics of the banking-financial system in each country.
[27] Recall that x is the name of intermediate inputs whereas j denotes one specific intermediate input.
[28] The growth rate of the economy is affected by r^D, Eq. (12). From Eq. (11) 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.
[29] The full comparative statics and the analysis of the conditions are in Appendix B.3.

Proof. Differentiate (12) wrt n.[30] □

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 (12) wrt η. □

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 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.[31]

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 granted[32] are taken from OECD Patent statistics. Raw data on

[30] Note, n is contained within r^D in (11) and r^D is contained within (12).

[31] The results of Propositions 1–4 show the marginal effect of each policy parameter on the spread of interest rates and on the growth rate of the economy (growth rate of patents) by taking as given the other policy parameter. We have also checked the joint effect of the two policy parameters by finding the following cross-partial derivative $\left[\partial^2(r^L/r^D)/\partial n\partial\eta\right]=\text{sgn}[1-z(\eta)-\eta z'(\eta)]$. The result is straightforward and available upon request and it suggests that if it exists case (iii) of Proposition 2 there is not joint effect between the two policy parameters. If case (ii) exists, then both reforms go to the same direction and the impact of micro reform becomes even bigger. Finally, if case (i) exists, then the two policy reforms go to a different direction and their joint effect can be checked through the empirical part. However, we can mention that (by looking at the empirical results from all the different econometric methods) the coefficient of macro policy reform is twice or three times bigger than the coefficient of the micro policy reform which implies that the overall effect of these two policy reforms on economic growth is negative.

[32] 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.

patents report the country of residence of each inventor following the International Patent Classification (IPC).[33] We consider only patents registered in the USA patents office (USPTO) to capture "high quality" innovation conducted in each country.[34] The technological domains covered in the USPTO include ICT, 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 deprecation 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 Fig. 2. This depicts the positive pattern between R&D intensity and innovation output. This is a well-documented empirical relationship discussed before.

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.[35] Fig. 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.

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 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.

3.2. Empirical specification

This section describes the equation used as an empirical device essentially for testing **Propositions 3 & 4**.[36] 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.[37] 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).

[33] 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).

[34] 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).

[35] It may also curb expansion and government finance towards 'priority sectors'.

[36] The dataset and the R codes to replicate our results are available on request.

[37] We restrict our time span to 1981 onward reflecting the starting availability of R&D data. Admittedly, alternative proxies for micro and macro reforms can be used to extend the span of the analysis beyond 2005. Indicatively, the share of assets of the five largest banks to total assets of the banking sector can approximate competition as the equivalent of micro reform (Diallo and Koch, 2018), while the ratio of Broad Money to total reserves can be used to account for the degree of liquidity in the market, identical to macro reform. Although these variables are available from the World Bank Development Indicators, they cover only the post-2000 period, whereas they do not follow the same definition as the measures in Abiad et al. (2010) (continuous vs. categorical variables). More importantly, most financial reforms occurred up to the late 1990's early 2000s without any reversals taking place. Consequently, extending the time span of the econometric analysis beyond 2005 would likely not offer substantial insights into the empirical relationship under question.

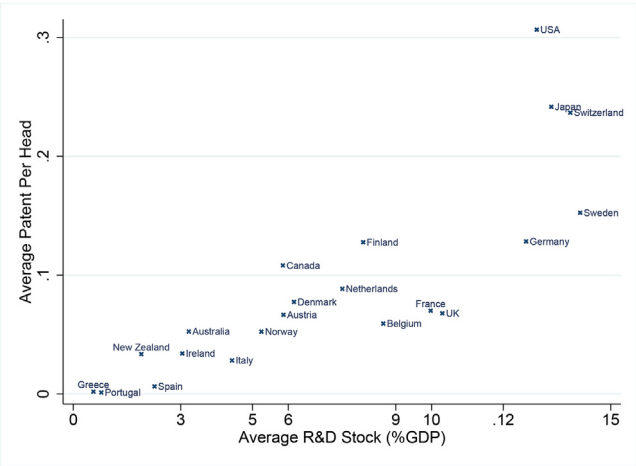

Fig. 2. The relationship between R&D stock and patents per capita. *Notes:* This figure plots the country averages over the same of R&D Stock as a % of GDP against patents per capita, by country. This satisfies the main assumption of the theoretical model which is described in Eq. (1).

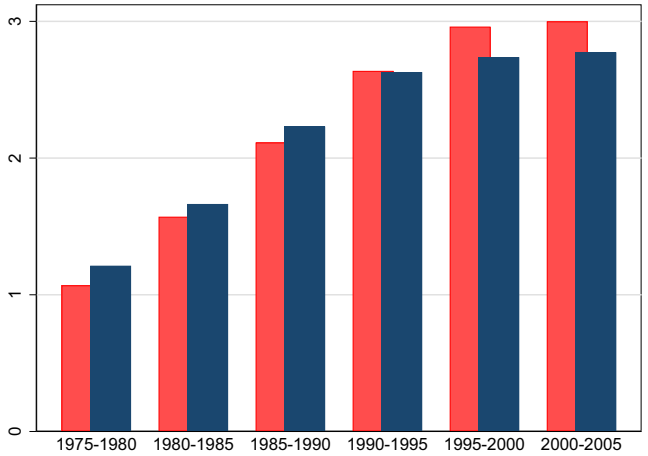

Fig. 3. Index of entry barriers (micro) and credit controls (macro) for 21 OECD countries. *Notes:* Values close to 3 indicates a fully liberalized regime in the respective categories. *Source:* Abiad et al. (2010).

