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Financial Risks and Research Contracts in a Model of Endogenous Growth*

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Financial Risks and Research Contracts in a Model of Endogenous Growth

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Preliminary Draft. Comments Welcome.

Abstract

This paper examines researchers' choices between either collaborating with venture capitalists (Regime C) or going independently (Regime I), and how their interaction affects long-run endogenous growth, in an economy characterized by incomplete contracts and financial market imperfections. Both research and production require labor and physical capital. We find that an improvement in financial regulation leads to a higher rate of innovation under Regime I. In contrast, an improvement in R&D incentives for researchers in Regime C can coincide with either an increase or a decrease in the long-run rate of innovation, due to the holdup problem in post bargaining over created value. We also rank the growth rates in the two regimes under different contractual and financial environments. Finally, we find that conflicts can arise when entrepreneurs choose one regime based on investment incentives but the other regime provides a higher growth rate.

Key Words: Endogenous Growth, R&D, Incomplete Contracts, Financial Imperfections

JEL Classification: O16

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1 Introduction

Starting a business requires many essential elements. To begin with, one needs "an idea", or a blueprint that is the result of an innovation. Capital, is necessary not only to make the blueprint into a real product, but also to carry out the original innovation. While many able researchers can borrow directly from banks (or close relatives and friends) to finance their research projects, very often, entrepreneurs and venture capitalists seek out each other, combine the former's good ideas and the latter's deep pockets, to create a blueprint, and finally to implement the innovation. Forbes (Jan., 2008) reports that companies that venture capitalists helped launch cashed in $34 billion from 86 public offerings and 304 acquisitions in 2007, amid the most severe financial crisis and recession in the post war era. The top financiers included, Kleiner Perkins Caufield & Byers, Sequoia Capital, Sherpalo, Stanford University, Sun Microsystems, etc. Policy makers see the venture capital industry as a potential means of boosting economic growth, and the conventional wisdom says that there is a positive correlation between the entrepreneurial culture and innovation.

This paper attempts to model the relationship between the entrepreneur's financing decision and the innovation rate, in an environment characterized by financial risks and incomplete contracts. Armed with an idea, entrepreneurs must choose between collaborating with venture capitalists (Regime C) or going independently (Regime I) to carry out the innovation. Successful innovation brings long-term profits. Under Regime C, these profits must be shared between the entrepreneur and the venture capitalist. Since negotiation occurs after the realization of profits, a holdup problem may arise in contracting if either party has an incentive for expropriation. In contrast, under Regime I, while the entrepreneur can retain full profits, in the event that innovation fails, risks associated with the recovery of money lent out by banks lead to a higher cost of financing capital. We analyze these interesting issues in an endogenous growth model, and examine how the contract environment and financial regulations affect the entrepreneur's choice of research regimes, subsequent innovation investments and eventually the economy-wide growth rate.

We first derive the conditions for a unique long-run equilibrium with a positive rate of innovation for each regime. Then in Regime I, we analyze how improvements in financial regulations affect the long-run innovation rate, through a reduction in financial market imperfections that allows entrepreneurs to finance physical-capital investment at a lower cost. We demonstrate that this increases the rate of innovation, which is supported by the empirical literature. For instance, King and Levine (1993a; 1993b) find positive correlation between a country's level of financial development and its prospects for growth that may stem from either the innovation activity of entrepreneurs or capital accumulation. However, we find that an improvement in financial imperfections has an ambiguous effect on the wage-rental ratio, because the latter depends on the relative factor intensities of production and innovation as well as the current rate of innovation.

Next in Regime C, we find surprisingly that changes in the contract environment that improve the position of entrepreneurs through an increase in their shares of created value, can have either a positive or a negative influence on the rate of innovation, depending on the current contract environment. In particular, the relationship between entrepreneurs' share of created value and growth has an inverted-U shape with a *maximum occurring for median ownership shares*. This surprising result is in line with the claim that too much legal protection may hurt innovation, as argued by some legal experts. For example, Graves and DiBouse (2006) state that non-competition covenants and trade secret laws inhibit innovation. Samila and Sorenson (2009) find evidence that venture capital has a greater impact on innovation and startups in regions with less stringent labor laws. Moreover, although Kortum and Lerner (2000) and Samila and Sorenson (2010) conclude that venture capital is associated with higher rates of patenting, Zucker et al. (1998) find that local venture capital may have a negative effect on the number of startups in a region when the abilities of scientists are controlled for. Hirukawa and Ueda (2008) also provide evidence that venture capital can have a negative impact on patenting when venture capitalists shift from R&D to sales strategies after successful innovations.

