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Innovation, Information, and Financial Architecture

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Abstract

Does a financial system architecture anchored on banks perform better than one centered on markets in fostering technological innovations as engines of growth? In a panel of industrial sectors across a large cross section of countries, I find that while market-based systems have a general positive effect on innovations in all economic sectors, bank-based systems foster more rapid technological progress in more information-intensive industrial sectors, suggesting a heterogeneous impact of financial architecture. Thus, the relative performance of bank-based systems vis-à-vis market-based systems depends on the industrial structure of the economy.

I. Introduction

The relative merits of financial intermediaries vis-à-vis financial markets as providers of capital is a recurring theme in corporate finance. A macroeconomic version of this issue is whether the financial architecture of an economy—i.e., the degree to which its financial system is bank-oriented or market-based—has any impact on economic performance in the real sector. Does financial architecture matter for long-term growth and, in particular, in fostering innovations and technology? The debate, which goes as far back as Schumpeter (1912) and Bagehot (1873), commenced with reference to Germany and the U.K. in the late 1800s, and later expanded to include the U.S. as a prototype market-based system and Japan as a representative of a bank-based economy.[1] This debate has become more fervent in recent times because financial system configuration is at the core of market reform policies in transition and emerging economies that are en route to capitalism after decades of totalitarian repression. This paper explores empirically the relation between technological innovation and financial architecture, focusing on differences between markets and banks in processing information.

The role of financial architecture in fostering innovation and technology is theoretically controversial. Both the bank- and the market-based views primarily

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[1] Allen and Gale (1995), Boot and Thakor (1997), and Allen and Gale (2000b) provide excellent reviews of the literature on the merits of bank- versus market-based systems.

emphasize the merits of banks or financial markets in mitigating informational imperfections. Markets and banks perform vital functions in an economy, including capital formation, risk sharing, information production, and monitoring. The case for bank-based or market-oriented systems is usually made by focusing on the relative effectiveness with which banks or markets execute these common functions. In particular, a key attribute of financial markets—a feature that distinguishes them from banks—is that prices formed in financial markets provide valuable information to real decisions of firms. This is called the "information feedback" function of markets. There are two important properties of this information feedback function, namely, that prices aggregate diverse informed opinions about the firm's investment opportunities, and that information is revealed to third parties relatively easily. With banks, instead of investors producing information through trading and conveying it via prices, loan officers generate information while evaluating projects for loan financing. In contrast, while such information generation is different from the price mechanism, bank-generated information is also relatively safe from leakage. These fundamental differences in the manner in which information is processed by banks vis-à-vis financial markets have critical implications for the relative performance of bank- versus market-based financial systems, particularly in fostering innovation and technology.

The market-based view holds that markets have attributes in processing information that intermediaries do not have and that these attributes are advantageous in fostering innovative technologies. In the first place, financial markets facilitate the identification of profitable innovative investment opportunities through their information feedback function (see, e.g., Boot and Thakor (1997)). Moreover, market-based systems facilitate innovation by allowing financing when diversity of opinion prevails (see Allen (1993), Allen and Gale (1999)). The argument is that the assessment of new technologies is difficult either because little information is available about their potential returns or because the information itself is difficult to judge without some expertise, indicating that there is often substantial diversity of opinion. Bank-based financing requires delegation of the decision regarding financing to a relatively small number of decision makers. When there is no disagreement, this delegation is effective and entails cost savings. It is, however, problematic when diversity of opinion persists, because some of the providers of funds may disagree with the decisions of the delegated monitor. Thus, bank-based finance is likely to underfund new technologies. Financial markets, on the other hand, permit individuals to agree to disagree, and therefore allow coalitions of investors with similar views to join together to finance projects. Hence, markets are effective in financing new industries and technologies where relevant data is completely lacking.[2]

On the other hand, the bank-based view emphasizes the relative disadvantages of markets in processing information that is particularly relevant for firms'

[2]Other arguments in favor of market-based systems are also offered. For example, as creditors, banks are risk averse or conservative, and have a bias against financing innovation (Weinstein and Yafeh (1998), Morck and Nakamura (1999)). Also, powerful banks reduce a firm's incentive to undertake innovative projects by extracting informational rents (Hellwig (1991), Rajan (1992)). In addition, capital markets, by allowing the financing of long-term projects by savers with short-term liquidity needs, enable the adoption of innovative but long gestation technologies (Hicks (1969), Bencivenga, Smith, and Starr (1995), and Saint-Paul (1992)).

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incentive to innovate. First, financial markets could lead to underinvestment in information acquisition in the first place, with a negative impact on identification of innovative projects. The argument is that efficient markets reduce the incentives of investors to generate information about firms because others could free-ride on one's costly information (Grossman (1976), Stiglitz (1985)). In contrast, banks dissipate less information to the public, providing incentives to generate information (Boot, Greenbaum, and Thakor (1993)). Second, and more importantly, financing innovations through markets may risk the revelation of proprietary technological information to the firms' competitors, providing greater incentives to finance innovation via banks (Bhattacharya and Chiesa (1995), Yoshi (1995)).[3] The idea is that firms with valuable innovations may value confidentiality. Information disclosed in multilateral financing (i.e., markets) will eventually be available to third parties including the firms' competitors. By contrast, bilateral (i.e., bank) financing results in less leakage. In equilibrium, high quality firms with valuable innovations prefer bilateral (i.e., bank) financing to multilateral (i.e., market) financing (Yoshi (1995)). Conversely, the architecture of the financial system affects the incentives of firms to innovate. The importance of confidentiality for innovative firms means that firms with observationally more sensitive information—those with the most to lose from leakage of their private information—fare better in bank-based financial systems.[4]

As the arguments on both sides of this historic debate are compelling, in this paper I take an agnostic position on the issue and explore the consistency of each side of the debate with the available data. Using industry-level panel data across a large cross section of countries, I examine the importance of financial architecture to fostering innovation and growth based on differences in information processing. I begin by evaluating the total, average effect of financial architecture on innovation. That is, I test whether, by and large, industries realize faster or slower rates of technological progress if they are supported by market- or bank-based systems. Given the opposing theoretical views, the answer to this question is not obvious. The evidence supports that market-based systems have, on average, a positive impact on innovation.

Going beyond the analysis of this average effect, I then ask whether firms or industries that differ in their *information intensiveness* fare relatively better

[3] A related notion is that of Dewatripont and Maskin (1995) who argue that bank-based financing is vulnerable to renegotiation problems, and that market-based finance might be superior because it maintains commitments not to renegotiate. This is so because of the free-rider problem and the high transaction costs involved in negotiating with a large number of bondholders. But others show that renegotiation is not necessarily bad; it is welfare-enhancing (see, e.g., Allen and Gale (2000b)).

[4] Other arguments for bank-based systems are also offered. First, bank-based systems are more effective in funding new and innovative activities that require staged financing (Stulz (2000)) because banks can credibly commit to making additional funding as the project develops. Second, banks more effectively finance industrial expansion in underdeveloped economies (Gerschenkron (1962), Boyd and Smith (1996), (1998)), since powerful banks can induce firms to reveal information better than markets in such economies (Rajan and Zingales (1999)). Third, bank-based systems encourage innovation by facilitating the financing of long-term projects through reducing liquidity risk (Greenwood and Jovanovic (1990), Bencivenga and Smith (1991)). Some also argue that banks are better for corporate governance. Efficient markets may hamper the effectiveness of takeovers as a corporate governance tool by providing incentives to atomistic investors to hold up (Grossman and Hart (1980)), and liquid markets may reduce the incentives of dispersed shareholders to monitor inside managers (Bhide (1993)).

or worse in market- or bank-based systems. Again, given the opposing theoretical views, one would expect informationally intensive sectors to realize faster rates of technological progress in either bank- or market-based systems. Using industry-specific information about the asset composition of firms as a measure of the degree of information intensity, I therefore ask if financial architecture has a heterogeneous impact across industrial sectors as suggested by the theory. I find that financial architecture, indeed, has a heterogeneous effect on innovation, whereby specific firms or industries appear to benefit from market-based systems while others benefit from bank-based systems.

The empirical test I conduct is as follows. Firms with greater intangible assets in their asset composition are considered to be more informationally intensive. In the literature, the extent of intangible assets in a firm's asset composition—the intangible intensity—has been utilized variously as a measure of the informational sensitivity of a firm's activities and as an indicator of a firm's vulnerability to informational asymmetry problems. Industries with a high level of intangibles in their asset mix are commonly knowledge-intensive sectors with nonstandard, relatively complex activities and outcomes that are less amenable to independent measurement. These are also sectors with soft assets that stand to lose more from information leakage. Furthermore, Claessens and Laeven (2003) shows that there is a systematic pattern in intangible intensity across industrial sectors that can be attributed to technological and market conditions. One would, therefore, expect to find stronger evidence of either effect of financial architecture by focusing the analysis on sectors that vary in intangible intensity. I examine the effects of market or bank orientation of the financial system on the realization of innovation by asking whether industrial sectors that typically use many intangible assets realize relatively faster rates of innovation in bank- compared to market-based systems. The results show robust evidence that such industries realize relatively faster rates of innovation in countries with more bank-oriented financial systems.

To sharpen the empirical tests, I also consider industrial differences on innovation-related measures of information intensiveness such as R&D activities and patent use intensities. In particular, I examine whether industrial sectors that typically spend a higher proportion of their revenues on R&D activities, or sectors that use relatively more patents, realize faster rates of innovation in bank- or market-based financial systems. The use of such measures confirms the main finding that informationally intensive industries realize faster innovation in countries with bank-oriented financial systems.

These results are robust to a number of checks, including alternative measures of the focal variables of interest, alternative explanations of the results, omitted variables bias, and tests for simultaneity bias. In interpreting the results, however, the usual caveats related to possible weaknesses in the data and the choice of a particular time period and country sample, as well as methodological issues, should apply.

The two results—that market-based systems foster innovation on average and that bank-based systems foster innovation in informationally intensive sectors—are not in contradiction. Rather, taken together, they confirm the basic predictions of the market- and bank-based views. Market-oriented financial systems foster innovation by enabling the identification and financing of new technolo-

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gies, and of industries in general where diversity of opinion persists (e.g., Allen (1993), Boot and Thakor (1997)). On the other hand, the impact of financial architecture is not homogeneous across economic activities. Bank-based systems promote innovation especially in informationally sensitive economic sectors. This could be so for many reasons, including the fact that these are firms that have more to lose from information leakage related to impending innovation, which is consistent with the key predictions of the bank-based views of Yoshi (1995) and Bhattacharya and Chiesa (1995) that emphasize the advantages of banks in handling proprietary information.

