Research, technological change and financial liberalization in South Korea

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ABSTRACT

Drawing on the recent developments in innovation-based growth models that emphasize the importance of financial factors and R&D activity, this paper explores the impact of research efforts and financial sector reforms on inventive activity, using Korea as the case study. Based on time series data over the period 1967–2005, the results consistently show that the implementation of a series of financial liberalization policies is strongly associated with a higher rate of knowledge generation. They also show that R&D intensity has a significant positive influence on ideas production, providing some support for the Schumpeterian endogenous growth framework.

1. Introduction

Recent work on endogenous growth theory suggests that R&D efforts and financial factors are important determinants of long-run growth (see, e.g., de la Fuente and Marín, 1996; Blackburn and Hung, 1998; Aghion et al., 2005; Aghion and Howitt, 2009). These models predict that financial market imperfections prevent innovators from obtaining sufficient external finance. Financial liberalization removes credit constraints and helps facilitate the adoption of modern technology to boost the development of knowledge and technology-intensive industries.

Although there is a growing body of empirical studies examining the impact of financial liberalization on economic growth (see, e.g., Edwards, 2001; Edison et al., 2002; Bekaert et al., 2005), these papers only examine the direct effect of financial liberalization on economic growth. Notwithstanding the important role of finance in innovative activity, there is little empirical analysis exploring the impact of financial liberalization on the rate of innovation – a key channel through which it can impact economic growth.

This study aims to enrich the existing literature by providing some empirical evidence to shed light on the way in which financial liberalization affects the evolution of innovation. Drawing on the Schumpeterian growth framework, we estimate the impact of R&D intensity and financial liberalization on the rate of innovation using Korea as the case study. Korea is an ideal candidate in this context given that it is a high growth economy that has also undergone significant financial sector reforms. It is probable that one of the key indicators of the impact of these reforms has come in the form of a significant variation in innovative activity. As such, these policy changes provide an appropriate historical setting to analyze the subject

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at hand. Moreover, as noted by Choe and Moosa (1999), Korea's experience in financial sector reforms has frequently been used as a benchmark for reforms in other developing countries, especially China.

We focus on documenting case study evidence instead of a larger sample of countries given that the effects of financial sector policies may be heterogeneous across countries at different stages of economic development. Case studies are particularly useful in disentangling the complexity of the financial environment and economic history of each country. As Temple (1999) notes, historical analyzes are more useful in identifying reasons for growth variations within countries. By analyzing case studies, the econometric findings of this project can be related to the prevailing institutional structure, and therefore inform academic as well as policy debate.

The rest of the paper is organized as follows. Section 2 reviews the macroeconomic environment and financial liberalization experience in Korea since the 1960s, focusing on the Korean approach to finance and development. Section 3 presents the Schumpeterian endogenous growth model. This analytical framework is used to test the effect of financial liberalization on innovative activity. Section 4 discusses variables construction and data sources. The estimation techniques are described in Section 5. Section 6 performs the empirical analysis and presents the results. Section 7 concludes.

2. Macroeconomic developments and financial sector reforms

The financial system in Korea was subject to extensive government interference during the 1960s and 1970s (Cho, 1988, 1989). In 1962, the government set up a series of comprehensive five-year economic development plans. In the process, financial regulations were enacted so that credit could be directed to small and medium sized enterprises and to industries that contributed to export growth. Following the first oil shock, these rules were further strengthened in 1974 to promote heavy industry, resulting in a greater misallocation of capital (BOK, 2000). Meanwhile, as part of the development strategy, the Bank also adopted a low interest rate policy, and the real interest rate was negative for most of the 1970s.

Although the Korean economy was able to sustain strong growth in the 1960s and 1970s through massive public investment programs and provision of subsidies to certain strategic industries, such active government intervention had resulted in a misallocation of resources and hampered initiatives in the private sector (BOK, 2000). Following almost two decades of rapid export-led growth, the Korean economy experienced an economic downturn in the late 1970s. This deteriorating economic environment was precipitated by a worsening external environment, accelerating price increases, and a large accumulation of foreign debt. This adverse situation was exacerbated by political uncertainties and the second oil crisis in 1979 (Park, 1994).

Poor economic performance and the inefficiency of government intervention eventually led to a shift in government policy towards economic liberalization in the early 1980s in order to improve the efficiency of resource allocation. As part of the overall economic reform, the financial system also underwent significant restructuring. These programs were aimed at promoting the function of market mechanism and encouraging the private sector creativity. The reforms included privatization of several major commercial banks, partial deregulation of interest rates, gradual decontrol of foreign exchange restrictions, and opening up capital markets to foreign competition. At the same time, the government attempted to boost technology development by inducing the private sector to invest more in technology through the provision of significant tax benefits on R&D expenditures and human capital development (BOK, 2000).

Although the reform objective was to achieve a market-based financial system so that interest rates could be determined on a competitive basis, financial deregulation in the 1980s appeared to be slow and limited in scope (Cho, 1988). Improved macroeconomic conditions towards the end of the 1980s provided a favorable environment for further deregulation. Consequently, financial sector reforms were accelerated in the early 1990s. Specifically, the Bank carried out a three-stage interest rate deregulation plan to remove controls on all interest rates (except some short-term deposit rates) during the period 1991–1995. Furthermore, the Bank also carried out measures aimed at improving efficiency in resource allocation, including the abolishment of mandatory lending to the manufacturing sector and reduced mandatory lending ratios to small and medium sized enterprises (BOK, 2000).

As a major part of the pursuit of financial liberalization, reserve requirement ratios were significantly lowered. The reserve requirements for demand and saving deposits were gradually reduced from 32% to 18%, respectively, in 1969, to 4.5%, regardless of deposit type, in 1983. However, compared to interest rate controls and reserve requirements, changes in the extent of directed credit programs were less dramatic. The share of policy-directed loans in total deposit money bank loans had only fallen to 29% in 1989 from 39% in 1980. This ratio fell further to 22% in 1999.