We then use the model to rank the growth rates in the two regimes under different contracting and financing environments. Specifically, if the financial market is well developed and the lending rate is low, then Regime I gives the higher growth rate. On the contrary, if the financial market is poor, Regime C provides the higher growth rate. These results suggest that countries with poor financial systems but relatively better contractual environments with less holdup problems should encourage research collaboration. Furthermore, in some developing countries where the overall financial system is poor, lending is often done among family members and close relatives and the lending rate is very low. Our model predicts that business startups in such environments more often occur in Regime I.

In addition, we examine the alignment issue of the entrepreneur's incentives for innovation with economic policy, and find cases with conflicts in which entrepreneurs will choose Regime C over Regime I even though the latter provides a greater rate of innovation, given the current contract environment and financial regulations.

Our paper contributes to the endogenous growth literature that examines the role of financial intermediaries. King and Levine (1993b) develop a theoretical framework in which financial intermediaries spur economic growth indirectly through the provision of screening, monitoring and risk diversification services that improve the probability of successful innovation activity. Michalopoulos et al. (2009) on the other hand show that growth is generated directly by the financial sector through innovations made in the screening technology of financial intermediaries. In an international context Matsuyama (2004) and Aghion et al. (2005) investigate how the structure of the financial market influences convergence in the wealth of rich and poor countries.

Our paper is also closely related to the literature that investigates the implications of incomplete contract theory for economic growth and productivity. Antras (2005) introduces a product cycle model where contractual frictions govern the intra-firm production shifts from North to South that eventually result in the fragmentation of the production process. Acemoglu and Antras (2007) examine the relationship between contractual incompleteness and technology adoption, and show that improvements in the contracting institutions can theoretically lead to large increases in productivity.

Finally, the corporate finance literature has extensively explored the creation of contracts between startups and venture capitalists.[1] For instance, Landier (2001) and Ueda (2004) investigate the financing choice of entrepreneurs and find that venture capital tends to be associated with a high degree of risk, low collateral, and high profitability. These papers employ static models, however, and are thus not concerned with implications for economic growth.

While the present model is closely related to the aforementioned theoretical analyses, our setup and focus are different. First, our simple setup enables us to examine financial imperfections and contractual problems in a unified framework with endogenous growth. We compare the entrepreneur's financing choices and their impacts on the subsequent R&D investments. Furthermore, we can clearly see how these affect the growth rate and can rank the growth rates according to different financial and legal environments, which should have appealing policy implications.

The rest of the paper proceeds as follows. Section 2 develops our basic model of innovation-based endogenous growth. In Section 3, we characterize the long-run equilibrium for Regime I, and investigate the effect of improvements in financial regulations. Section 4 describes the long-run equilibrium for Regime C and examines the impact of changes in the contracting environment for entrepreneurs. Section 5 compares growth rates and analyzes the alignment issue between the optimal innovation regimes for long-run growth and the R&D incentives of entrepreneurs. Section 6 provides concluding remarks.

[1] Hall and Woodward (2007) examine the monetary incentives for entrepreneurs that use venture capital to finance their startups.

2 The Model

This section presents an endogenous growth model in which R&D associated with product development is characterized by imperfect financial markets and incomplete contracts. We consider a simple economy with two sectors, manufacturing and innovation. In the manufacturing sector monopolistically competitive firms produce horizontally differentiated product varieties. In the innovation sector new product varieties are designed. Entry into manufacturing is the end result of a product development process that takes place in the innovation sector. There are two factors of production, labor (L) and physical capital (K), which are employed in both sectors.

2.1 Households

The demand side of the economy consists of a dynastic representative household that maximizes lifetime utility over an infinite horizon. The household's preferences are described by the following intertemporal utility function:

$$U = \int_0^\infty e^{-\rho t} \ln Y(t) dt,$$

where $\ln Y(t)$ is instantaneous utility derived from consumption of a manufacturing composite of differentiated product varieties, and ρ is the subjective rate of time preference. Intertemporal utility maximization under a standard flow budget constraint requires that the household choose an expenditure-savings path that follows the Ramsey saving rule, as indicated by the following Euler equation:

$$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho, \tag{1}$$

where $E(t)$ is household expenditure, $r(t)$ is the risk free interest rate, and a dot over a variable indicates differentiation with respect to time. We follow Grossman and Helpman

(1991) and set expenditure as the model numeraire, $E = 1$, and the risk-free interest rate equal to the subjective discount rate at all moments in time, $r = \rho$. For the remainder of the paper we suppress time notation where doing so does not cause confusion.