This paper contributes to the emerging empirical literature on the financial architecture-growth nexus.[5] Levine (2002) examines the impact of financial architecture on per capita gross domestic product (GDP) growth and total factor productivity growth (TPG), and Beck and Levine (2002) explore whether the output growth of industries that differ in their dependence on external finance depends on financial architecture. Both Levine (2002) and Beck and Levine (2002) find overall financial development and not financial system architecture is important for growth. Demirguc-Kunt and Maksimovic (2002) report that whether the financial system is bank- or market-oriented has little effect on firm growth. Tadesse (2002), on the contrary, finds that across financially underdeveloped countries, industry growth is faster in bank-based systems than in market-based systems and vice versa across financially developed countries. Countries dominated by small firms grow faster in bank-based systems and those with large firms in market-based systems. Thus, financial architecture, in and of itself, is relevant for growth. Hence, in summarizing the literature, Allen and Gale (2000a) note that the empirical evidence on the merits of bank- versus market-based systems is mixed. In the context of this controversy, this paper examines and provides evidence on the role of appropriate financial architecture for spurring technological innovation as an engine of growth.

This paper also extends the literature by analyzing and documenting an information-based channel through which financial architecture could affect economic performance. Earlier studies focus on differences in financial architecture in terms of capital provision (e.g., Levine (2002) and Beck and Levine (2002)), finding no difference, and others emphasize differences in the compatibility of financial system design to countries' legal and contractual environments (e.g., Tadesse (2002)). Beck and Levine (2002), for example, examine whether industries that are heavy users of external capital grow faster in bank- or market-based systems, underlining the differences in the two systems in mobilizing capital for externally dependent firms. In contrast, recognizing that financial systems provide both capital mobilization and governance services in the form of information processing and monitoring, this paper complements existing research by arguing that the dif-

[5]The debate on the relative merits of bank- versus market-based financial systems is historical, and the literature goes back much further. For example, Goldsmith (1969) provides a comparison of the financial systems of Germany and the U.K., and Gerschenkron (1962) reports on the importance of the bank, Credit Mobilier, for the industrialization of France and that of the Great Banks for the development of Germany. Mayer (1990) reports how the Japanese banking system contributed to its post-war development, and Cohen (1967) documents on the role of such banks as Banca Commerciale Italiana for Italy. On the other hand, Bagehot (1873) and Hicks (1969) emphasize the role of the mature securities markets in Great Britain as a precursor of the Industrial Revolution.

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ferential effectiveness of bank- versus market-based systems may arise from the relative comparative advantages of the two systems in processing information. Based upon such a view, I identify a particular channel through which financial system design could influence economic performance, i.e., via its effect on firms' conduct in adopting new technologies. Hence, instead of searching for a general association between financial architecture and performance as in, for example Levine (2002), this paper examines a particular channel by focusing on the technological response of industries with diverse asset structures to variations in financial architecture. In so doing, the paper provides the first evidence on the effect of financial architecture on the attainable technological progress of industries that vary in their asset composition, reflecting their informational environments.

The balance of the paper is organized as follows. Section II introduces the empirical methodology and the data. Section III reports the main results. Section IV provides robustness tests, and Section V concludes.

II. Methodology and Data

A. Empirical Model Specification

To explore the relations among financial architecture, information, and technological innovations, I use the setup of Rajan and Zingales ((1998), RZ hereafter),[6] who introduce an innovative methodology to explore the relation between financial development and economic growth in a cross-industry cross-country setting. They argue that, if financial development matters, firms with greater "natural" demand for external finance should grow faster in financially developed countries. To test this, they need a measure of the natural demand for external finance. RZ construct a measure of the dependence of industries on external finance based on the degree of external financing by U.S. firms. They argue that the relative sophistication and efficiency of capital markets in the U.S. allow U.S. firms to raise external capital to their *desired* level. Hence, there should be technological and economic reasons why some industrial sectors depend more on external finance than others in the U.S., and these differences across industrial sectors should prevail in other countries as well. This does not imply that two industrial sectors in two countries will have an identical degree of external dependence; rather the rank order of industries by their degree of external dependence should be similar across industries. Therefore, RZ use the external dependence of U.S. industries as a proxy for the technology-driven natural degree of external dependence in other countries as well, and show that industries that are more dependent on external finance grow faster in financially developed countries.

Claessens and Laeven (2003) utilize the RZ framework to examine the role of property rights in spurring economic growth. They postulate that strong property rights protection should be more important to firms with high intangibles in their asset mix, since soft assets are more vulnerable to expropriation including outright theft. Following RZ (1998), Claessens and Laeven (2003) argue that

[6]Other studies that use the RZ methodology include, among others, Cetorelli and Gambera (2001) who study the impact of banking industry structure, and Fisman and Love (2002a) who examine the role of trade credit.

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"the well-protected property rights in the U.S. should allow U.S. firms to achieve the desired . . . asset structures for their respective industrial sectors" (p. 2406). They then use this "desired extent of asset mix" by U.S. industries as the optimal asset mix of an industry anywhere in the world. Indeed, they find that intangible intensive industries, i.e., industries with greater intangible usage in their asset composition, grow faster in countries with stronger property rights.

In this study, I argue that industrial sectors that differ in their asset composition in terms of their intangible intensity should fare relatively better or worse in countries with different financial architectures. I argue that the differential asset mix across U.S. industries also reflects differences in the complexity and sensitivity of information, reflecting the nature of the underlying technologies and economic activities. Thus, I use the intangible intensity of industrial sectors as a proxy for the informational intensiveness of the sectors' economic activities that is driven by technological and market conditions. The bank- and market-based views provide opposing predictions about the impact on the innovative activities of such sectors. Intangible intensive activities are relatively knowledge-based, soft, hard to monitor, and generally more complex activities. The market-based view that financial markets allow financing of innovations in situations where diversity of opinion is substantial suggests that more complex activities fare better in market-based economies. On the other hand, the bank-based views of Yoshi (1995) and Bhattacharya and Chiesa (1995) predict that such industries should prosper in bank-based economies because of the high value of confidentiality. Claessens and Laeven (2003) show that the degree of intangible intensity in firms' asset mixes vary across industrial sectors. Hence, evidence that industries with greater intangible intensity realize faster rates of innovation in market- or bank-based systems provides a direct test of the market- or bank-based view of the role of financial system configuration with respect to innovation.

What is needed, ideally, is a ranking of industrial activity by degree of complexity and sensitivity of information—the informational environment of an industry—that is reflective of the nature of innovation-related economic activity. I use the measure of intangible intensity as a proxy for the information intensiveness of the industry for a number of reasons. First, intangible assets represent activities with inherently uncertain long-term payoffs, such as assets representing R&D efforts and those related to brand names. High intangible activities are generally knowledge-based, hard to monitor, and less amenable to valuation agreements, an attribute of the information environment I wish to measure. Second, as a result, firms with substantial intangibles are also considered to have more informational asymmetry (see, e.g., Barth, Kasznik, and McNichols (2001)), and the fact that they have soft, hard to monitor assets also means that intangibles are relatively prone to information leakage. Finally, the asset mix of the industry is reflective of the nature of the underlying economic activities. Since the values of intangible assets (versus tangible properties) are relatively more firm-specific, a measure based on intangible intensity should be reflective of the firms' internal information environment. Other potential measures could include measures of the difficulty of performance measurement by outsiders, such as the degree of analyst forecast consensus and more direct measures of innovation-related activities, such as R&D costs and the use of patents. The problem with using analysts' fore-

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cast consensus is that it primarily reflects the noise in the reporting environment, rather than the nature of the firm's activities. In addition, lack of consensus may simply reflect firm-specific risk (volatility) rather than the level of information (Clarke and Shastri (2001)). Nonetheless, the ranking of industries by intangible intensity closely mirrors the ranking based on financial analysts' difficulty in earnings forecast. As a robustness check, I also perform the analysis using forecast consensus for U.S. industries. Additionally, sharper measures of the information environment surrounding industrial innovation-related activities might be more direct measures of innovation, such as the degree to which the industry invests in R&D activities and the degree to which it relies on the acquisition and protection of patents. In my context, the use of these measures introduces a significant endogeneity problem, as these same measures are also commonly used as measures of technological innovation. Nonetheless, I also report the results using R&D activities and industrial patent use for robustness.

I use manufacturing industrial sectors as units of observation,[7] and examine if industries that vary in their use of intangibles in their asset mix fare better or worse in bank- or market-based systems. In the basic empirical model, following RZ, I regress a measure of the industrial rate of innovation on a variable that interacts a measure of the industry's intangible intensity and the financial architecture of the country, controlling for non-observable country, industry, and time-related sources of industrial innovation.[8] The specification of the basic empirical model is

$$
\begin{aligned}
(1)\quad \text{TECH}_{ict} \;=\; & \alpha + \Gamma_1 \text{IndustryDummy}_i + \Gamma_2 \text{CountryDummy}_c \\
& + \Gamma_3 \text{YearDummy}_t + \gamma_4 \text{IntangibleIntensity}_i * \text{FinancialArchitecture}_c \\
& + \gamma_5 \text{IndustryShareofValueAdded}_{ict} + \varepsilon_{ict},
\end{aligned}
$$

where TECH is a measure of the rate of technological innovation (to be fully explained below), subscript i indicates that the variable refers to the ith industry, subscript c indicates a variable referring to the cth country, and subscript t refers to the tth year. Uppercase coefficients indicate vectors. The industry and year dummies control for industry- and period-specific sources of variation in technical innovation. The industry's share in value added, measured as the total value added of industry i in the country as a ratio of total value added of the country's manufacturing sector, measures the relative importance of the industry in the country. The country controls include regressors customarily used in cross-country growth regressions.

[7] As RZ note, this is done "... in order to reduce the dependence on country-specific factors, like natural resources ..." (RZ (1998), p. 567).

[8] To address the main research question, I need variations in the independent variables, such as financial architecture. One approach is to examine how the technological performance of industries changes as a country moves from one form of financial architecture to another over time. However, this is less feasible because the financial architecture of a country does not show much variation over time. The movement of countries from relatively bank- to market-based systems and vice versa is gradual. Another approach is to observe the technological responses of *similar* industries across countries as a function of financial architecture (which has cross-country variation). This is the approach taken in this paper, and it is in line with the literature on financial architecture (e.g., Levine (2002), Beck and Levine (2002)), finance and growth (e.g., RZ (1998)) as well as the extensive empirical literature on economic growth.

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Financial architecture is an index of the relative importance of financial markets vis-à-vis banks. The focal coefficient of interest is γ_4. A $\gamma_4 > 0$ indicates that industries that utilize greater intangibles in their asset composition as a proxy for information intensity innovate faster in market-based financial systems. A $\gamma_4 < 0$, on the other hand, would be consistent with the bank-based view. In addition, to isolate the total effect of financial architecture, the country controls will include the variable FinancialArchitecture separately. Again, the sign of the coefficient of this variable is ambiguous a priori.