Although these reforms have led to significant growth and modernization in Korea's financial sector, Korea's poorly implemented financial liberalization has contributed to the size and pace of the financial crisis in 1997. Cho (2001) argues that the implementation of financial liberalization was poorly phased and lacked a comprehensive strategy. There was also inadequate prudential regulation and supervision. Consequently, the acceleration of reforms in the 1990s to expedite the globalization of the Korean economy has made the economy vulnerable to external shocks, significantly weakening the financial structure following the crisis.

3. Analytical framework

This section sets out the analytical framework underlying our empirical modeling strategy. Recent developments in endogenous growth theory have emphasized the importance of R&D efforts as an engine of growth. Accordingly, the

Schumpeterian endogenous growth model can be presented using the following generic expression (see, e.g., Ha and Howitt, 2007; Madsen, 2008):

$$\dot{A} = \lambda \left(\frac{X}{Q}\right)^{\sigma} A^{\phi} \qquad Q \propto L^{\beta} \text{ in steady state} \tag{1}$$

where $\dot{A}$ is the amount of new knowledge or ideas produced (i.e., the inventive output), A measures the stock of knowledge or ideas, X is R&D input, Q is product variety, and L is employment or population. The growth enhancing effect of R&D input is counterbalanced by the deleterious effect of product variety (Ha and Howitt, 2007). The ratio (X/Q) is commonly referred to as research intensity. λ is a research productivity parameter, σ is a duplication parameter (0 if all innovations are duplications and 1 if there are no duplicating innovations), ϕ is returns to scale in knowledge, and β is the parameter of product proliferation. The Schumpeterian theory assumes constant returns to knowledge ($\phi = 1$) and the presence of a product variety effect ($\beta = 1$).

In their seminal work, McKinnon (1973) and Shaw (1973) noted that financial repression policies were largely accountable for the poor economic performance of developing countries in the 1960s, where low saving and credit rationing were widely observed. Investment suffered both in terms of quantity and quality as funds were allocated at the discretion of policy makers. They challenged the financial repression ideology and provided a new paradigm in the design of financial sector policies. Their theories proposed that distortions in the financial systems, such as loans issued at an artificially low interest rate, directed credit programs and high reserve requirements, would reduce saving, retard capital accumulation and prevent efficient resource allocation. The elimination of these distortions would significantly deepen financial systems and therefore foster economic growth.

Recent developments in the theories of endogenous growth that consider financial factors are in line with the McKinnon–Shaw financial liberalization thesis. Financial liberalization facilitates inventive activity for a number of reasons. In the work of de la Fuente and Marín (1996), the relationship between finance and growth is analyzed in a model of product innovation in which efficiency of the financial system arises endogenously. Risk aversion and private information in R&D activity lead to a moral hazard problem, and this makes innovative activity unattractive for risk-averse entrepreneurs. This problem, however, can be mitigated through improved monitoring by financial systems, which allow intermediaries to offer better insurances terms. Hence, more efficient financial systems, which can be achieved through financial sector reforms, should yield a higher level of innovative activity.

Using a product variety model, Blackburn and Hung (1998) postulate that firms have incentives to hide successful R&D activity to avoid repaying their loans. Such a problem of moral hazard gives rise to the enforcement of an incentive-compatible loan contract through a costly monitoring system. In their model, greater financial liberalization allows financial intermediaries to diversify among a large number of projects that significantly reduces delegation costs. Lower costs of monitoring therefore spur R&D activity and economic growth.

More recently, in the Schumpeterian growth model developed by Aghion et al. (2005), it is assumed that firms can conceal the results of successful innovations and thereby avoid repaying their creditors. A low degree of creditor protection makes fraud an inexpensive option, and this limits firms' access to external finance, which discourages the production of ideas. Financial development, which often follows from greater financial liberalization, tends to increase the hiding costs through providing better laws and institutions. This makes credit more readily available to entrepreneurs and allows them to undertake innovative activity. Moreover, Aghion and Howitt (2009, chap. 6) also show that reducing credit constraints results in lower screening and monitoring costs, thus mitigating agency problems and increasing the frequency of innovations.

The above discussions clearly highlight that financial liberalization plays a crucial role in boosting innovative activity in a number of ways. Ang and Madsen (2008) suggest that the following knowledge creation function can be used to test the effect of financial liberalization on ideas production:

$$\ln \dot{A}_t = \alpha + \beta \ln A_t + \chi \ln(X/Q)_t + \delta \ln FL_t + \varepsilon_t \tag{2}$$

where $\dot{A}$ is inventive output, A measures the stock of knowledge or ideas, $(X/Q)_t$ is a measure of research intensity, and ε_t is Gaussian errors. β is expected to be positive and carry a value of one, based on the predictions of the Schumpeterian growth theory. The expected sign for χ is also positive since R&D activity is expected to promote innovations. Our earlier discussion suggests that financial liberalization (FL_t) will have a positive impact on knowledge production, and hence δ is expected to carry a positive sign. The above equation will be estimated using annual data for Korea over the period 1967–2005.

4. Construction of variables and data sources

4.1. Patent data

As suggested by Kortum (1993), the amount of patenting activity can be used as a proxy for the extent of innovation activity. Hence, we use the number of patents filed by domestic residents as the measure for inventive output ($\dot{A}_t$). The data are obtained from the World Intellectual Property Organization (WIPO). The domestic stock of knowledge (A_t) is constructed based on $\dot{A}_t$ using the perpetual inventory method with a depreciation rate of 10%. The initial knowledge stock is set equal to the number of patents in 1967 divided by the depreciation rate plus the average growth in patents over the period 1967–2005.

4.2. R&D intensity measures

R&D input (X_t) is measured by R&D labor (N_t) and real R&D expenditure (R_t). R&D labor is defined as the number of scientists and technicians engaged in R&D activity. Nominal R&D expenditure is deflated using an unweighted average of the economy-wide value-added price deflator and hourly earnings. The following measures of research intensity are considered: (1) N_t/L_t; (2) $h_t^N N_t/h_t^L L_t$; and (3) R_t/Y_t, where L_t is the labor force, h_t^N is human capital per R&D worker, h_t^L is human capital per ordinary worker, and Y_t is real GDP. The second measure of research intensity is adjusted for educational attainment for each type of worker to account for the fact that skilled and unskilled workers may contribute to technological improvements by varying degrees (see, e.g., Papageorgiou, 2003; Vandenbussche et al., 2006). The consideration of human capital is especially important given that previous work by Lucas (1993) and Papageorgiou and Perez-Sebastian (2006) have found human capital to play an important role in the miraculous development process of Korea.