Following Dixit-Stigiltz (1977), the composite manufacturing good takes the form of a CES-type quantity index over the total number of product varieties n that have been introduced to date:

$$Y = \left(\int_0^n x(i)^\theta di \right)^{\frac{1}{\theta}}, \quad 0 < \theta < 1, \tag{2}$$

where $x(i)$ is the demand for variety i, $\theta = 1 - 1/\sigma$ is the degree of product differentiation, and σ is the constant elasticity of substitution between any two given product varieties. The household allocates income budgeted for expenditure across product varieties to maximize instantaneous utility. As such, under (2) the well-known instantaneous demand function for a given product i is

$$x(i) = p(i)^{-\sigma} P_Y^{\sigma-1}, \tag{3}$$

where $p(i)$ is price, and the price index over available product varieties is

$$P_Y = \left(\int_0^n p(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}},$$

which is decreasing in the number of product varieties.

2.2 Manufacturing

The manufacturing sector is characterized by a mass of n symmetric firms each producing a unique differentiated variety and competing according to monopolistic competition. As is standard in many love-of-variety models, these incumbent firms face no risk of failure and therefore remain in the market indefinitely.

All firms employ capital and labor in production using the following constant returns to scale technology:

$$x(i) = a l_X(i)^{\alpha} k_X(i)^{1-\alpha}, \tag{4}$$

where $l_X(i)$ and $k_X(i)$ are firm-level employments of labor and capital, $0 < \alpha < 1$ is the intensity of labor in production, and $a = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$ set to simplify algebra.

The unit cost function associated with the production function (4) is $w_L^{\alpha} w_K^{1-\alpha}$, where w_L and w_K are respectively the wage rate and the capital rental rate. Taking these factor prices as given, the operating profit of a representative manufacturing firm is

$$\pi(i) = \left(p(i) - w_L^{\alpha} w_K^{1-\alpha}\right) x(i).$$

We assume that the mass of manufacturing firms is sufficiently large to eliminate strategic interaction between firms, and thus each firm sets its price equal to a constant mark-up over unit cost, $p = w_L^{\alpha} w_K^{1-\alpha}/\theta$. Using this pricing rule in the operating profit function yields optimal profits equal to

$$\pi = \frac{1}{\sigma n}, \tag{5}$$

where we have used the demand function (3) and we have dropped the firm index to indicate that all firms earn the same operating profit.

The labor and capital demands for the manufacturing sector can be obtained using Shephard's Lemma on the unit cost function and aggregating across firms:

$$L_X = \alpha n x \left(\frac{1}{\omega}\right)^{1-\alpha}, \quad K_X = (1-\alpha) n x \left(\frac{1}{\omega}\right)^{-\alpha}, \tag{6}$$

where $\omega \equiv w_L/w_K$ is the relative factor price (i.e., wage rental ratio).

2.3 Innovation

Entry into the manufacturing sector requires the development of a new product design through a research project in the innovation sector. Each research project is directed by a research team and requires investments of labor and physical capital. The physical capital can exhibit in the form of labs, research equipment and other materials. The research team has two options when financing such physical capital investment: one is to borrow directly from banks (Regime I), and the other is to enter into a contractual arrangement with a venture capitalist (Regime C). As will be explained in detail below, the borrowing rates and repayment methods differ under the two options, and the research team may choose either type of financing depending on the financial and contractual environments.

The value of the new product design is equal to the present value of the future stream of operating profits (5) that can be earned with entry into the manufacturing sector:

$$v(t) = \int_t^{\infty} e^{-(\tau - t)\rho} \pi(\tau) d\tau, \tag{7}$$

where we have used $r = \rho$. This value is earned upon completion of the research project and is used to cover loans taken out to finance the costs of product development and to pay for the use of venture capital if that financing option has been chosen.

The successful development of a new product design ensures market entry and access to the same flow of operating profits (7). A representative research project develops a single product design according to

$$1 = bnl^{\beta} k^{1-\beta}, \tag{8}$$

where n is the number of existing product varieties, l and k are respectively labor and capital employment in innovation, $0 < \beta < 1$ is the factor intensity of labor in innovation, and $b = \beta^{\beta}(1 - \beta)^{-(1-\beta)}$. As in Romer (1990), the creation of new product designs is subject to intertemporal externality, where a sector-wide learning curve results from the accumulation of knowledge capital as a by-product of product creation, thereby increasing the productivity of future research projects. Here the number of existing product varieties n is used as a proxy for knowledge capital. While the research team supplies labor required for the research project, physical capital is rented, and the cost of renting k is covered through either a bank loan or investment by a venture capitalist.