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).[38] 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 (2) 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 reforms on the growth rate of patents appears through the R&D investment. Finally, from (11) and (12) 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:

$$\begin{aligned}\Delta \log p_{it} = {} & \beta_0 + \beta_1 \log p_{i0} + \beta_2 \log H_{it} + \beta_3 \log RD_{it} + \beta_4 \log Risk_{it} \\ & + \beta_5 \underbrace{entry_{it} \times \log R\&D_{it}}_{\textbf{micro}} + \beta_6 \underbrace{credit_{it} \times \log R\&D_{it}}_{\textbf{macro}} + X'\beta + e_{it}\end{aligned} \tag{15}$$

The first line of (15) is the basic empirical analogue of (2), the second incorporates interaction terms in the financial reforms and R&D activity and the final line adds relevant controls.

[38] 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.

Table 1
Growth rates of patents before and after financial reforms.

	Micro Reform (entry barriers)				Macro Reform (credit controls)				
	Switch[†]	Before	After	Always Liberalized[‡]	Switch	Before	After	Always Liberalized	Never 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		
UK				2.60				2.60	
USA	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.

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 $i = 1, 2, \ldots N$ at year $t = 1, 2, \ldots T$.[39] We include $\log p_{i0}$ to capture initial conditions in the innovation status of each country. This is consistent with Eq. (2) 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 modeled as an $EGARCH(1,1)$ (exponential generalized autoregressive conditional heteroscedastic) process.[40] Term β_0 is an overall regression constant and $e_{it} \overset{iid}{\sim} (0, \sigma_e)$ is the error term. We estimate (15) on an unbalanced panel of 21 OECD countries over 1981–2005 using fixed effects to allow for unobserved heterogeneity; Table 2 provides summary statistics of the variables of interest pooled across countries.[41]

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. If on the contrary the rents are small there is interest to invest in other assets.[42] 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 (15) 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).[43] Security markets contain stock markets, bond markets and derivatives markets. Moreover, high yield of long run bonds means high confidence of the investors

[39] 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.

[40] 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).

[41] 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.

[42] 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 to lower investment, R&D expenditure and economic growth.

[43] 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.

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

Table 3
Estimates of patent stock per capita, Eq. (15): copula estimates.

coef./case	A	B	C
β_0	**0.105**	**0.105**	**0.096**
	[0.085,0.129]	[0.082,0.104]	[0.075,0.123]
$\log p_0$	**−0.016**	**−0.016**	**−0.015**
	[−0.021,−0.012]	[−0.021,−0.012]	[−0.02,−0.011]
$\log H$	**0.023**	**0.023**	**0.024**
	[0.007,0.042]	[0.007,0.043]	[0.008,0.042]
$\log R\&D$	**0.036**	**0.036**	**0.036**
	[0.022,0.051]	[0.021,0.051]	[0.021,0.050]
$\log Risk$	−0.003	−0.002	−0.002
	[−0.005,0.000]	[−0.005,0.000]	[−0.005,0.001]
micro	**0.002**	**0.002**	0.001
	[0.000,0.003]	[0.000,0.003]	[−0.001,0.003]
macro	**−0.007**	**−0.007**	**−0.007**
	[−0.009,−0.005]	[−0.009,−0.005]	[−0.0010,−0.005]
$\log Angel$		0.000	0.000
		[−0.002,0.002]	[−0.003,0.001]
SecMark		0.000	0.000
		[−0.001,0.001]	[−0.001,0.001]
$\log\ Stock$			0.003
			[−0.000,0.006]
$\overrightarrow{\log H}$	0.000	0.000	0.000
	[−0.007, 0.006]	[−0.006,0.006]	[−0.007,0.005]
$\overrightarrow{\log R\&D}$	−0.007	**−0.007**	**−0.008**
	[−0.012,−0.002]	[−0.012,−0.002]	[−0.013,−0.003]
σ_e	0.025	0.025	0.024
AIC	−1491.35	−1488.191	−1488.96
N	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* × *RD* and *credit* × *RD*. $\overrightarrow{\log R}$ and $\overrightarrow{\log H}$ 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. The fitted model allow for fixed effects. Estimation with a general time trend had a negligible impact on the remaining parameters and was suppressed for parsimony.

to invest in alternative assets and not in the risk-less 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.