Human capital is computed using the Mincerian approach, i.e., $h_t^{L,N} = \exp[f(S_t^{L,N})]$. Following the seminal work of Klenow and Rodriguez-Clare (1997) and Bils and Klenow (2000), this approach to constructing human capital stock has been widely adopted in the literature (see, e.g., Papageorgiou, 2003; Papageorgiou and Sebastian, 2004). We use the average years of schooling for the population over 25 years old as the measure for educational attainment for ordinary workers (S_t^L). The years of schooling per unit of R&D labor (S_t^N) are approximated using an approach similar to that of Vandenbussche et al. (2006). Accordingly, the average number of years of tertiary education (T_t) is given as: $T_t = n^{IC}(p_t^{IC} + p_t^C) + n^C p_t^C$, where n^{IC} is the additional years of incomplete schooling in tertiary education (2 years) and n^C is the additional number of years to complete tertiary education (2 years), p_t^{IC} is the percentage of adult population (aged 25 and above) who have not completed tertiary education, and p_t^C is the percentage of adult population who have completed it.

Assuming that all research workers have at least completed some tertiary education, the years of education per R&D worker (S_t^N) is the sum of T_t and the total years of schooling in elementary and secondary education (i.e., 13 years in Korea). The data are obtained from the Barro and Lee (2001) education dataset. We follow the approach of Hall and Jones (1999) by assuming that $f(S_t)$ is piecemeal linear, where a rate of schooling return of 13.4% (average for Sub-Saharan Africa) is assumed for the first 4 years of education, 10.1% (average for the whole world) for the next 4 years, and 6.8% (average for the OECD) for schooling more than 8 years. These rates of return are based on the surveys evidence of Psacharopoulos (1994).

R&D data are taken from various issues of the Statistical Yearbook published by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Some missing data between years are interpolated. Data for the labor force and real GDP are obtained from various issues of the Korea Statistical Yearbook. The time series plots of these variables are presented in Fig. 1. It is worth noting that the amount of patenting activity increased rapidly in the 1980s and the early 1990s, coinciding with the implementation of a series of financial sector reforms.

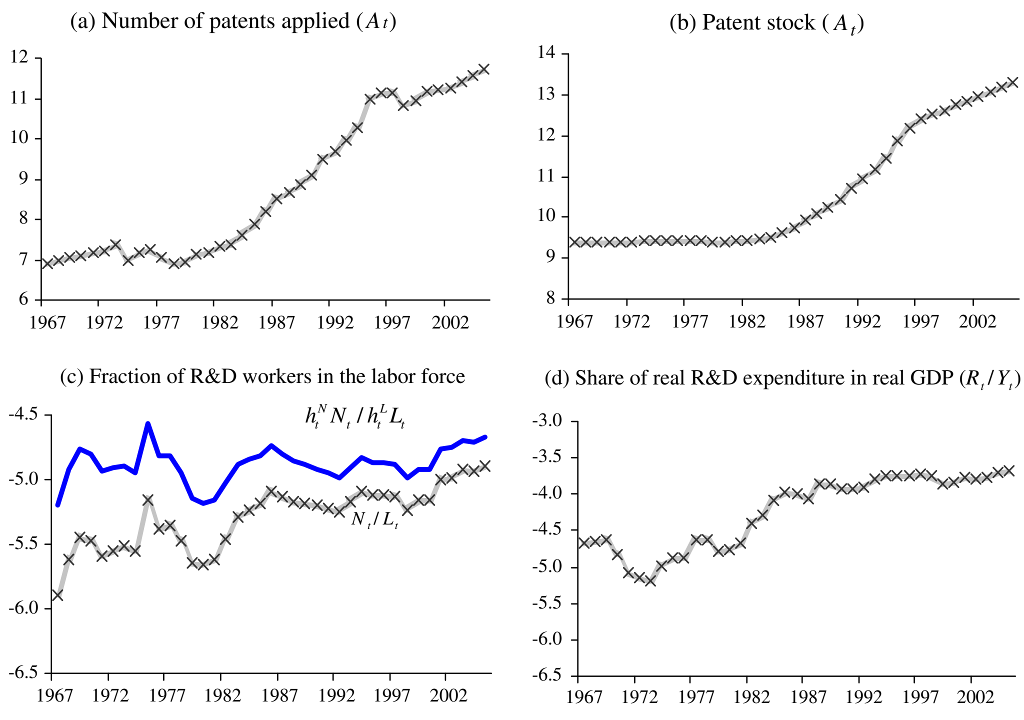

Fig. 1. Time series plots of key variables (on log scale).