The following subsections look into the specific features associated with each method of financing in innovation.

2.3.1 Financial Market Imperfections

Researchers can choose to undertake innovation independently (Regime I), when they must seek financing for capital-equipment investment directly from financial institutions, and face financial market imperfections. Following Galor and Zeira (1993), we assume that these imperfections arise from monitoring costs incurred by lenders attempting to prevent possible debt evasion by borrowers.

Specifically, while normal financial institutions (e.g., banks) can obtain funds at the risk-free interest rate ρ, they incur a monitoring cost of z after lending funds to individual research projects. A loan of value kw_K, where w_k is the rental rate on capital as before, has an interest rate γ that is set higher than the risk-free interest rate $\rho\ (=\ r)$ in order to cover monitoring costs, that is $\gamma kw_K = \rho kw_K + z$.[2] If a default occurred, the lender would not get back its loan. To prevent this from happening, authorities impose financial regulations that satisfy an incentive-compatibility constraint $kw_K(1+\gamma) = \mu z$, where we interpret $\mu > 1$ as the toughness or completeness of the financial regulations on loan default. Equivalently, lenders can set the level of monitoring high enough to ensure that borrowers have no incentive to default, and therefore always pay off their loans. These conditions lead to a lending rate,

$$\gamma(\mu) = \frac{1+\mu\rho}{\mu-1} > \rho, \tag{9}$$

that is strictly greater than the risk-free interest rate ρ, and is decreasing in μ. When μ is close to 1, financial regulations are relatively lax and lenders charge a large mark-up over ρ to cover monitoring costs. Alternatively, for large values of μ the financial regulations are

[2] Note that we are assuming a competitive banking industry where lenders earn zero economic profits.

relatively strict and lenders reduce the gap between $\gamma(\mu)$ and ρ.

Venture capitalists are a special type of financial institution; that is, they are able to finance physical-capital investment at the risk-free interest, ρ, which is lower than the rate provided by banks to independent researchers, γ. However, under this type of financing, the research team must share the generated profits with the venture capitalist. This creates a tension in the research project's choice between independent financing through banks (Regime I) and a research collaboration with the venture capitalist (Regime C).

2.3.2 Independent Research Projects

As discussed above, in the case of independent research projects (Regime I), entrepreneurs must obtain loans directly from the financial market at a higher interest rate to cover the cost of renting physical capital, but the good side is, the research team can keep all its profits. We assume there exist either zero or many such research teams.

From (7) and (8), a given research project is capable of creating value equal to v each period. Taking the cost of borrowing funds as given, the research team chooses the optimal effective labor and physical capital inputs with the objective of maximizing net value creation:

$$\max_{h_I,k_I} \quad vbnl_I^{\beta}k_I^{1-\beta} - h_I w_L - (1+\gamma)k_I w_K, \tag{10}$$

where l_I and k_I are the labor and physical capital inputs for an independent research project (subscript I denotes variables associated with independent research projects).

The first order conditions for net value maximization determine the optimal effective labor and physical capital investments respectively as $w_L l_I = \beta v$ and $(1+\gamma)w_K k_I = (1-\beta)v$. Free entry into innovation and substituting the above into (8) yields:

$$v_I = \frac{(1+\gamma)^{1-\beta} w_L^{\beta} w_K^{1-\beta}}{n}, \tag{11}$$

where the right-hand side is the unit cost of product development and is increasing in the wage, rental, and interest rates, and decreasing in the stock of knowledge n.

The total factor demands for innovation in Regime I can be obtained using Shephard's Lemma on the unit product development cost and aggregation:

$$L_I = g\beta \left(\frac{1+\gamma}{\omega}\right)^{1-\beta}, \quad K_I = g(1-\beta)\left(\frac{1+\gamma}{\omega}\right)^{-\beta}, \tag{12}$$

where $g = \dot{n}/n$ is the rate of innovation. Once again, the factor demands are determined by the wage rental ratio $\omega \equiv w_L/w_K$.

2.3.3 Research Contracts

The other option is Regime C, which involves a research collaboration between a research team and a venture capitalist (e.g., a research institute). The research team leads the research project and invests effective labor while the venture capitalist provides low-cost financing for product development and invests physical capital. Again we assume there exists either zero or many research teams and venture capitalists.