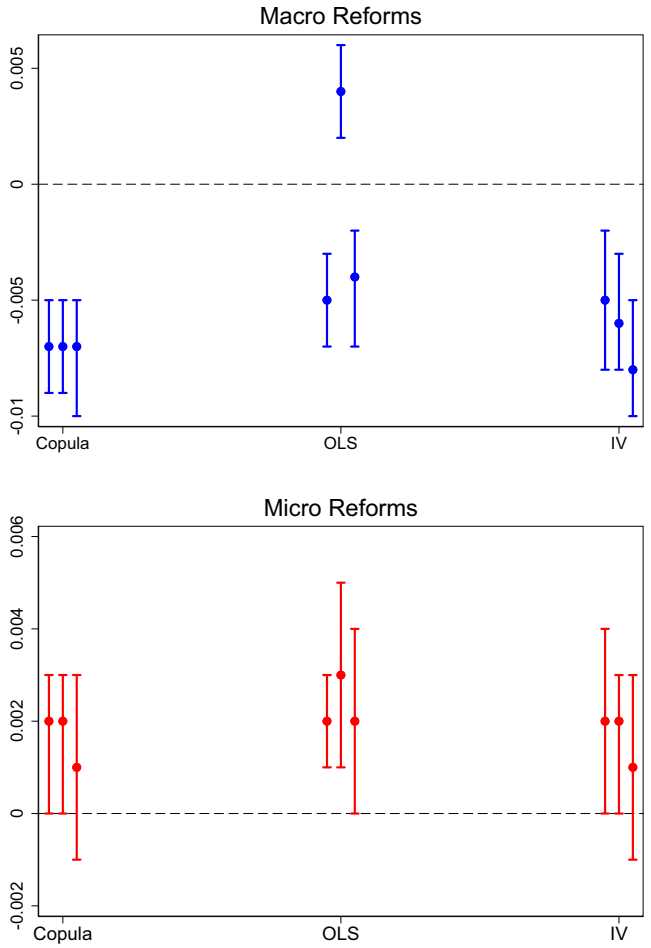

Fig. 4. Parameter values and bootstrapped confidence intervals for micro and macro terms. *Notes:* These figures plot the estimation results from the *macro* and *micro* parameter values in Eq. (15). The circle is the central parameter estimates and the lines above and below represent the respective 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. To sum up, the empirical results robustly verify the predictions of the theoretical model and in terms of the reserve paradox that appears in the theoretical part of the paper, it is not present since the effect of macro reform is mainly negative (the risk of default due to lower reserve requirements dominates the positive liquidity effect).

3.3. Econometric estimations and results

OLS estimates for (15) 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.[44]

In particular, in practice there is a difficulty in finding the appropriate instruments. This means that instruments explain little variation in the endogenous regressor thus leading to inaccurate estimates of the coefficient of the endogenous regressor. In addition, weak instruments cause the distribution of the estimator to deviate considerably from a normal one producing thus erroneous statistical inference, see Bound et al. (1995).

[44] More specifically, in our context, since both R&D expenditure and human capital determine the growth rate of patents as inputs but at the same time an economy which is more oriented to the innovation process devotes more resources for R&D and for improving school quality, it is evident that may exist reverse causality and therefore endogeneity. Moreover, there are many other unobserved variables which can determine simultaneously the growth rate of patents, R&D expenditure and human capital level. Therefore, it is hard the discovery of instruments which are high correlated with the regressors (R&D expenditure and human capital) without being correlated with the error term of the regression. The use of Copula method helps to solve this issue by taking into account, as it is described in the current paper and in the mentioned literature, the distribution properties of the residuals and therefore transforming appropriately the endogenous regressors.

To overcome limitations associated with instrument identification, we use the copula technique within a time series-cross sectional context as per Patton (2006) and Christopoulos et al. (2021) (see also the discussion in Kourtellos et al. (2016), Kourtellos et al. (2021)).[45] Copulas model the joint distribution of the endogenous regressors with the error term and the information obtained is used to restore consistent and unbiased estimates without employing any instrumentation.[46]

This free of instruments approach does not require the error term to follow a normal distribution, while it generates estimates of the slope parameters that outperform IV estimates, see for example Park and Gupta (2012), Christopoulos et al. (2021) and Yang et al. (2022). Appendix D describes the key steps of the copulas transformation and estimation.[47]

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 for the main copula estimation case are shown in Table 3 (with all results available in Appendix E), whilst Fig. 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). On 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 $-0.007 \times \log R\&D_{it}$ where the $\log R\&D_{it}$ 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.

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 produces a straightforward result: a decrease in lending rates. This policy potentially stimulates R&D investment through the competition-stability scenario, 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.

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 econometric specification under consideration). That, in turn, provides some credibility to the presence of a "reserves paradox". In essence, more liquidity does not always benefit innovation, since insurance premiums remain high to offset high default rates.

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. Recent experience has shown that banking crises have more likely resulted from increased liquidity, thus prudential regulation requires higher insurance demand of deposits and higher premiums. Reforms that favor higher liquidity do not increase the willingness of banks to finance innovation projects. Both our theoretical and empirical findings raise some skepticism 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, 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.

Data availability

Data will be made available on request.

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

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

[47] Copulas have been used to address the problem of endogeneity to both linear and non-linear models, see for example Park et al. (2011) and Christopoulos et al. (2021).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, athttps://doi.org/10.1016/j.jimonfin.2023.102820.

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