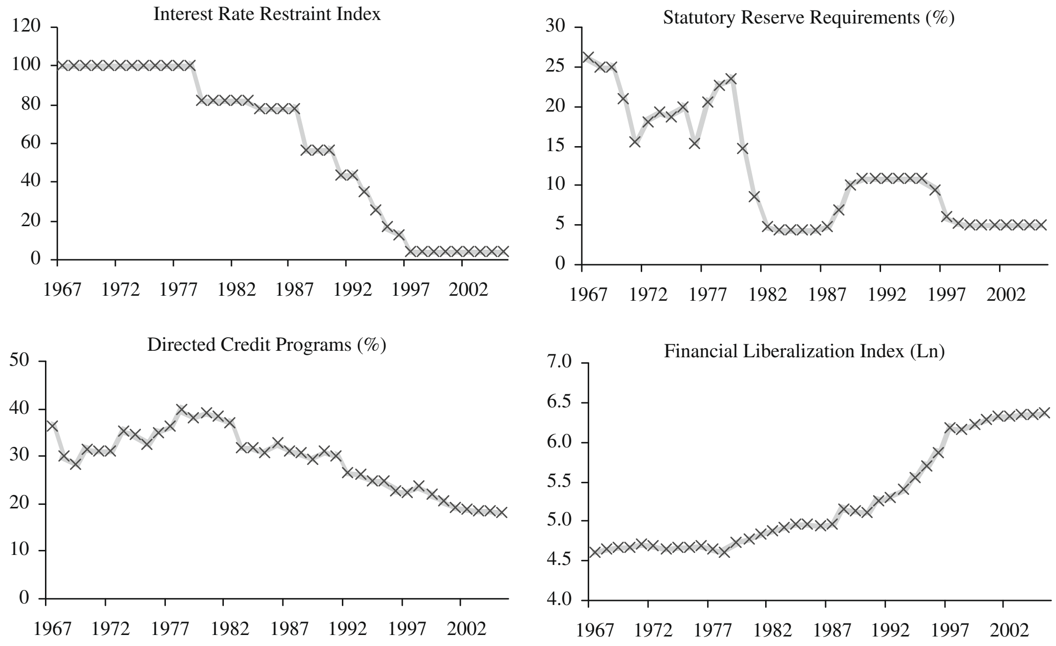

Fig. 2. Evolution of financial sector policies (1967–2005).

4.3. Financial liberalization index

To construct an index of financial liberalization, we consider three types of financial sector policy: (1) interest rate controls, (2) statutory reserve requirements and (3) directed credit programs. The choice of these three components is based on the financial liberalization thesis of McKinnon (1973) and Shaw (1973). These data series are either directly obtained or compiled from various issues of the Annual Report, Monthly Bulletin and Economic Statistics Yearbook of the Bank of Korea. Although data on financial policy are available from the 1950s, our empirical analysis begins in 1967 due to constraints on R&D data. To measure the extent of interest rate controls, we consider a number of interest rate policies implemented in Korea. This involves the consideration of 23 interest rate policy measures adopted in Korea over the last few decades. These policy controls are translated into dummy variables which take the value of 1 if a control is present and 0 otherwise. We take the simple average of these series and normalize the first observation to 100 to provide a single measure for the extent of interest rate restraints in Korea.[1]

Statutory reserve requirements are direct measures expressed in percentages. Unlike Malaysia for which the priority sector target lending rates are directly available (see Ang and McKibbin, 2007; Ang, 2009b), Korea has no consistently recorded direct *de jure* measure for directed credit programs. Therefore, we follow the approach of Park (1994) and Ang (2009a) by using a *de facto* measure, which involves measuring the share of actual directed loans in total loans. Fig. 2a–c plot the time series evolution of these variables. In general, all repressionist policies exhibit a downward trend over the last four decades, reflecting an increase in the level of financial liberalization over time.

In principle, these policy measures can be used individually in the empirical specification in order to assess the effectiveness of each policy. However, this may give rise to some econometric problems due to the small sample used in this study (39 annual observations). Moreover, the underlying policy variables may be highly correlated since the Reserve Bank of Korea has jointly imposed some of these controls. A solution to these problems is to reduce the number of policy variables to just one summary measure, which can account for the joint influence of all policy variables.

Given this objective, the method of principal component analysis appears to be a natural choice. It is the standard approach to examine the patterns of relationships among the variables, with the objective of summarizing the information content of several observed variables into one component or a handful of representative key components. The method involves computing the linear combinations of the original variables that capture their maximum variance. These components can capture a large proportion of the variance in the original variables and can therefore serve the same purpose as the full set, but in a much more succinct manner.

The results of the principal component analysis are presented in Table 1. The eigenvalues indicate that the first principal component explains about 84.7% of the total variation, the second principal component explains another 13.6% and so on. The first principal component is computed as a linear combination of the three financial sector policy measures with weights

[1] Interest rate deregulation measures considered in the analysis include the abolishment of interest rate controls on installment saving deposits, personal checking deposits, foreign currency loans, foreign currency deposits, export promotion financing loans, long-term, equipment investment loans, corporate bonds, time deposits with different maturity dates, bank overdrafts, aggregate credit ceiling system, etc.

Table 1
Principal component analysis for the financial liberalization index.

	Principal component 1	Principal component 2	Principal component 3
Eigenvalues			
Value	2.542	0.407	0.051
Percent of variance	0.847	0.136	0.017
Cumulative %	0.847	0.983	1.000
Eigenvector			
IRR_t	0.601	−0.368	−0.709
SRR_t	0.527	0.850	0.006
DCP_t	0.600	−0.377	0.705

Notes: IRR_t, interest rate restraints; SRR_t, statutory reserve requirements; and DCP_t, directed credit programs.

given by the first eigenvector. We use the percentages of variance as the weights to obtain the final index. The resulting index is positively and significantly correlated with all underlying variables, providing some evidence that it is a reasonably good indicator for the extent of financial repression imposed on the Korean financial system. Given that this measure reflects the strength of financial sector policies designed to repress the financial system in Korea, we take its inverse and interpret it as the degree of financial liberalization.

The resulting composite financial liberalization index displayed in Fig. 2d coincides rather well with the actual policy changes that took place in Korea during the sample period discussed earlier. The first observation of the index is normalized to 100 (or 4.605 on natural log scale), noting that an index number of 100 does not necessarily reflect a fully liberalized financial system. Relative to other periods, there were very few policy changes in the Korean financial system during the 1960s and 1970s. From the beginning of the 1980s the government gradually reformed the financial sector, and this process was expedited in the early 1990s. The implementation of these liberalization measures is reflected by an upward swing in the series since the early 1980s. The pace of liberalization slowed down significantly in the aftermath of the 1997–1998 Asian financial crisis.

5. Estimation techniques

The dynamic adjustment of the ideas generation process can be characterized by a conditional error-correction model (ECM), which can be used to test for the existence of a long-run relationship using the ARDL bounds test developed by Pesaran et al. (2001) and the ECM test of Banerjee et al. (1998). The former involves a standard *F*-test whereas the latter is a simple *t*-test. Accordingly, the underlying ECM can be formulated as:

$$\Delta \ln \dot{A}_t = \alpha_0 + \beta_0 \ln \dot{A}_{t-1} + \sum_{j=1}^{k} \beta_j DET_{j,t-1} + \sum_{i=1}^{p} \gamma_{0i} \Delta \ln \dot{A}_{t-i} + \sum_{i=0}^{p} \sum_{j=1}^{k} \gamma_{ji} \Delta DET_{j,t-i} + \varepsilon_t \tag{3}$$

where $\dot{A}_t$ is the number of patents applied by domestic residents and DET_t is a vector of the determinants of innovative activity, which includes $\ln A_t$, $\ln (X/Q)_t$ and $\ln FL_t$.