The initiation of a new R&D collaboration requires the creation of a contractual relationship stipulating the mission of the research project and ownership rights over created value. We model this process following the literature that examines the influence of threats of expropriation on negotiations in the incomplete contract environment developed by Grossman and Hart (1986) and Hart and Moore (1990). The ex ante contract does not cover rights over all aspects of value creation as the full characteristics of the final product design are not known until the completion of the project. The collaboration thus faces a risk of lost value from either party leaving the project before the final product design is complete. The research team may be able to part with the venture capitalist without reporting key research results. This enables the research team to threaten the venture capitalist into renegotiating the contract once a major research breakthrough has been made. Alternatively, if the venture capitalist has specialized knowledge of the industry or maintains a concern in a competing research project, it may be able to complete the research project without the entrepreneur (Kaplan and Stromberg; 2003, 2004). Both the research team and the venture capitalist balance their investments of labor and capital against the knowledge that ex-post rights over created value will be renegotiated before the research project has been completed.

Specifically, we adopt Nash bargaining to determine the researchers' share of the created value, $\delta \in (0, 1)$. Setting the negotiation powers of the two parties to $1/2$, Nash bargaining yields a value for δ that maximizes $G \equiv [\delta v - o_L v]^{1/2} [(1-\delta)v - o_K v]^{1/2}$. We rule out the corners when $\delta = 0$ and $\delta = 1$. In the event that these negotiations break down, the values retained by the research team and the venture capitalist are respectively $o_L v$ and $o_K v$, which represent their outside options during negotiations. Parameters $o_L, o_K \in [0, 1]$ can be interpreted as the inverse of market thickness of researchers and venture capitalists. For instance, a higher o_L implies lower competition among researchers, yielding higher outside options for them. Alternatively, these parameters may also represent the balance of protection provided to each party by the legal regime. Graves and DiBoise (2006), for example, argue that non-compete clauses and trade secret laws may work to restrict innovation. Moreover, in the sample of venture capital investments examined by Kaplan and Stromberg (2003) approximately 70% include some form of non-competition clause, suggesting that venture capitalists perceive expropriation by entrepreneurs as a potential risk.

If, on the other hand, negotiations are successful, the research team derives a value of δv and the venture capitalist a value of $(1-\delta)v$. Given the above, we obtain

$$\delta = \frac{1 + o_L - o_K}{2}. \tag{13}$$

δ is therefore increasing in the researcher's outside option and decreasing in that of the venture capitalist.

One of the advantages of collaboration with a venture capitalist is the lower cost of financing physical capital investment. Given (13) and the researcher's labor investment, the venture capitalist sets its capital investment to maximize its residual profit, $(1-\delta)vbnl_C^{\beta}k_C^{1-\beta} - (1+\rho)w_K k_C$, where l_C and k_C are the investments of labor and physical capital. Maximization with respect to k_C gives an optimal capital investment of

$$k_C = \frac{(1-\delta)(1-\beta)v}{(1+\rho)w_K}. \tag{14}$$

A comparison of this first order condition with that for an independent research project shows that, for the research project as a whole, the efficient investment of capital is only made when the venture capitalist has full ownership rights over created value, or $\delta = 0$. As the ownership share of the research team increases, inefficiency in capital investment arises as the venture capitalist only has an incentive to makes suboptimal capital investments. The inefficiency generated in capital investment by renegotiation over ownership rights reaches its highest level when $\delta = 1$ and capital investment is reduced to zero.

The research team, taking the venture capitalist's investment of physical-capital as given, maximizes its residual profit $\delta vbnl_C^{\beta}k_C^{1-\beta} - w_L l_C$, with respect to labor investment, yielding

$$l_C = \frac{\delta\beta v}{w_L}. \tag{15}$$

Once again, comparison of this first order condition with that for an independent research project, we can see that suboptimal labor investments are made when the research team does not retain full ownership rights over created value. The inefficiency caused by suboptimal labor investment is greatest when $\delta = 0$ and labour investment is zero.

Substituting the optimal labor and capital investments into (8) provides the unit product development cost in Regime C:

$$v_C = \frac{\zeta w_L^{\beta}(1+\rho)^{1-\beta}w_K^{1-\beta}}{n}, \tag{16}$$

where $\zeta \equiv 1/\delta^{\beta}(1-\delta)^{1-\beta}$. Similar to Regime I, this unit cost is increasing in the wage, rental, and interest rates, and decreasing in the stock of knowledge. The combined effect of the inefficiencies generated in capital and labor investment by the holdup problem associated with bargaining are described by ζ. When $\delta = 1$, there is no incentive for capital investment, and product development costs become prohibitively large as $\zeta = \infty$. Similarly, when $\delta = 0$, there is no labor investment, $\zeta = \infty$, and once again high costs inhibit product development. ζ has a minimum at $\delta = \beta$, where the overall inefficiency associated with the holdup problem, and hence the cost of product development, is minimized.