One of the advantages of this specification is that it overcomes the identification problems encountered in the standard cross-country regressions by interacting a country characteristic (financial architecture) with an industry characteristic (intangible intensity). The approach is less subject to criticism relating to omitted variable bias. Strengthening these advantages further, I estimate versions of the model with explicit country controls using a random effects specification, which has the advantage of i) accounting for both intra-industry and intra-country correlations, and ii) enabling identification of the effects of country factors, such as financial architecture, more accurately.

B. Data

1. Data on Technological Innovation

To measure the dependent variable, the rate of technological innovation, I estimate structured production functions and identify technological progress as that portion of observed output growth attributable to changes in the underlying production function as a representation of the technology. In so doing, I follow a long tradition in the growth economics literature going back to Solow (1957). Specifically, an aggregate index of improvement in an economic unit, extensively used in the literature, is the growth rate in output $(\dot{y})$. I first isolate the contributions of input factors (such as labor and capital) to output growth $(\dot{y})$ from the contributions of TFP based on inter-country production frontiers. I further model the TFP component of growth to be arising from either industry-specific efficiency improvements or technological innovations. The effect of technological progress is measured as the shift in the production frontier over time holding input quantities constant.

Structurally, I assume that there exists an unobservable production frontier that represents the maximum attainable output level for a given combination of inputs. Letting $g[.]$ represent this best-practice technology, the potential output level on the frontier at time t given a vector of factors of production $x(t)$ is

$$y_{ci}^{F}(t) = g[x_{ci}(t), t]. \tag{2}$$

Any observed output $y_{ci}(t)$ of industry i in country c using $x_{ci}(t)$ as inputs can then be expressed as

$$y_{ci}(t) = y_{ci}^{F}(t)e^{u_{ci}(t)} = g[x_{ci}(t), t]e^{u_{ci}(t)}, \tag{3}$$

where $u_{ci}(t) < 0$ is the level of (in)efficiency corresponding to actual output $y_{ci}(t)$ and represents the shortfall of actual output from the maximum, holding the level

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of technology constant. Differentiating the log of equation (3) with respect to time,

$$\frac{\dot{y}_{ci}(t)}{y_{ci}(t)} = g_x \frac{\dot{x}_{ci}(t)}{x_{ci}(t)} + \underbrace{g_t + \dot{u}_{ci}(t)}_{\dot{\text{TFP}}}. \tag{4}$$

Equation (4) decomposes output growth into the combined effects of factor accumulation and scale economies (the first term), the shift in the production technology (g_t), and efficiency changes during period t. Empirically, I represent equation (3) by a translog stochastic production frontier (see Appendix 2). I then generate the values of the realized rates of technological change (i.e., g_t) based on the parameter estimates of the frontier. The empirical proxy thus obtained, ΔTECH1, operationalizes g_t. Note that ΔTECH1 represents increases in output yield due to shifts in the best-practice technology, $g[.]$. As Appendix 2 explains, in computing ΔTECH1 the production frontier is estimated for a panel of industries across the sample countries, with country and industry effects appropriately controlled through a random effects specification. Controlling for such country effects ensures that ΔTECH1 does not pick up differences in production technologies owing to country peculiarities. The parameter estimates from which the measures of technological change are constructed do not reflect country-specific sources of variation in production technologies so that the resultant measures are comparable across countries. Alternatively, to check the robustness of the main results, I derive the corresponding measures of the rate of technical innovation based on a stochastic *cost* frontier (see Section IV.A).

The data for estimating the inter-country stochastic production and cost functions is obtained from the United Nations Industrial Statistics database. The database, which contains industry-level data on production and cost characteristics, has been extensively used in the finance growth literature (see, e.g., RZ (1998), Tadesse (2004)).

Table 1 provides a summary of the variables for the sample countries. There is a wide variation in economic performance across countries (see Panel A). Realized rates of technological change range from -0.5% per annum in Sri Lanka to 3.6% in Japan. In ranking countries by their average realized rates of technical innovations, I observe as in Figure 1 that technological progress is much faster in developed countries than in developing economies. This may be a reflection of developed countries' larger wherewithal to spur technological innovation, and as such it provides additional credence that my measure captures the cross-country differences in production technologies consistent with economic intuition. In contrast, overall productivity does not appear to be significantly different between developed and developing countries (not reported). Realized productivity growth in the U.S. (3.1% per annum) compares well with that of the Philippines (3.3%).

There is also an enormous variation across industries (see Panel B of Table 1), with the highest rate of technical progress registered in the industrial chemicals industry (2.6%), which includes pharmaceutical and biotech firms, and the lowest in the apparel industry (0.8%). As would be expected, traditional industries exhibit slower rates of technical progress than their younger counterparts. External validation of the veracity of my measures of technological change is extremely

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TABLE 1

Technological Innovation and Financial Architecture Averages (1980–1995)

Growth in real value added is the annual compounded growth rate in real value added for each of the 10 industries in each of the 34 countries over the period 1980 to 1995. Technological Progress (ΔTECH1) measures the shift in the production frontier over time, and represents increases in real output due to adoption of better technology. The alternative measure of technological progress (ΔTECH2) measures the downward shift in the cost function over time, holding output constant, and represents the decrease in total cost due to better technologies. Industry Share in Manufacturing is calculated by dividing the real output of the industry in the country by the total real output of the manufacturing sector of the country. Financial Architecture is a continuous variable that measures the degree of market orientation of a financial system and is a principal component of the size, activity, and efficiency dimensions of financial architecture. Per Capita GDP is the logarithm of real GDP per capita in 1980.

		Technological Progress (based on stochastic production frontier) (∇TECH1)	Technological Progress (based on stochastic cost frontier) (∇TECH2)	Industry Share in Manufacturing (SHARE)	Financial Architecture (ARCHITECTURE)	Log(Per Capita GDP)
Panel A. Averages by Countries						
Australia		0.023	0.030	0.043	0.938	9.704
Austria		0.023	0.027	0.038	−1.552	9.856
Belgium		0.027	0.031	0.032	0.205	9.791
Canada		0.024	0.029	0.029	0.951	9.899
Chile		0.012	0.022	0.026	0.198	6.086
Colombia		0.014	0.024	0.061	−0.314	7.711
Denmark		0.020	0.026	0.050	−0.037	7.096
Egypt		0.015	0.026	0.061	−1.104	10.085
Finland		0.020	0.024	0.042	−0.593	10.081
Germany		0.033	0.035	0.045	−0.173	9.963
Greece		0.017	0.023	0.054	−0.512	8.968
India		0.015	0.028	0.051	−2.604	5.780
Indonesia		0.007	0.021	0.040	−2.350	6.315
Israel		0.014	0.022	0.037	0.465	9.287
Italy		0.028	0.032	0.051	−0.486	9.757
Japan		0.036	0.036	0.046	0.676	9.966
Jordan		0.022	0.023	0.123	0.554	7.008
Korea		0.022	0.027	0.055	0.491	8.527
Malaysia		0.016	0.023	0.043	1.287	7.730
Mexico		0.016	0.023	0.055	0.768	7.975
Netherlands		0.025	0.028	0.057	0.454	9.786
New Zealand		0.015	0.023	0.068	0.651	9.444
Norway		0.021	0.027	0.043	−0.207	10.179
Pakistan		0.006	0.019	0.043	−0.260	5.794
Peru		0.019	0.026	0.051	0.433	7.524
Philippines		0.010	0.022	0.058	0.355	6.566
Portugal		0.022	0.028	0.048	−2.439	8.690
Singapore		0.013	0.021	0.037	1.295	9.422
Spain		0.025	0.029	0.045	−0.353	6.496
Sri Lanka		−0.005	0.014	0.079	−0.290	9.344
Sweden		0.021	0.028	0.040	0.759	10.123
Turkey		0.018	0.025	0.046	0.711	7.880
U.K.		0.030	0.033	0.044	1.112	6.984
Venezuela		0.024	0.029	0.047	−0.434	9.949
Panel B. Averages by Industries						
Food Products	(ISIC 311)	0.022	0.029	0.116		
Beverages	(ISIC 313)	0.023	0.028	0.041		
Tobacco	(ISIC 314)	0.019	0.024	0.028		
Textiles	(ISIC 321)	0.021	0.028	0.056		
Wearing Apparel	(ISIC 322)	0.008	0.010	0.029		
Industrial Chemicals	(ISIC 351)	0.026	0.030	0.050		
Rubber Products	(ISIC 355)	0.017	0.024	0.015		
Plastic Products	(ISIC 356)	0.014	0.023	0.021		
Iron and Steel	(ISIC 371)	0.026	0.031	0.041		
Machinery, except Electrical	(ISIC 382)	0.016	0.024	0.067		
Panel C. All Observations						
No. of Observations		2,679	2,679	2,626	34	34
Mean		0.019	0.026	0.044	−0.154	8.627
Standard Dev.		0.012	0.007	0.041	1.051	1.380
Minimum		−0.019	0.003	0.002	−2.604	5.780
Maximum		0.056	0.053	0.326	1.295	10.179

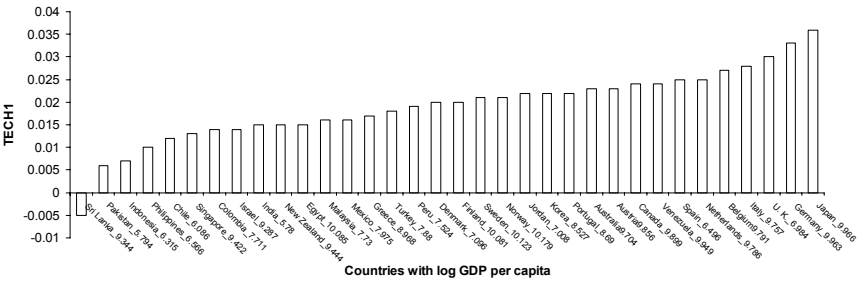
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difficult to achieve because of the lack of other comprehensive and consistent measures of innovation at the industry level. However, the technological profile of the industries emerging from my measures appears to be consistent with indicators of technological activities from other sources. For example, Allen (1996) provides data on the ratio of scientific and engineering employment to total employment for selected industries in the U.S. for 1979 through 1989. This ratio is the lowest at 0.2% for the apparel industry and the highest at 10.9% for the chemicals industry, with primary metals at a modest 3.3%. Patent use by U.S. industries in the 1980 through 1983 period ranks the apparel industry near the bottom while industries such as drugs, industrial chemicals, and machineries are among the top (Lach (1995)). The ratio of company R&D funds to net sales over 1984–1990 as reported by the National Science Foundation (1993) is the lowest for textiles and apparel at 0.44% and is one of the highest for drugs and medicines at 8.7%.