The equation above can be estimated by OLS since Pesaran and Shin (1998) have shown that the OLS estimators of the short-run parameters are consistent, and the ARDL based estimators of the long-run coefficients are super-consistent in small sample sizes. Hence, valid inferences on the long-run parameters can be made using standard normal asymptotic theory. The main advantage of this approach is that it can be applied to the model regardless of whether the underlying variables are $I(0)$ or $I(1)$. Specifically, two separate statistics are employed to test for the existence of a long-run relationship in Eq. (3): (1) an *F*-test for the joint significance of coefficients on lagged levels terms of the conditional ECM ($H_0 : \beta_0 = \beta_1 = \ldots = \beta_k = 0$), and (2) a *t*-test for the significance of the coefficient associated with $\ln \dot{A}_{t-1}$ ($H_0 : \beta_0 = 0$).

The test for cointegration is provided by two asymptotic critical value bounds when the independent variables are either $I(0)$ or $I(1)$. The lower bound assumes all the independent variables are $I(0)$, and the upper bound assumes they are $I(1)$. If the test statistics exceed their respective upper critical values, the null is rejected and we can conclude that a long-run relationship exists. The above ARDL model also provides a convenient step to derive the long-run estimates and short-run dynamics for the knowledge production function, as detailed in Pesaran and Shin (1998).

While our preferred approach is the ARDL estimator due to its superior statistical properties, the dynamic ordinary least squares (DOLS) estimator is also considered to provide a robustness check for the results, given that it is one of the most commonly used single-equation estimators in the literature. The DOLS approach is asymptotically equivalent to the Johansen maximum likelihood VECM estimator. Based on Monte Carlo simulations, Stock and Watson (1993) show that it outperforms several alternative estimators of long-run parameters. A more recent study by Caporale and Pittis (2004), however, suggests that the DOLS approach is among several estimators that perform worst in small samples. In contrast, the ARDL approach detailed in Pesaran and Shin (1998) is one of the 28 estimators analyzed that possesses the most desirable small sample properties. We therefore place more emphasis on the results derived from the ARDL estimator and report the DOLS estimates only for sensitivity checks. This consideration is particularly important given the small sample size used in the study.

$$\ln \dot{A}_t = a_0 + \sum_{j=1}^{k} b_j DET_{j,t} + \sum_{i=-p}^{p} \sum_{j=1}^{k} d_{ji} \Delta DET_{j,t-i} + \varepsilon_t \tag{4}$$

The procedure involves regressing one of the $I(1)$ variables on the remaining $I(1)$ variables, the $I(0)$ variables, leads (p) and lags ($-p$) of the first difference of the $I(1)$ variables, and a constant, as given in Eq. (4). By doing so, it corrects for potential endogeneity problems, omitted lagged variable bias and small sample bias, and provides estimates of the cointegrating vector which are asymptotically efficient. The long-run model for $\ln \dot{A}_t$ can be obtained from the reduced form solution by setting all differenced terms of the regressors to be zero. An error-correction model is formulated to provide an analysis for the short-run dynamics. The error-correction term (ECT), which captures the speed of adjustment towards the equilibrium, is obtained by considering $\ln \dot{A}_{t-1} - a_0 - b_1 DET_{1,t-1} - \ldots - b_k DET_{k,t-1}$. The general-to-specific modeling approach is adopted to derive a satisfactory short-run dynamic model. This involves testing down the general model by successively eliminating statistically insignificant regressors and imposing data acceptable restrictions on the parameters to obtain the final parsimonious dynamic equation.

6. Empirical findings

6.1. Integration and cointegration analyses

We begin our empirical analysis by employing three unit root tests to assess the order of integration of the underlying variables – the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowiski–Phillips–Schmidt–Shin (KPSS) tests. The ADF and PP test the null of a unit root against the alternative of stationarity whereas the KPSS tests the null of stationarity against the alternative of a unit root. The results, which are not reported here to conserve space but available upon request, show that all variables appear to be either stationary, i.e., $I(0)$, or integrated at order one, i.e., $I(1)$. Given that none of the variables appears to be integrated at an order higher than one, this allows legitimate use of the proposed cointegration procedures.

Next, to perform cointegration tests on the knowledge production equation, we regress the conditional ECM in Eq. (3) by allowing for up to two lags. We do not consider a larger lag structure in order to preserve the degrees of freedom in estimation. To ascertain the existence of a level relationship between the variables, this requires satisfying both the F- and t-tests. Table 2 gives the F-statistics for the ARDL bounds tests, t-statistics for the ECM tests, model selection criteria AIC and SBC, and several diagnostic test statistics. The table contains results for three models, where each model corresponds to the estimation results using different measures of research intensity.

With a more parsimonious modeling approach of only one lag, the results indicate that the null hypothesis of no level knowledge production equation is rejected at the conventional levels of significance, as suggested by both the ARDL bounds and ECM tests. While the results are not sensitive to the choice of research intensity measures, the econometric specifications fail a number of diagnostic tests, especially the tests for serial correlation. When two lags are chosen, the null of no cointegration is firmly rejected at the 1% level in nearly all cases, irrespective of the method of cointegration tests and research intensity measures. This provides strong support for the existence of a long-run relationship between knowledge production and its determinants. Moreover, no evidence of cointegrating is found when other variables are used as the dependent variables, suggesting that these variables can be interpreted as the long-run forcing variables explaining $\ln \dot{A}_t$. Finally, we do not find any evidence of serial correlation, autoregressive conditional heteroskedasticity, and heteroskedas-

Table 2
Cointegration tests.