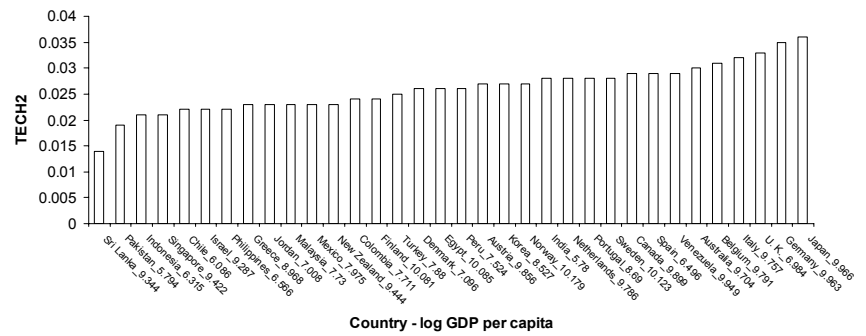
FIGURE 1

Rates of Technological Innovation across Countries

Graph A. Technological Innovation Based on Stochastic Production Frontier (∇TECH1)



Graph B. Technological Innovation Based on Stochastic Cost Frontier (∇TECH2)



2. Financial Architecture

There is no uniformly accepted empirical definition of whether a given country's financial system is market- or bank-based. Previous studies use stylized facts

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based on a handful of countries such as Germany, representative of a bank-based system, and the U.S., the prototype of a market-based system. I use a variety of financial architecture indicators that are based on aggregate cross-country data recently compiled at the World Bank. The data set described in Demirguc-Kunt and Levine (2001) as well as Beck, Demirguc-Kunt, and Levine (2000) contains measures of the relative size, activity, and efficiency of the banking and the financial market subsectors of the financial system for a broad cross section of countries over the period 1980 to 1995. I use a continuous variable, ARCHITECTURE, as a measure of financial architecture. The definition of the variable, ARCHITECTURE, and its components listed below is based on Tadesse (2002).

ARCHITECTURE is an index of the degree of stock market orientation of a financial system and is based on three indices that measure the relative importance of the stock market compared to the banking sector in an economy. The three indices are measures of the relative size, activity, and efficiency of the stock market in a given country vis-à-vis those of the banking sector. The variable ARCHITECTURE reflects the principal component of the following three variables: Architecture-Size, Architecture-Activity, and Architecture-Efficiency. Higher values of ARCHITECTURE indicate a more market-oriented financial system.

Architecture-Size measures the size of stock markets relative to that of banks in the financial system. The size of the domestic stock markets is measured by the market capitalization of domestic stocks relative to the GDP of the country. The size of the banking sector is measured by the bank credit ratio defined as the claims of the banking sector against the private real sector as a percentage of GDP. This excludes claims of non-bank intermediaries and credits to the public sector. Architecture-Size combines the two size measures as a ratio of the capitalization ratio to bank credit ratio. Larger values indicate more market orientation in terms of relative size.

Architecture-Activity measures the activity of stock markets relative to that of banks. It is denoted by the ratio of the total value of stocks traded to the bank credit ratio. Total value traded as a share of GDP measures stock market activity relative to economic activity; the bank credit ratio (defined above) indicates the importance of banks in the economic activities of the private sector.

Architecture-Efficiency measures the relative efficiency of a country's stock markets vis-à-vis that of its banks. Stock market efficiency is measured by the total value traded ratio, which is defined as the share of the total value of shares traded to GDP. Banking efficiency is measured by the bank overhead ratio, defined as the ratio of banking overhead costs to banking assets. Architecture-Efficiency is the product of the total value traded ratio and the overhead ratio. Demirguc-Kunt and Levine (2001) also present measures using the turnover ratio (instead of value traded) and find the same rankings.

I take the principal component of the three series (the capitalization to bank credit ratio, the value traded to bank credit ratio, and the product of the value traded and the overhead ratios) and compute the composite measure ARCHITECTURE. As a robustness test, I also use the construction of the variable as a means-

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removed simple average of the series. In addition, I use the three components—Architecture-Size, Architecture-Activity, and Architecture-Efficiency—separately as a measure of the market orientation of the financial system.

ARCHITECTURE provides a measure of the comparative role of banks and markets in the economy. The underlying measures, which reflect the degree of bank development and stock market liquidity, are shown to have effects on economic performance (see Levine (1997) for a review). A high score on Architecture is associated with stronger investor protection and high accounting standards (Demirguc-Kunt and Levine (2001)), indicating that the measure of financial architecture reflects the legal and regulatory differences across countries. The alternative measures are also closely related with each other. The main ARCHITECTURE measure is strongly correlated with the Architecture-Size (coefficient = 0.954), Architecture-Activity (coefficient = 0.952), and Architecture-Efficiency (coefficient = 0.639). It is also highly correlated with the measure of market orientation independently constructed by Demirguc-Kunt and Levine (2001) as a means-removed simple average of the three series (correlation = 0.636), and the architecture measure by Beck and Levine (2002) as a principal component of the series (correlation = 0.744). The Architecture variable makes the intuitively attractive classification of the U.K., the U.S. (not in the sample because of its use as a benchmark), Canada, and Singapore as more market-based systems, and Germany, Austria, and Portugal as more bank-based. ARCHITECTURE also identifies Japan as in between because Japan has a large, active market. This ordering is similar to what is found in the literature (e.g., Beck and Levine (2002)).

3. Data on Industry Characteristics

I use the degree of intangible asset usage in an industry's asset composition—intangible intensity—as an industry attribute relevant for the degree of impact of the financial system on the industry's technological innovation. Claessens and Laeven (2003) construct a measure of the intangible intensity for manufacturing industries based on the intangible intensity of industries in the U.S. They argue, following RZ (1998), that "the well-protected property rights in the U.S. should allow U.S. firms to achieve the desired ... asset structures for their respective industrial sectors" (p. 2406). This desired extent of asset mix could then be used to identify the optimal asset mix of an industry anywhere in the world. Intangible intensity is computed as the ratio of intangible assets to net fixed assets. Intangibles are measured as the net value of intangible assets (COMPUSTAT item 33) and include blueprints or building designs, patents, copyrights, trademarks, franchises, organizational costs, client lists, computer software patent costs, licenses, and goodwill. I use the intangible intensity measures for U.S. industries from Claessens and Laeven (2003) as measures of the desired asset composition unique to the corresponding industries in other countries. One advantage of this procedure is that it minimizes a potential endogeneity problem because I would exclude the U.S. industries from the analysis. Additionally, to construct the measures of intangible intensity, I use accounting data for U.S. industries from financial statements based on U.S. accounting standards. As a result, I eliminate the potential measurement error that could arise due to different accounting treatment of assets because of differences in accounting standards and procedures across countries.

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Alternatively, for robustness, I use two other industry variables to characterize the information intensity of the sector. The first is the degree to which an industry invests in R&D activity, measured as the ratio of R&D costs as a proportion of revenue. The second is the extent of patent use by U.S. industries from Lach (1995). In addition, I use the average analyst earnings forecast consensus in the U.S. by industry.

C. Sample Selection

The sample is a panel of 10 manufacturing industries across 34 countries over the period 1980 to 1995. The sample period coincides with the period for which the index of financial architecture is available, hence limiting the study period. Panel C of Table 1 summarizes the characteristics of the sample. Although I have complete data for 35 countries, following RZ, I use the U.S. as a benchmark to identify the intangible intensiveness of the industries, and exclude it from the analysis.

III. Results

Table 2 presents the main empirical results. I begin with evaluating the impact of financial architecture on the average industry, irrespective of the latter's asset composition. To do so, I relax the specification of the basic model in equation (1) by replacing the country dummies with explicit country-specific variables, including financial architecture. In column 1 of Table 2, financial architecture is the only country-level variable, and the interaction term (meant to capture the particular channel that is the focal of this study) is excluded. I would like to evaluate the pure general effects of financial architecture. The results indicate that the average industry realizes a faster rate of technological progress in more market-based financial systems. This is consistent with the market-based view that markets have comparative advantages over banks in identifying and funding innovations (Allen and Gale (1999), Boot and Thakor (1997)).

This specification, however, is subject to omitted variables bias as it does not account for variables that have been shown to be important for economic growth and, by implication, for innovations. Examples of such variables that have been used in the growth literature include the level of per capita GDP, human capital, property rights, and measures of financial development (Barro (1991), Claessens and Laeven (2003), and Levine and Zervos (1998)). In particular, Levine and Zervos (1998) find that stock market liquidity and overall bank development positively impact long-run growth. I use stock market liquidity, measured as the stock market turnover ratio, and bank development, measured by the ratio of domestic credit to the private sector to GDP (following Levine and Zervos (1998) and Cetorelli and Gambera (2001)) to control for effects of financial development, and expect these variables to have positive effects. The importance of property rights protection for growth is increasingly recognized (see, e.g., Claessens and Laeven (2003)). Stern, Porter, and Furman (2000) show that the strength of a country's protection of intellectual property rights affects its innovative capacity. I use a broad index of property rights from the International Country Risk Guide (ICRG)

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TABLE 2

The Average and Differential Impacts of Financial Architecture on the Rate of Technological Innovation of Industries that Vary in Intangible Intensity

The dependent variable in all regressions is the rate of technological progress for each industrial sector in each country. Share of Industry Value Added to Manufacturing is calculated by dividing the real value added of the industry in the country by the total real value added of the manufacturing sector of the country. Financial Architecture is a continuous variable that measures the degree of market orientation of a financial system and is a principal component of the size, activity, and efficiency dimensions of financial architecture. Intangible Intensity is the ratio of intangible assets to net fixed assets of U.S industries. Stock market capitalization is market value of listed stocks outstanding divided by GDP. Stock Market Liquidity is total value of stocks traded divided by stock market capitalization. Bank Development is domestic credit to the private sector divided by GDP. Property Rights is a broad index of property rights protection based on indices on the quality of bureaucracy, corruption, rule of law, risk of expropriation, and risk of repudiation of contracts by the government from the International Country Risk Guide (ICRG). Human Capital is the average for 1980 of the years of schooling attained by the population over 25 years of age from Barro and Lee (1993). Per Capita GDP is the logarithm of GDP per capita in 1980. Other regressors included, but not reported are country dummies, industry dummies, and year dummies. Heteroskedasticity-consistent standard errors are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	1	2	3	4
Share of Industry Value Added to Manufacturing	0.054*** (0.005)	0.064*** (0.005)	0.064*** (0.005)	0.067*** (0.004)
Intangible Intensity∗Financial Architecture			−0.0036*** (0.0011)	−0.0041*** (0.0008)
Financial Architecture	0.0014*** (0.00018)	0.0006*** (0.0002)	0.0018*** (0.0004)	
Property Rights		0.0013*** (0.0002)	0.0014*** (0.0002)	
Stock Market Liquidity		0.0037*** (0.0006)	0.0041*** (0.0007)	
Bank Development		0.0052*** (0.0006)	0.0050*** (0.0007)	
Human Capital		−0.0000 (0.0001)	0.0000 (0.0001)	
Per Capita GDP		2.99E−7 (6.0E−8)	2.4E−7*** (7.2E−8)	
R^2	0.2745	0.5397	0.5151	0.7588
No. of Observations	2,624	2,392	1,728	1,882
Countries	34	34	34	34

to measure property rights protection, and expect it to be positively related to technological change. The level of human capital is measured as the average of the number of years of schooling attained by the population over 25 years of age in 1980 (Barro and Lee (1993)) and is expected to have a positive effect on growth and innovation. Per capita GDP is included to capture innovation that enhances other institutional differences across countries. Because developed countries have the resource wherewithal to keep them on the technological edge, I expect a positive association between the level of development and technical progress.