	Model A: $(X/Q)_t = (N/L)_t$		Model B: $(X/Q)_t = (h^N N)_t/(h^L L)_t$		Model C: $(X/Q)_t = (R/Y)_t$	
	$p = 1$	$p = 2$	$p = 1$	$p = 2$	$p = 1$	$p = 2$
ARDL bounds test (Pesaran et al., 2001)	5.202**	8.664***	5.288**	8.821***	5.338**	8.905***
ECM test (Banerjee et al., 1998)	−3.613*	−4.796***	−3.725*	−4.879***	−4.035**	−4.214**
AIC	−2.396	−3.165	−2.402	−3.166	−2.302	−2.840
SBC	−1.692	−2.267	−1.698	−2.268	−1.687	−1.951
χ^2_{SERIAL}	7.022*** (0.008)	2.563 (0.109)	14.469*** (0.001)	0.799 (0.371)	5.528** (0.019)	0.842 (0.359)
χ^2_{ARCH}	1.689 (0.193)	0.934 (0.334)	1.216 (0.271)	0.676 (0.411)	5.771** (0.016)	1.421 (0.233)
χ^2_{WHITE}	14.697 (0.473)	13.077 (0.835)	15.103 (0.445)	11.789 (0.895)	24.880** (0.024)	21.017 (0.336)

Notes: p is the lag length. The test statistics of the bounds tests are compared against the critical values reported in Pesaran et al. (2001). The estimation allows for an unrestricted intercept and no trend. The 10%, 5% and 1% critical value bounds for the F-test are (2.72, 3.77), (3.23, 4.35) and (4.29, 5.61), and for the t-test are (−2.57, −3.46), (−2.86, −3.78) and (−3.43, −4.37), respectively. χ^2_{SERIAL} is Breusch–Godfrey LM test statistics for no first-order serial relationship, χ^2_{ARCH} is the Engle's test statistic for no autoregressive conditional heteroskedasticity, and χ^2_{WHITE} denotes the White's test statistic to test for homoskedastic errors. Numbers in parentheses indicate p-values.

* 10% level of significance.

** 5% level of significance.

*** 1% level of significance.

ticity at the conventional levels of significance level when two lags are chosen. We will therefore choose two lags for the remaining analyses, as also suggested by AIC and SBC.

6.2. The effect of financial liberalization on knowledge production

Table 3 presents the results for the ideas production model estimated using the ARDL estimator. It is evident that the stock of knowledge variable enters the long-run knowledge production equation significantly at the 5% level with the expected sign. Specifically, the coefficients of the stock of knowledge variables are found to be in the range of 0.448–0.742. The use of a Schumpeterian growth framework is supported by the finding of a statistically and economically significant relationship between the measures of research intensity and knowledge production. Results from both Models A and B give a similar estimate of about 0.5 whereas Model C yields a much smaller coefficient of 0.091. To the extent that R&D intensity has a positive effect in generating innovations, increased R&D activity is likely to result in higher inventive activity, which will in turn induce higher innovation-driven growth.

However, we do not find full support for the Schumpeterian growth theory given that the assumption of constant returns to knowledge stock does not hold. Using the Wald tests, the null $\beta_1 = 1$ is rejected in all models. To the extent that most developing countries are not at the forefront of their R&D, the assumption of constant returns to knowledge is more likely to hold since technological laggards can enjoy a large pool of knowledge stock developed elsewhere. Our finding of decreasing returns to scale is plausible in this context since Korea is a technology leader that has one of the highest numbers of research workers in the world.

Financial liberalization is found to have a beneficial impact on knowledge creation, consistent with the findings of Ang and Madsen (2008) for India. Its effect is found to be highly significant at the conventional levels in all regressions. Specifically, a 1% point increase in the index of financial liberalization is associated with a 0.906% and 1.264% point rise in ideas production in Model A and Model B, respectively. Its elasticity value is found to be somewhat smaller in Model C when research intensity is measured using the share of R&D expenditure in total output. The finding of a positive effect of financial liberalization lends some support to the McKinnon–Shaw thesis, which proposes that distortionary policies in the financial systems should be removed in order to induce higher growth. The results are also in line with the R&D-induced endogenous frameworks of de la Fuente and Marín (1996), Blackburn and Hung (1998), Aghion et al. (2005) and Aghion and Howitt (2009), which postulate that greater financial liberalization reduces moral hazard problems and credit constraints, thereby resulting in more inventive activity.

Our results are broadly in line with Choe and Moosa (1999), who have shown that financial development leads to higher economic growth in Korea. Similarly, the results are also broadly consistent with Cho (1988), who demonstrates that financial liberalization in Korea has improved the allocative efficiency of credit. The results underscore the importance of liberalizing the financial system in Korea so as to stimulate economic growth via increasing innovative activity. Given that the extent of financial liberalization may affect the speed of technological accumulation and innovations, and that financial development may act as an effective mechanism in facilitating the adoption of new technologies in the domestic economy,

Table 3
ARDL estimate for the knowledge creation function (1967–2005).

	Model A: $(X/Q)_t = (N/L)_t$		Model B: $(X/Q)_t = (h^N N)_t/(h^L L)_t$		Model C: $(X/Q)_t = (R/Y)_t$	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
I. The long-run relationship (*Dep.* $= \ln \dot{A}_t$)						
Intercept	0.089	0.951	−0.725	0.616	−2.323**	0.028
$\ln A_t$	0.579***	0.001	0.448**	0.044	0.742***	0.000
$\ln(X/Q)_t$	0.485**	0.031	0.464*	0.093	0.091**	0.037
$\ln FL_t$	0.906**	0.015	1.264***	0.009	0.228**	0.018
II. The short-run dynamics (*Dep.* $= \Delta \ln \dot{A}_t$)						
Intercept	0.039	0.949	−0.271	0.635	−0.861*	0.084
ECT_{t-1}	−0.439***	0.002	−0.373***	0.004	−0.358**	0.015
$\Delta \ln A_t$	3.779***	0.000	3.861***	0.000	3.860***	0.000
$\Delta \ln(X_t/Q_t)$	0.213**	0.044	0.173*	0.095	0.035	0.604
$\Delta \ln FL_t$	0.398***	0.006	0.472***	0.002	0.365**	0.037
$\Delta \ln A_{t-1}$	−1.347***	0.007	−1.561***	0.001	−1.699***	0.001
	Test statistic	*p*-value	Test statistic	*p*-value	Test statistic	*p*-value
III. Diagnostic checks						
χ^2_{SERIAL}	0.073	0.786	0.686	0.408	1.791	0.181
χ^2_{ARCH}	0.302	0.582	0.017	0.896	1.422	0.233
χ^2_{WHITE}	0.485	0.486	0.077	0.782	0.330	0.565

Notes: A maximum lag length of two was used, following the results of the cointegration tests. The optimal lag structure for the resulting ARDL model was chosen using SBC.
* 10% level of significance.
** 5% level of significance.
*** 1% level of significance.