In this extended model, financial architecture enters again with a large statistically significant positive coefficient, indicating that the market orientation of the financial system has a general positive impact on technological progress. The average industry realizes a faster rate of innovation in more market-based systems. This result lends support to the prior evidence that market-based systems foster technological innovations. The other country controls have the expected relations with technological progress. As expected, technological progress is faster in countries with better protection of property rights. Further, consistent with previous studies (e.g., Levine and Zervos (1998)), financial development as measured by stock market liquidity and bank development has significant positive impact.

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Human capital has a statistically insignificant but negative coefficient. This is comparable to RZ's (1998) finding of a similar effect on industry growth. Finally, as expected, industries in developed countries realize faster technical progress, as those industries are more important in the country, as measured by the share of an industry's value added to total manufacturing value added.

I now turn to the focal relation of interest, namely, the differential effects of financial architecture across industries that vary in their asset composition. To examine this particular channel, column 3 of Table 2 includes the interaction between intangible intensity and financial architecture. Intangible intensity measures the informational intensiveness of the economic activity of an industry. In addition, to control for the economy-wide effect of financial architecture, I include the variable separately as the only country-level control. To minimize the potential problem of omitted variables in this specification, column 3 also includes other country controls common in standard growth regressions. The model contains industry and period dummies as well. The results indicate that informationally intensive industries realize relatively faster technological progress in relatively bank-oriented countries. The interaction term is negative and statistically significant at the 1% level. The general effect of financial architecture remains the same: the average industry realizes a faster rate of innovation in more market-based systems. The two effects of financial architecture are robust to the inclusion of the various control variables, all with coefficient estimates consistent with priors. In the industries with higher intangible intensity, the benefits of bank-based systems appear to outweigh those of market-based systems. For less intensive industries, the net benefit of market-based systems is positive, implying that the general effects of market-based systems outweigh the heterogeneous industry-specific effects for these industries.

The two major findings—that market-based systems promote technological innovation in general and bank-based systems promote innovation in industries with greater intangible-intensity—may appear to be in conflict. In fact, the combined results are consistent with the theoretical priors. On the one hand, the results suggest that market-based systems have a positive effect on innovation that, on average, affect all sectors indiscriminately. This finding is consistent with market-oriented financial systems enabling the identification and financing of new technologies in cases where diversity of opinion persists, thereby benefiting all sectors in the economy (Allen (1993), Allen and Gale (1999)). On the other hand, introducing differences in industries in knowledge intensiveness, I find an industry-specific positive effect of a bank-oriented (and negative effect of a market-oriented) financial system. This is consistent with the theoretical prior that banks have a comparative advantage in economizing transactional and informational costs in funding innovations, which could be more important in sectors that are informationally intensive. As such, this finding is consistent with the bank-based view that relies on the advantages of banks in areas of information processing (e.g., Bhattacharya and Chiesa (1995), Yoshi (1995)).

In column 4 of Table 2, I estimate the regression that includes indicator variables for all countries and for all industries, effectively controlling for all country-, industry-, and period-related sources of variation in the dependent variable. The coefficient estimate of the interaction terms is robustly negative and significant at

the 1% level. It does not appear that one country or industry is responsible for the results. The explanatory power of the regression increases significantly, suggesting the importance of omitted inter-country and inter-industry differences in explaining variations in the rates of innovation. This is the basic empirical model I use in the rest of the paper.

IV. Statistical Robustness Tests

To ensure accurate inferences and to avoid mechanical explanations for the main results so far, I now provide a series of robustness tests, for which I focus on the basic empirical model specification. I also conduct all the pertinent robustness tests on the first-order effects of financial architecture, and find that the results are very robust.

A. Alternative Measures of Rate of Technological Innovations

In the foregoing, as a dependent variable I use a measure of technological innovation derived from the underlying production function as a representation of the technology, as represented by $g[.]$. There is another way to construct measures of technological change. Duality theory suggests that under certain regularity conditions,[9] if producers pursue the cost-minimizing objective, the production function can be uniquely represented by a cost function and, therefore, one can infer the rate of technological progress from the cost function. Letting $h(.)$ be the best-practice variable cost frontier, the minimum possible variable cost for period t, given input price w, the fixed input I, and output y, is given by

$$C^F_{ci}(t) = h(w_{ci}(t), I_{ci}(t), y_{ci}(t), t). \tag{5}$$

The observed cost, $C_{ci}(t)$, of industry i in country c for period t can then be expressed as

$$C_{ci}(t) = C^F_{ci}(t)e^{\theta_{ci}(t)} = h(w_{ci}(t), I_{ci}(t), y_{ci}(t), t)e^{\theta_{ci}(t)}, \tag{6}$$

where $\theta_{ci}(t) \geq 0$ represents the degree of economic efficiency and measures the excess of actual cost over the minimum, holding the level of technology, input prices, and output constant. Differentiating the log of equation (6) with respect to t, and noting that improvements in terms of cost mean cost diminution, I obtain

$$-\frac{\dot{C}_{ci}(t)}{C_{ci}(t)} = -\left\{h_w\frac{\dot{w}_{ci}(t)}{w_{ci}(t)} + h_I\frac{\dot{I}_{ci}(t)}{I_{ci}(t)} + h_y\frac{\dot{y}_{ci}(t)}{y_{ci}(t)} + h_t + \dot{\theta}_{ci}(t)\right\}. \tag{7}$$

Equation (7) decomposes the rate of cost diminution into the share-weighted rate of growth in input prices (first term), shadow values of fixed inputs (second term), output scale economies (third term), technological progress (fourth term), and

[9]To be a valid representation of the technology, a cost function should be a non-negative, non-decreasing function of output y, a non-negative, non-decreasing concave function of input prices, and twice differentiable with respect to input prices. Furthermore, a restricted (variable) cost function should be a non-positive and convex function of quasi-fixed input quantities.

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efficiency improvements. Note that h_t represents the downward shift in the cost frontier over time and is considered to be the cost effect of technological progress. Empirically, I represent equation (6) by a translog stochastic cost frontier (see Appendix 1). I then generate the predicted values of realized rates of real cost reduction based on the parameter estimates of the frontier. The proxy thus obtained is ΔTECH2, which is the empirical equivalent of h_t.

Columns 1 through 3 of Table 3 present the main results using this alternative measurement of the dependent variable. The findings clearly indicate that the main results are robust. Financial architecture has a positive first-order effect (columns 1 and 2) and a negative industry-specific second-order effect (columns 2 and 3). Both effects are statistically highly significant and of the same order of magnitude as those in Table 2.

B. Alternative Measure of Financial Architecture

The measure of the market orientation of the financial system, ARCHITECTURE, is constructed as the first principal component of three separate indices that measure the relative importance of markets versus banks in terms of their relative size, extent of activity, and efficiency. The variable provides an intuitive classification of countries into bank- and market-based systems. The rank ordering is also consistent with previous research (e.g., Demirguc-Kunt and Levine (2001), Beck and Levine (2002)).

To check for the robustness of the results to measurement issues related to this independent variable, I use alternative measures in columns 4 through 10 of Table 3. Column 4 uses a measure of financial architecture constructed as a means-removed simple average of the measures of size, activity, and efficiency, and is taken from Demirguc-Kunt and Levine (2001). The results are robust to measuring financial architecture using this variable. Beck and Levine (2002) use three different measures to characterize financial architecture: a principal component aggregation of the Architecture-Size and Architecture-Activity indices, the degree of state ownership of banks, and the degree of regulatory restrictions on banks. They argue that bank-based systems are also characterized by state ownership and regulatory restrictions. Columns 5 through 7 use the indices of Beck and Levine (2002). The results are very robust. The interaction terms with financial architecture (column 5), indicating more of a market orientation, are negative and significant, while the interactions with more state ownership (column 6) and more restriction (column 7), indicating more of a bank orientation, are positive and statistically significant.

Columns 8 through 10 use the component measures of Architecture-Size, Architecture-Activity, and Architecture-Efficiency separately instead of the aggregate index. The result is again robust; the interaction term carries a negative coefficient that is both statistically significant and of the same order of magnitude.

C. Alternative Measures of Industrial Information Intensity

As a measure of informational intensity by industry, I use the intangible intensity typical of industrial sectors in the U.S. The use of this variable as well as

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TABLE 3

The Average and Marginal Impacts of Alternative Measures of Financial Architecture on the Rate of Technological Innovation of Industries that Vary in Intangible Intensity

The dependent variable in all regressions is the rate of technological progress for each industrial sector in each country. The rates of technological progress used in columns 1 through 3 are derived from estimation of stochastic cost functions. Columns 5 through 7 use measures of financial architecture from Beck and Levine (2002). Columns 8 through 10 use the components of the aggregate index of financial architecture. Share of Industry Value Added to Manufacturing is calculated by dividing the real value added of the industry in the country by the total real value added of the manufacturing sector of the country. Financial Architecture is a continuous variable that measures the degree of market orientation of a financial system and is a principal component of the size, activity, efficiency dimensions of financial architecture. Intangible Intensity is the ratio of intangible assets to net fixed assets of U.S industries. Stock market capitalization is market value of listed stocks outstanding divided by GDP. Stock Market Liquidity is the total value of stocks traded divided by stock market capitalization. Bank Development is domestic credit to the private sector divided by GDP. Human Capital is the average for 1980 of the years of schooling attained by the population over 25 years of age from Barro and Lee (1993). Per Capita GDP is the logarithm of GDP per capita in 1980. Other regressors included, but not reported, are country, industry, and year dummies. Heteroskedasticity-consistent standard errors are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	1	2	3	4	5	6	7	8	9	10
Share of Industry Value Added to Manufacturing	0.038***	0.044***	0.047***	0.067***	0.066***	0.066***	0.065	0.068***	0.067***	0.066***
	(0.0034)	(0.0035)	(0.0035)	(0.0036)	(0.0036)	(0.0036)	(0.0036)	(0.004)	(0.003)	(0.003)
Intangible Intensity∗Financial Architecture		−0.0016**	−0.0026***	−0.0047***	−0.0057***	0.00006**	−0.0013***	−0.0050***	−0.0023***	−0.0014*
		(0.0008)	(0.0008)	(0.0011)	(0.0009)	(0.00003)	(0.0003)	(0.0008)	(0.0006)	(0.0008)
Financial Architecture	0.0002*	0.0008**	0.0007**							
	(0.0001)	(0.0003)	(0.0003)							
Property Rights (ICRG)			0.0009***							
			(0.0001)							
Stock Market Liquidity			0.0028***							
			(0.0004)							
Bank Development			0.0025***							
			(0.0005)							
Human Capital			0.0000							
			(0.0000)							
Per Capita GDP			2.3E−8							
			(5.0E−8)							
R^2	0.3257	0.3252	0.4687	0.7577	0.7495	0.7452	0.7467	0.7604	0.7571	0.7554
No. of Observations	2,485	1,882	1,728	1,882	1,831	1,831	1,831	1,882	1,882	1,882
Countries	34	34	34	34	34	34	34	34	344	34

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employing the U.S. as the benchmark country may raise a number of concerns. To begin with, the U.S. financial system is a prototype market-based system, and thus it may be argued that the use of the U.S. as a benchmark may bias the results in favor of market-based financial architecture. Furthermore, the measures of intangible intensity for U.S. industries reflect accounting standards and procedures in the U.S. To check for the robustness of the results to these concerns, I use Germany and Japan, two typical bank-based systems, as the benchmark countries. I compute the mean intangible intensity (intangible assets to tangible assets ratio) for each of the 10 industries of the sample in Germany and Japan, respectively. The data is obtained from the WorldScope database, and the average intangible intensity for the respective industry is calculated over the period 1980 through 1995. In column 1 of Table 4, I use the intangible intensities of German industries instead of U.S. industries. Accordingly, because Germany is the benchmark country, it is dropped from the sample and the U.S. is included. The results in column 1 indicate that changing the benchmark country does not alter the main results. The intangible intensity-financial architecture relation is significantly negative. In column 2, I use the intangible intensity measures of Japanese industries instead. The sample is adjusted to exclude Japan, the benchmark country, but include Germany and the U.S. Again, the results are robust. Industries with a high level of intangible intensity realize faster rates of technical innovation in more bank-oriented financial systems, regardless of which benchmark country is used. In addition, this finding provides evidence that the results hold despite differences in accounting standards that may affect the measurement of intangible intensity.

I use intangible intensity as a measure of information intensiveness peculiar to the technological environment of the industry. Alternatively, it may be suggested that more direct measures of technological activity, such as the extent of R&D activities or patent acquisitions might be appropriate. The main problem of using such measures is that measures of R&D activity and their outcome, patenting, are commonly used as measures of technological innovation (see, e.g., Bartel and Sicherman (1999)), and hence their use as explanatory variables introduces endogeneity. Nonetheless, in columns 3 through 6, I determine whether the results are robust if I measure information intensiveness differently. In columns 3 through 5, I use the extent of R&D activity by industries, that is, R&D intensity. The variable is constructed as the ratio of R&D costs as a percentage of revenue based on financial statement data in the WorldScope database. I calculate the average R&D intensity for each firm in the industry over the sample period 1980 through 1995. The industry R&D intensity is the median of the firm mean averages. The regressions use the R&D intensities of the U.S., German, and Japanese industries, respectively in columns 3 through 5. In each case, I drop the benchmark country from the sample, minimizing the endogeneity problem discussed above. The results confirm the robustness of the main findings. Industries high in informational intensity appear to realize faster technological innovations in more bank-oriented countries.

In column 6 of Table 4, I use the extent of patent use in the industry as an alternate measure of information intensity relevant to technology in the industry. Patent data is generally collected by technology field, and is available by indus-

TABLE 4

The Differential Impacts of Financial Architecture on the Rate of Technological Innovation of Industries that Vary in Measures of Informational Intensity

The dependent variable in all regressions is the rate of technological progress for each industrial sector in each country. Share of Industry Value Added to Manufacturing is calculated by dividing the real value added of the industry in the country by the total real value added of the manufacturing sector of the country. Financial Architecture is a continuous variable that measures the degree of market orientation of a financial system and is a principal component of the size, activity, and efficiency dimensions of financial architecture. Intangible Intensity is the ratio of intangible assets to net fixed assets of German and Japanese industries. R&D Intensity is the ratio of R&D costs to sales revenue for industrial sectors in the U.S., Germany, and Japan. Patent Intensity in U.S. is the number of patents used in manufacturing industries in the U.S. obtained from Lach (1995). Analyst Consensus in the U.S. is the coefficient of variation in analyst forecast of annual earnings for U.S. industries. Other regressors included, but not reported, are country dummies, industry dummies, and year dummies. Heteroskedasticity-consistent standard errors are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	1	2	3	4	5	6	7
Share of Industry Value Added to Manufacturing	0.066*** (0.003)	0.061*** (0.003)	0.064*** (0.003)	0.069*** (0.003)	0.0062*** (0.003)	−0.068*** (0.004)	0.069*** (0.003)
Intangible Intensity of German Industries∗ Financial Architecture	−0.0035*** (0.0008)						
Intangible Intensity of Japanese Industries∗ Financial Architecture		−0.0003** (0.0001)					
R&D Intensity of U.S. Industries∗ Financial Architecture			−0.018*** (0.003)				
R&D Intensity of German Industries∗ Financial Architecture				−0.1440*** (0.020)			
R&D Intensity of Japanese Industries∗ Financial Architecture					−0.0590*** (0.018)		
Patent Intensity of U.S. Industries∗ Financial Architecture						−0.0025*** (0.0003)	
Analyst Consensus for U.S. Industries∗ Financial Architecture							−0.0423*** (0.007)
R^2	0.7905	0.7639	0.7687	0.7942	0.7644	0.7700	0.8069
No. of Observations	2,525	2,664	2,624	2,525	2,664	1,882	2,180
Countries	34	34	34	34	34	34	34

try. I use the number of patents issued to manufacturing industries in the U.S. in the 1980s that Lach (1995) analyzes. The variable is the number of patents used from 1980 through 1983, the last year for which data is available, as a fraction of those used in the 1970s. The use of patents as a proxy for information intensity suffers from endogeneity bias in that this variable is also a measure of the extent of innovation. However, in the regression, I drop the U.S., the benchmark country, from the sample and use the U.S. industries' extent of patenting as a proxy for information intensity in industries in other countries to mitigate some of the endogeneity problem. Column 6 again confirms the main findings of the study. Industries with higher information intensity realize relatively faster technical innovation in bank-based economies. The interaction term between patent intensity and financial architecture is robustly negative.

Another way to measure information intensity might be to assess the difficulty outsiders, such as financial analysts, encounter in assessing firm performance. For example, the extent of consensus in financial analysts' forecasts of

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a firm's earnings could provide a signal about the complexity of the firm's activities, and hence the difficulty with which its outcome can be assessed. Analyst forecast consensus is also used extensively in the literature as a measure of informational asymmetry (see, e.g., Clarke and Shastri (2001)). The problem in using such a variable as a measure of information intensiveness for an industry is that a lack of analyst forecast consensus may reflect more the external informational environment or the noise outside of the firm. For example, low consensus may be attributable to a lack of investors' interest and thus low analyst following. Hence, analyst forecast consensus is, at best, a noisy proxy of information intensity attributable to the technology of a firm. With these caveats, in column 7 of Table 4, I use a measure of analyst forecast consensus for U.S. industries. Forecast consensus is measured as the coefficient of variation of annual earnings forecasts from the mean annual forecast based on data from the Institutional Brokers Estimate System (IBES). I calculate the average forecast consensus for each firm in the industry over the sample period of 1980 through 1995. The industry forecast consensus is the median of the firm averages. I drop the benchmark country, the U.S., from the sample. The results in column 7 confirm the basic findings that informationally intensive industries, measured this way, fare better in relatively bank-based systems.

D. Could the Results Be Due to Better Property Rights Protection?

The importance of property rights protection for fostering growth and innovation is increasingly recognized (see Besley (1995), Claessens and Laeven (2003)). Stern et al. (2000) provides strong evidence that the degree of protection afforded to intellectual property rights affects countries' innovative capacity. Therefore, it might be argued that the financial architecture measure is simply a proxy for the degree of property rights protection in the country, and so the effects documented could be simply effects of better property rights instead of financial architecture. I can check for this possibility by explicitly including measures of property rights protection. From various sources, I use six different measures of the degree to which countries protect property rights. These are i) a broad index of property rights from the International Country Risk Guide (Property Rights ICRG), ii) a rating of protection of property rights from the index of economic freedom (Property Freedom), iii) a rating of intellectual property rights protection based on the "special 301" placements of the U.S. Trade representative (Intellectual Property), iv) a patent rights index by Ginarte and Park (1997) (Patent Rights), v) an index of the general legal protection of private property from the World Economic Forum (WEF), and vi) an index of intellectual property rights from the World Economic Forum (Intellectual WEF). A detailed definition of the variables is provided in Appendix 1. Each of these variables has been used in previous research. For example, Claessens and Laeven (2003) find that property rights protection affects growth by shaping firms' asset allocation decisions.