Table 4
DOLS estimate for the knowledge creation function.

	Model A: $(X/Q)_t = (N/L)_t$		Model B: $(X/Q)_t = (h^N N)_t/(h^L L)_t$		Model C: $(X/Q)_t = (R/Y)_t$	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
I. The long-run relationship $(Dep. = \ln \dot{A}_t)$						
Intercept	−1.046	0.205	−1.477**	0.042	−1.815***	0.003
$\ln A_t$	0.688***	0.000	0.619***	0.000	0.838***	0.000
$\ln(X/Q)_t$	0.297**	0.019	0.268**	0.047	0.167**	0.033
$\ln FL_t$	0.710***	0.000	0.875***	0.000	0.396*	0.066
II. The short-run dynamics $(Dep. = \Delta \ln \dot{A}_t)$						
Intercept	0.007	0.712	0.806**	0.019	0.018	0.333
ECT_{t-1}	−0.523**	0.013	−0.576**	0.021	−0.467**	0.013
$\Delta \ln A_t$	3.920***	0.000	3.725***	0.000	3.906***	0.000
$\Delta \ln(X_t/Q_t)$	0.224***	0.001	0.207**	0.025	−0.043	0.656
$\Delta \ln FL_t$	0.161	0.213	0.431*	0.054	0.071	0.594
$\Delta \ln A_{t-1}$	−1.037**	0.031	−2.048***	0.000	−1.371***	0.008
	Test statistic	*p*-value	Test statistic	*p*-value	Test statistic	*p*-value
III. Diagnostic checks						
χ^2_{SERIAL}	0.204	0.651	1.172	0.279	0.039	0.844
χ^2_{ARCH}	0.004	0.947	0.628	0.428	0.433	0.511
χ^2_{WHITE}	15.812***	0.007	3.653	0.601	14.201**	0.014

Notes: Two lags were used in the estimation, following the results of the cointegration tests. The standard errors were corrected where necessary using the Newey–West procedure to obtain robust estimates due to the presence of heteroskedastic errors.
* 10% level of significance.
** 5% level of significance.
*** 1% level of significance.

it is essential to develop a sound financial system in order to reap the benefits of these efficiency gains and achieve sustained economic growth in the long-run.

Turning to the short-run dynamics, the regression results for the conditional ECM of $\Delta \ln \dot{A}_t$ reported in panel II of Table 3 show several desirable features. Specifically, nearly all coefficients are statistically significant at the conventional levels. In first-differenced contemporaneous form (i.e., $\Delta \ln A_t, \Delta \ln(X_t/Q_t)$ and $\Delta \ln FL_t$), the variables have intuitive signs, consistent with the results reported in the long-run models. The coefficients of ECT_{t-1}, which measure the speed of adjustment back to the long-run equilibrium value, are statistically significant at the 1% level and correctly signed, i.e., negative. This implies that an error-correction mechanism exists in the knowledge production function so that the deviation from long-run equilibrium has a significant impact on the growth rate of innovation. These results reinforce the findings of cointegration reported in Table 2 earlier. Knowledge production in Korea adjusts at the speed of 35.8–43.9% every year, or it takes on average 2.6 years, to restore equilibrium when there is a shock to the steady-state relationship.

The results reported in panel III of Table 3 show that the regression specifications fit remarkably well. All models pass the diagnostic tests against serial correlation, autoregressive conditional heteroskedasticity and heteroskedasticity. The structural stability of the knowledge production equation is examined using the cumulative sum (CUSUM) tests on the recursive residuals. The test is able to detect systematic changes in the regression coefficients. The results (not reported) show that the statistics generally lie within the 5% confidence interval bands, suggesting no structural instability in the residuals of the knowledge production equation. Moreover, the predicted levels of knowledge production, which are obtained using the steady-state estimates reported in panel I of Table 3, are able to track the actual series very closely over time, suggesting that the estimated models fit the knowledge creation function very well.[2]

6.3. The DOLS estimates

The sensitivity of the results is further assessed using the DOLS approach. The results presented in Table 4 show that although the magnitude of the coefficients shows some variations, the qualitative aspects of the results are, by and large, consistent with those obtained using the ARDL estimator. Importantly, the main finding that financial liberalization facilitates inventive activity remains unaltered. The short-run estimates and diagnostic test results are also similar to those obtained using the ARDL estimation technique. We therefore conclude that the results are insensitive to the choice of estimator.

6.4. Robustness checks

This section addresses the concern regarding whether the previous results are robust to the inclusion of other macroeconomic variables, especially those that may have a crucial effect on inventive activity. The following control variables are

[2] These results are not reported for space reasons, but they are available upon request.

Table 5
Robustness checks ($Dep. = \ln \dot{A}_t$).

	$CV_t = IM_t$	$CV_t = TB_t$	$CV_t = SPIL_t$	$CV_t = A_t^{ROW}$	$CV_t = DTF_t$	$CV_t = FDI_t$	$CV_t = MP_t$	$CV_t = IPR_t$
I. The long-run ARDL estimates								
Intercept	−0.133	−0.614	0.303	−8.267**	−2.589	0.145	0.195	−2.542**
$\ln A_t$	0.567***	0.528***	0.560***	0.739***	0.943***	0.576***	0.582***	0.674***
$\ln(N/L)_t$	0.492**	0.531**	0.503**	0.271**	0.653***	0.509*	0.407**	0.282**
$\ln FL_t$	0.943**	0.925***	0.971**	0.355**	0.612*	0.918**	0.919***	0.615***
$\ln CV_t$	−0.174	−0.141	−0.031	0.556**	0.422**	−0.009	−0.043	0.425*
II. Diagnostic checks								
χ^2_{SERIAL}	0.135	0.085	0.159	0.004	0.386	0.086	0.021	0.158
χ^2_{ARCH}	0.261	0.001	0.122	1.577	2.239	0.437	0.792	2.595
χ^2_{WHITE}	0.345	0.295	0.278	1.411	0.173	0.524	0.014	1.766
III. Cointegration tests								
ARDL bounds test	8.197***	4.974**	8.685***	6.181***	4.557**	6.359***	4.432**	5.631***
ECM test	−5.278***	−4.341**	−4.071**	−4.534**	−4.402**	−3.183	−3.747*	−4.109**