Table 5 shows that the main results are robust to inclusion of these alternative measures of property rights. In columns 1 through 6, I include an interaction of each of the property rights variables with intangible intensity in the model containing the interaction of intangible intensity with financial architecture. The

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intangible intensity-financial architecture interaction is consistently negative and the coefficients are statistically significant at the 1% level. As would be expected and consistent with Claessens and Laeven (2003), industries with a higher level of intangibles realize relatively faster rates of technological progress in countries with better property rights protection.[10]

TABLE 5

The Marginal Impacts of Financial Architecture and Property Rights Protection on the Rate of Technological Innovation of Industries that Vary in Intangible Intensity

The dependent variable in all regressions is the rate of technological progress for each industrial sector in each country. Financial Architecture is a continuous variable that measures the degree of market orientation of a financial system and is a principal component of the size, activity, and efficiency dimensions of financial architecture. Intangible Intensity is the ratio of intangible assets to net fixed assets of U.S industries. Share of Industry Value Added to Manufacturing is calculated by dividing the real value added of the industry in the country by the total real value added of the manufacturing sector of the country. Property Rights (ICRG) is a broad index of property rights protection based on indices on the quality of bureaucracy, corruption, rule of law, risk of expropriation, and risk of repudiation of contracts by the government from the International Country Risk Guide (ICRG). Property Freedom is a broad index of property rights from the Index of Economic Freedom, the Heritage Foundation. Intellectual Property is an index of protection of intellectual property rights from the Office of the U.S. Trade Representative. Patent Rights are an index of protection of patent rights in 1980 from Ginarte and Park (1997). WEF is an index of property rights protection from the World Economic Forum. Intellectual WEF is an index of intellectual property rights protection from the World Economic Forum. Other regressors included, but not reported, are country, industry, and year dummies. Heteroskedasticity-consistent standard errors are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	1	2	3	4	5	6
Share of Industry Value Added to Manufacturing	0.067*** (0.0036)	0.067*** (0.003)	0.072*** (0.004)	0.068*** (0.004)	0.068*** (0.0036)	0.0680*** (0.0036)
Intangible Intensity∗ Financial Architecture	−0.0042*** (0.0008)	−0.0050*** (0.0008)	−0.0041*** (0.0008)	−0.0047*** (0.0008)	−0.0042*** (0.0009)	−0.0043*** (0.0008)
Intangible Intensity∗ Property Rights ICRG	0.0004 (0.0004)					
Intangible Intensity∗ Property Freedom		0.0036*** (0.0010)				
Intangible Intensity∗ Intellectual Property			0.0016 (0.0012)			
Intangible Intensity∗ Patent Rights				0.0022** (0.0009)		
Intangible Intensity∗ WEF					0.0009 (0.0009)	
Intangible Intensity∗ Intellectual WEF						0.0014** (0.0006)
R^2	0.7588	0.7603	0.7420	0.7596	0.7599	0.7603
No. of Observations	1,882	1,882	1,807	1,882	1,875	1,875
Countries	34	34	34	34	34	34

E. Could the Results be Driven by Omitted Variables?

It may be argued that differences in other country-specific comparative advantages (i.e., other than financial architecture) or industry-specific characteristics (i.e., other than intangible intensity) may be driving the observed relations on industrial technological progress. However, these results cannot be explained unless the dependence of the industry on that comparative advantage is correlated with

[10]To be exact, Claessens and Laeven (2003) include an intangible intensity-property rights interaction in a model that contains the interaction between external dependence and financial development, and find both interactions to be positive where the dependent variable is growth. I replicate their results using my data as well.

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intangible intensity, and financial architecture is a proxy of this unobserved comparative advantage. I minimize the possibility of this type of omitted variable bias by focusing only on manufacturing industries, thereby reducing, for example, the influence of the availability of natural resources.

In addition, I can directly test if financial architecture or intangible intensity stands for something else. For example, it could be argued that the results are simply a reflection of the well-known effects of financial development (e.g., RZ (1998)). To check if this is the case, I include the interactions of intangible intensity with measures of financial development in the basic specification with the intangible intensity-financial architecture interaction. A proxy for financial development used in many studies (e.g., Cetorelli and Gambera (2001), RZ (1998)) is bank development, measured as the ratio of domestic credit to the private sector to GDP. RZ (1998) also uses an aggregate measure of financial development reflecting both the stock market and the banking sector. I construct an aggregate measure of financial development as a principal component of stock market capitalization, stock market turnover, and bank development. Columns 1 and 2 of Table 6 presents the results. The main result that industries with greater intangible intensity realize relatively faster technological progress in bank-oriented systems remains robust, controlling for the fact that such industries also fare well with financial development.

It could be argued that knowledge-intensive economic sectors are dependent on human capital as well. If financial architecture is correlated with human capital, the observed effect might be a proxy for the interaction of an industry's dependence on human capital and the availability of a trained labor force in the country. To test for this possibility, I include in column 3 the interaction of intangible intensity and human capital in the basic model that contains the intangible intensity-financial architecture interaction. Consistent with expectations, the coefficient of the human capital-intangible intensity interaction is significantly positive, but the interaction between intangible intensity and financial architecture remains significantly negative and of the same order of magnitude.

It might also be argued that the use of intangibles may reflect industry growth opportunities. This concern is analogous to Fisman and Love's (2002b) critique of RZ (1998) that external financial dependence may reflect the relative growth opportunities of industries. Using U.S. industries' sales growth as measures of sectoral growth opportunities, they find that the interaction of this measure with financial development is robustly positive while the RZ (1998) interaction between external dependence and financial development disappears.

If the argument is valid in my case, for a given financial architecture it may not be informationally intensive industries that realize faster technical progress, but instead those with better growth opportunities. If industrial growth opportunities are systematically correlated with financial architecture, the reported relations between technical progress and the interaction term will be spurious. To check for this possibility, column 4 of Table 6 includes an interaction of a measure of an industry's growth opportunity and financial architecture in the basic model that contains the focal interaction variable. I use the average growth rate in sales of U.S. industries from Fisman and Love (2002b) as a measure of industrial investment opportunities. The coefficient of the interaction between financial ar-

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TABLE 6

The Differential Impacts of Financial Architecture on the Rate of Technological Innovation of Industries that Vary in Intangible Intensity

The dependent variable in all regressions is the rate of technological progress for each industrial sector in each country. Share of Industry Value Added to Manufacturing is calculated by dividing the real value added of the industry in the country by the total real value added of the manufacturing sector of the country. Financial Architecture is a continuous variable that measures the degree of market orientation of a financial system and is a principal component of the size, activity, and efficiency dimensions of financial architecture. Intangible Intensity is the ratio of intangible assets to net fixed assets of U.S industries. Human Capital is the average for 1980 of the years of schooling attained by the population over 25 years of age from Barro and Lee (1993). Per Capita GDP is the logarithm of GDP per capita in 1980. Other regressors included, but not reported, are country dummies, industry dummies, and year dummies. Heteroskedasticity-consistent standard errors are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	1	2	3	4	5	6	7 (IV)
Share of Industry Value Added to Manufacturing	0.068*** (0.003)	0.067*** (0.003)	0.067*** (0.0035)	0.067*** (0.0036)	0.067*** (0.0036)	0.0068*** (0.0036)	−0.074*** (0.004)
Intangible Intensity∗ Financial Architecture	−0.0038*** (0.0008)	−0.0050*** (0.0011)	−0.0050*** (0.0008)	−0.0027*** (0.0008)	−0.0045*** (0.0008)	−0.0050*** (0.0008)	−0.0791*** (0.0147)
Intangible Intensity∗ Bank Development	0.0065*** (0.0019)						
Intangible Intensity∗ Financial Development		0.0014 (0.0011)					
Intangible Intensity∗ Human Capital			0.0010*** (0.0003)				
U.S. Growth in Sales∗ Financial Architecture				−0.0589*** (0.0011)			
External Dependence∗ Financial Architecture					−0.0007 (0.0006)		
Intangible Intensity∗ Per Capita GDP						0.0027*** (0.0006)	
R^2	0.7604	0.7589	0.7598	0.7623	0.7663	0.7612	0.7477
No. of Observations	1,858	1,882	1,882	1,882	1,882	1,882	1,676
Countries	34	34	34	34	34	34	34

chitecture and intangible intensity is robustly negative, suggesting that intangible intensity may not be a proxy for growth opportunities. The result replicates the positive effect of growth opportunities reported in Fisman and Love (2002b).

Similarly, it could be that the effect of financial architecture via intangible intensity documented here might be a reflection of the effects of external financial dependence. To the extent that firms rely on external finance to fund growth opportunities, it may be argued that the asset structure of industries may reflect their degree of external dependence. Beck and Levine (2002) find that the growth of externally dependent industries is unaffected by financial architecture. Column 5 of Table 6 shows that the results are robust to such a concern. I include an interaction of financial architecture with a measure of external finance dependence for U.S. industries from RZ (1998) in the basic regression that contains the intangible

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intensity-financial architecture interaction. The coefficient of the intangible intensity interaction is strongly negative. Consistent with previous research, financial architecture does not explain performance across industries that differ in degree of external financial dependence.

Another concern could be that financial architecture might be a proxy for general country-wide investment opportunities or for the general level of economic development. In that case, any relation between technological change and the interaction term would be spurious because it may reflect differences in growth opportunities rather than the differences in the comparative advantages of financial architectures in funding industries' innovation. To check for this, in column 6 I add the interaction of the log of per capita with intangible intensity in the basic model that includes the interaction of financial architecture and intangible intensity. The coefficient of the financial architecture interaction remains significantly negative. Consistent with RZ (1998), the interaction with income is positive.

F. Reverse Causality?

The results from the basic regression so far do not explicitly control for the potential for endogeneity. In examining the association between technological innovation and financial architecture, I measure the latter using proxies that I assume to be exogenous and predetermined. It might be argued that the configuration of the financial system adapts to the technological characteristics of the country and, hence, financial architecture may simply be "a leading indicator rather than a causal factor."

The cross-country cross-industry results are less susceptible to this concern than the cross-country regression results. First, I present a reasonable explanation of the mechanism through which financial architecture could lead to a differential degree of technological progress among firms that differ in their asset composition. As an advantage over the traditional cross-country methodology, a finding of a within-country between-industry difference in technological progress based on degree of intangible intensity is, in the words of RZ, "the smoking gun" in the debate about causality. Second, by design, I use the U.S. industries' intangible intensity to explain technological progress of industries in other countries, thereby reducing the potential endogeneity problem that would rise if I include the U.S. in the sample. Third, I explicitly account for potential omitted variables, such as property rights.

To address any remaining reverse causality concerns, however, I estimate the basic model using instrumental variables (IV) methodology. The ideal instruments are variables that might affect financial architecture, but are less likely to be affected by it. To select the appropriate instruments, I use theory and recent empirical work. First, some identify the legal environment of countries as the critical factor that shapes its institutions. La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998) argue that legal protections afforded to investors and a country's legal origin determine financial development, and that these, in turn, are primarily determined by a country's colonial history. RZ (1998) and Levine and Zervos (1998), among many others, use these variables as instruments for financial development. I include these variables as a potential set of instruments. The second

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set is the geographic or environmental endowments of countries. The endowment theory of economic development contends that the geographical/environmental endowment of countries has left an indelible mark on long-lasting institutions (e.g., Acemoglu, Johnson, and Robinson (2001)). Institutions in many countries were shaped by their experiences during European colonization. Early colonists encountered various climates around the world. Acemoglu et al. (2001) argue that current institutions reflect the willingness of colonial powers to settle. In colonies with inhospitable climates (mostly the tropics), the colonial powers avoided settlement, preferring to establish "extractive" institutions. In colonies with hospitable climates (mostly the temperate), they established settler institutions that support private property and restrain the power of the State. Natural endowments, therefore, may influence a broad array of institutions. I use the latitudinal distance of countries from the equator as a proxy for endowments.

Column 7 of Table 6 presents the IV results. The first-stage regressions reject the null hypothesis that they do not explain any of the cross-country variation in financial architecture. Column 7 confirms the major finding from Tables 2 and 3 that financial architecture has a heterogeneous impact on industrial technological progress. Specifically, the coefficients of the interaction term between intangible intensity and financial architecture is strongly negative. The exogenous components of financial architecture predetermined by the extent of legal protection afforded to investors and the geographic/climate endowments of countries have a statistically significant impact on technological progress. Hence, the relations between technological innovation and financial architecture identified in this study are less likely to be explained by endogeneity.

V. Concluding Remarks

Recent empirical research in finance and growth has established that financial development has a positive impact on economic growth. The consensus on the finance-growth link has ignited a renewed interest in the historic debate of whether a nation's financial architecture, i.e., the degree to which the financial system is market or bank oriented, matters to its long-run economic growth and, in particular, to fostering innovations and technology. The theoretical debate on both sides of the issue is strong, and the available evidence is both anecdotal and mixed.

Based on data that covers a broad cross section of countries and industries, this study attempts to shed light on this debate, focusing on arguments on the relative merits of banks versus financial markets in processing information. The findings suggest that financial architecture has a significant impact on industrial innovative activities. This paper reports evidence that market-based financial systems have a first-order positive effect on technological progress. This is consistent with the theoretical predictions that markets have a comparative advantage in identifying and funding new technologies where diversity of opinion matters. On the other hand, the study also finds evidence that financial architecture has a heterogeneous effect across industries. In particular, knowledge-intensive industries, with soft, hard to monitor complex activities fare better in bank-based financial systems. This finding is consistent with theoretical models that emphasize the

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comparative advantages of banks in resolving transactional and informational imperfections, and models that emphasize the value of confidentiality and relations.

The implications of the paper are numerous. First, the findings indicate that financial architecture matters for long-term growth, and that the choice of an appropriate financial architecture is a source of value in and of itself. In particular, the appropriate financial architecture is a function of the industrial structure of a country. Second, from a public policy perspective, at least in terms of the effects on innovation and technology, there does not appear to be a Pareto dominant policy regarding the optimal financial architecture. Market-based systems do not dominate bank-based systems and, vice versa, at all times. Third, given the financial architecture of the country, individual industries could attain different rates of innovation. That is to say the financial architecture of a country has heterogeneous impacts on the technological progress and productivity of industries. Hence, financial architecture plays an important role in shaping the industrial structure of a country. Finally, and in sum, financial architecture partially dictates the pace of countries' technological progress.

Appendix 1. Definitions and Sources of Variables

Variable	Definition	Sources
Dependent Variables		
Rate of Technological Progress	A measure of the change in real output attributable to technological innovation. It is measured as the shift in the production frontier over time holding input factors and production efficiency constant, and represents increases in real output due to the adoption of better technology. Alternatively, it is measured as the rate of real cost reduction computed as the downward shift in the cost function over time, holding output and cost efficiencies constant.	Constructed based on production and cost functions estimated using data from the UNIDO database.
Independent Variables		
Financial Architecture	An index of the degree of stock market orientation of a financial system. It is an aggregate of three indices of the market orientation based on i) the relative size of the stock market to that of banks, ii) the relative intensity of activity in stock markets vis-à-vis the banking sector, and iii) the relative efficiency of stock markets vis-à-vis the banking sector. The size, activity, and efficiency indices are aggregated as a principal component.	Constructed based on data in Beck et al. (2000).
Intangible Intensity	Ratio of intangible assets to net fixed assets of U.S. firms by industry sector over the period 1980 to 1989. Primary Source: COMPUSTAT. Intangibles is COMPUSTAT item 33 and represents the net value of intangible assets. Intangibles in COMPUSTAT includes blueprints or building designs, patents, copyrights, trademarks, franchises, organizational costs, client lists, computer software patent costs, licenses, and goodwill. Net fixed assets is COMPUSTAT item 8 and represents net property, plant, and equipment.	Claessens and Laeven (2003).

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Variable	Definition	Sources
Control Variables		
Human Capital	The average for 1980 of the years of schooling attained by the population over 25 years of age.	Barro and Lee (1993).
Per Capita GDP	The logarithm of real per capita GDP in 1980.	World Development Indicators.
Industry Share in Manufacturing (value added)	Fraction of an industry's real value added to the value added of the manufacturing sector.	Calculated from data in the UNIDO database.
Stock Market Capitalization	Value of listed shares of stock outstanding divided by GDP.	Emerging Markets Database.
Stock Market Turnover	Value of shares of stocks trades as a ratio of stock market capitalization.	Emerging Markets Database.
Bank Development	Domestic credit to the private sector as a ratio of GDP.	International Finance Series from the IMF.
Property Freedom	A rating of property rights protection (on a scale from 1 through 5), based on the degree of legal protection of private property and the likelihood of expropriation by the government. Median rating over 1995 through 1999.	Index of Economic Freedom, Heritage Foundation.
Intellectual Property	An index of intellectual property rights (scale 1 through 5), based on the "special 301" placements of the Office of the U.S. Trade Representative (USTR). Special 301 requires the Office to identify those countries that deny adequate protection of intellectual property rights. Based on this rating, countries are categorized as Priority Foreign countries (i.e., countries with the least protection of intellectual rights), 306 monitoring, Priority Watch, Watch list and Not listed countries.	USTR.
Patent Rights	Index of patent rights protection in 1980.	Ginarte and Park (1997).
Property Rights (WEF)	An index of property rights (scale 1 through 7) in 2001 from the WEF.	WEF.
Intellectual Property (WEF)	An index of intellectual property rights protection (scale 1 through 7) in 2001 from the WEF.	WEF.
Property Rights (ICRG)	A broad index of property rights protection based on indices on the quality of bureaucracy, corruption, rule of law, risk of expropriation, and risk of repudiation of contracts by the government from the International Country Risk Guide (ICRG).	ICRG.
U.S. Industry Sales Growth	Real annual growth in sales of U.S. firms by industry averaged over the period 1980 through 1989.	Fisman and Love (2002b).
Legal Origin	The origin of the legal tradition of the country. The origin could be English common law, French civil law, and German civil law.	LLSV (1998).
Legal Protection	Indices of the legal protection afforded to shareholders and creditors in each country.	LLSV (1998).
Distance from the Equator	The distance of the country from the equator, scaled between 0 and 1.	LLSV (1999).

Appendix 2. Estimation of Rates of Technological Change

A2.1. Empirical Measures of Technological Change Based on the Stochastic Production Function

I assume that there exists an unobservable function, a stochastic production frontier, representing the maximum attainable output level for a given combination of inputs. I

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represent these best-practice production technologies by a translog production function of the form,[11]

$$\text{(A2.1.1)}\quad \ln y_{ci}(t) = \beta_0 + \sum_j \beta_j \ln x^j_{ci}(t) + \beta_t t + \tfrac{1}{2}\left(\sum_j \sum_k \beta_{jk} \ln x^j_{ci}(t) \ln x^k_{ci}(t) + \beta_{tt} t^2\right) + \sum_j \beta_{jt} \ln x^j_{ci}(t) t + \mu_{ci}(t) + \varepsilon_{ci}(t),$$

where $\varepsilon_{ci}(t) = \alpha_c + \eta_i + \nu_{ci}(t)$, $x^j_{ci}(t)$ and $x^k_{ci}(t)$ are production inputs j and k used in industry i of country c during period t. The production inputs are capital (K) and labor (L). I use the variable t, an index of time, to represent the level of technology. The term $\mu_{ci}(t)$ is a one-sided random variable and measures the degree of inefficiency of industry i of country c in period t. The specification is a random effects model in which latent country and industry effects are specified as random variables. The terms α_c and η_i are the random unobservable country- and industry-specific effects, respectively, and $\nu_{ci}(t)$ is the usual white noise. The distributional assumptions on the error components are

$$\text{(A2.1.2)}\quad \begin{aligned} \alpha_c &\approx iidN\left(0, \sigma^2_\alpha\right) \\ \eta_i &\approx iidN\left(0, \sigma^2_\eta\right) \\ \mu_{ci}(t) &\approx iid - halfNormal\left(0, \sigma^2_\mu\right), \quad \mu_{ci}(t) \le 0, \quad \text{and} \\ \nu_{ci}(t) &\approx iidN\left(0, \sigma^2_\nu\right). \end{aligned}$$

I estimate the model by the method of maximum likelihood to obtain unbiased and efficient estimates of the parameters. The predicted estimates of technological progress are obtained from the parameter estimates of the production function as

$$\text{(A2.1.3)}\quad \nabla \text{TECH1}_{cit} = \frac{\partial \ln y_{ci}(t)}{\partial t} = \beta_t + \sum_j \beta_{jt} \ln x^j_{ci}(t) + \beta_{tt} t.$$

A2.2. Empirical Measures of Technological Change Based on the Stochastic Cost Function

Under certain regularity conditions, the underlying production technology can be uniquely represented by a dual cost function. Employing this duality, I represent the underlying technology by a restricted translog cost function of the form,

$$\text{(A2.2.1)}\quad \begin{aligned} \ln C_{ci}(t) = {} & \beta_0 + \beta_k \ln K_{ci}(t) + \beta_y \ln Y_{ci}(t) + \beta_t t \\ & + \tfrac{1}{2}\left\{\beta_{kk}(\ln k_{ci}(t))^2 + \beta_{yy}(\ln Y_{ci}(t))^2 + \beta_{tt} t^2\right\} \\ & + \beta_{ky} \ln K_{ci}(t) \ln Y_{ci}(t) \\ & + \beta_{kt} \ln k_{ci}(t) t + \beta_{yt} \ln Y_{ci}(t) t + \theta_{ci}(t) + \varepsilon_{ci}(t), \end{aligned}$$

where $\varepsilon_{ci}(t) = \alpha_c + \eta_i + \xi_{ci}(t)$, and $\theta_{ci}(t)$ is a one-sided random variable denoting the degree of economic inefficiency, α_c and η_i are country- and industry-specific error components, and $\xi_{ci}(t)$ is the usual disturbance term with mean zero and standard deviation σ_ξ. The error components and the disturbance term follow the distributional assumptions in equation (A2.1.2). $\ln C$ is the log of costs. $\ln Y$ is the log of output and $\ln K$ is the log of capital stock. Also note that, with the imposition of homogeneity, the input price of labor becomes a numeraire, effectively entering in the intercept term. The empirical measure of technological progress based on the cost function represents the rate of cost reduction per year and is given by

$$\text{(A2.2.2)}\quad \nabla \text{TECH2}_{ci}(t) = \beta_t + \beta_{kt} \ln K_{ct}(t) + \beta_{yt} \ln Y_{ci}(t) + \beta_{tt} t.$$

[11] The choice of this particular functional form is dictated by its flexibility. There is also evidence that manufacturing production is non-homothetic and exhibits scale economies, both of which are accommodated in the translog form.

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