Notes: CV_t, control variable, which includes: IM_t, import intensity (imports over GDP); TB_t, trade barriers (customs and other import duties/total imports); $SPIL_t$, international R&D spillovers; A_t^{ROW}, patent stock of the rest of the world; DTF_t, distance to the frontier (the frontier's patent stock/Korea's patent stock); FDI_t, the ratio of FDI inflows to GDP; MP_t, macroeconomic policy index (1st principal component of the sum of exports and imports over GDP, inflation rate and the ratio of budget surplus to GDP); and IPR_t, intellectual property rights protection. The 10%, 5% and 1% critical value bounds for the *F*-test are (2.45, 3.52), (2.82, 4.01) and (3.74, 5.06), and for the *t*-test are (−2.57, −3.66), (−2.86, −3.99) and (−3.43, −4.60), respectively.
* 10% level of significance.
** 5% level of significance.
*** 1% level of significance.

considered. First, according to the literature on trade and growth, openness to international trade may have a significant impact on economic growth. We use import intensity (the ratio of imports to GDP, IM_t) and the tariff rate (the ratio of customs and other import duties to total imports, TB_t) to capture the effect of international trade on the variation of patenting activity.

Second, there is now an established literature arguing that innovative activity is positively associated with international knowledge diffusion (see, e.g., Coe and Helpman, 1995). Given that cumulative knowledge stocks embodied in imported intermediate inputs may have an impact on domestic patenting activity, we measure international R&D spillovers via the channel of imports ($SPIL_t$) following the approach of Lichtenberg and Van Pottelsberghe de la Potterie (1998). It considers the average of the domestic R&D capital stocks of Korea's trade partners, which include 20 other OECD countries, weighted by the fraction of their total output that is exported to Korea.[3] Furthermore, international knowledge may transmit across borders independently of the trade channel (see Bottazzi and Peri, 2007). In this case, the accumulation of patent stocks in the rest of the world may allow ideas to travel freely across borders. The world stock of knowledge available to Korea (A_t^{ROW}) is simply the sum of all patent stocks across the world excluding Korea.

Third, Bernard and Jones (1996) argue that changes in innovative activity may also depend on technological catch-up. Countries which are relatively backward can grow faster by utilizing technologies developed in the leading country. To allow for this, we include a proxy for distance to the frontier (DTF_t), which is measured by the ratio of the frontier's patent stock to Korea's patent stock. The frontier is determined by the country having the highest accumulated patents in the world at a particular time, which turns out to be either Japan or the US Fourth, technology transfer in Korea may have occurred directly through inflows of foreign investment. We therefore include the ratio of foreign direct investment to GDP (FDI_t) to capture this effect.

Fifth, it is likely that our measure of financial liberalization may also capture changes in other policy environments apart from the financial system. To allow for this possibility, we estimate the ideas production function by controlling for the effect of macroeconomic policy (MP_t). To do this, we follow the approach of Burnside and Dollar (2000) by creating a summary index for macroeconomic policy. This involves considering the first principal component of the sum of exports and imports over GDP, the inflation rate and the ratio of budget surplus to GDP. The resulting index shows a strong upward trend up to the mid 1980s and some moderate fluctuations since then, which coincide rather well with the actual changes in the overall policy environment in Korea.

Finally, the number of patent applications may be affected by a significant change in patent laws. A strengthening patent protection framework may prevent the free flow of ideas and retard technological development. But on the other hand, it may enhance the innovators' ability to recoup expensive R&D costs, thereby encouraging further innovation. The intellectual property rights index (IPR_t) constructed by Park and Lippoldt (2005) is used to capture the extent of patent protection. The missing years are interpolated.

In the remaining analyses, the estimates are derived based on Model A using only the ARDL estimator. Moreover, for space reasons, the short-run estimates are not reported. The estimates reported in Table 5 show that our core results remain robust to the inclusion of these control variables. Specifically, the measures of research intensity and financial liberalization remain

[3] The OCED countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherland, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US.

highly significant in most cases. The stock of knowledge generated in the rest of the world (A_t^{ROW}) and technology gap (DTF_t) appear to have a positive effect on patenting activity. An increase in the patent protection framework also tends to encourage innovative activity. Moreover, we continue to find fairly strong evidence of cointegration in all regressions. Consistent findings with those obtained earlier suggest that our results are not sensitive to the inclusion of these control variables.

7. Conclusions

This paper assesses the impact of financial liberalization on innovative activity using annual time series data for Korea over the period 1967-2005. Using the ARDL bounds and ECM cointegration techniques, the empirical evidence shows a significant long-run relationship between knowledge production and its determinants. After documenting these basic cointegration results, we derive the long-run estimates using two different single-equation estimators.

Our results consistently suggest that financial liberalization has the potential to improve economic growth, via increasing knowledge production. The shift in financial policy from an interventionist one towards a more market-oriented one since the early 1980s has resulted in more inventive activity, contributing to higher economic growth. Thus, our results suggest that financial allocation should be determined by markets based on the Korean experience.

Overall, the conclusion that financial liberalization results in more inventive activity is consistent with the theoretical studies reviewed in this paper. The findings of this paper have important policy implications for developing countries. To the extent that financial sector reforms have positive effects in generating innovations, the presence of a more liberalized financial system is likely to motivate inventive activity, which may in turn induce higher economic growth.

The results also show that R&D is an important determinant for growth, providing some support to the notion that R&D-based endogenous growth models are useful in explaining the growth phenomenon in the context of a high growth economy. To the extent that innovation-based growth models are useful in predicting the growth pattern in Korea, more R&D activity will contribute to long-run growth via increasing innovative activity. On the whole, the results are insensitive to the choice of estimation technique and measures of research intensity.

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