The total factor demands for innovation under Regime C can then be obtained using Shephard's Lemma on the unit cost function and aggregating across investment projects:

$$L_C = g\beta\zeta\left(\frac{1+\rho}{\omega}\right)^{1-\beta}, \quad K_C = g\beta\zeta\left(\frac{1+\rho}{\omega}\right)^{-\beta}. \tag{17}$$

2.3.4 Free Entry

Regardless of which innovation regime arises, a positive rate of innovation requires that the appropriate free-entry condition bind, i.e., either (11) or (16) hold. Denoting the value of a product design generated as v_i, where $i = I, C$, the time derivatives of (11) or (16) yield an asset condition that equates the rate of return to a new product design with the risk-free interest rate:

$$\rho = \frac{\pi}{v_i} + \frac{\dot{v}_i}{v_i}, \tag{18}$$

where the first and second terms on the RHS are respectively the dividend rate and the rate of capital gains.

2.4 Factor Markets

The model can be closed by deriving a relative factor price $\omega \equiv w_L/w_K$ that clears the markets for labor and physical capital, which leads to

$$L = L_X + L_i, \quad K = K_X + K_i, \tag{19}$$

where $i = I, C$. In the long-run equilibrium these conditions can be used to solve for the rate of innovation g as a function of the relative factor price ω. The specific form for these conditions depends, however, on whether Regime I or Regime C arises.

3 Independent Research Projects

We examine a steady-state equilibrium with a constant allocation of labor and capital across manufacturing and innovation activities, which requires constant factor prices, and we therefore have $\dot{w_L} = \dot{w_K} = 0$. In the long-run equilibrium of Regime I, all innovation is undertaken by independent research projects.

Beginning with the factor market clearing conditions, substitution of the factor demands (6) and (12) into (19) gives:

$$L = \alpha\omega^{\alpha-1}X + \beta(1+\gamma)^{1-\beta}\omega^{\beta-1}g, \quad K = (1-\alpha)\omega^{\alpha}X + (1-\beta)(1+\gamma)^{-\beta}\omega^{\beta}g, \tag{20}$$

where $X \equiv nx$ is aggregate production. These conditions can be solved for the long-run values of X and g as functions of ω:

$$X_I = \frac{1}{\omega^{\alpha}}\left[\frac{\beta(1+\gamma)K - (1-\beta)\omega L}{(1-\alpha)\beta(1+\gamma) - \alpha(1-\beta)}\right], \tag{21}$$

$$g_I = \left[\frac{(1-\alpha)\omega L - \alpha K}{(1-\alpha)\beta(1+\gamma) - \alpha(1-\beta)}\right]\left[\frac{1+\gamma}{\omega}\right]^{\beta}. \tag{22}$$

They define a range of the relative factor price over which both the manufacturing and innovations sectors are active. In particular, the numerator of (21) can be written as $\frac{\beta(1+\gamma)w_K}{(1-\beta)w_L} - \frac{L}{K}$, where the first term is the ratio of the marginal products for labor and capital in innovation, and thus represents the slope of the output expansion path for the innovation sector. Similarly, the numerator of (22) can be organized as $\frac{L}{K} - \frac{\alpha w_L}{(1-\alpha)w_K}$, where the second term is the slope of the output expansion path for the manufacturing sector.

It is therefore clear that the denominators of (21) and (22) indicate the relative factor intensities of production and innovation, or the ranking of expansion path slopes. When innovation is relatively labor intensive, the denominator is positive and ω adjusts to ensure that the output expansion paths for innovation and production respectively lie above and below the labor-capital ratio in the economy.[3] Note that, given values for α and β, changes in the lending rate γ may induce a reversal of the factor intensity ranking for production and innovation.

Next, using the product market clearing condition $pnx = 1$, the pricing rule for manufacturing firms $p = w_L^{\alpha} w_K^{1-\alpha}/\theta$, and the operating profit (5), we can rewrite the no-arbitrage condition (18) as

$$X = (\rho + g)(\sigma - 1)(1 + \gamma)^{1-\beta}\omega^{\beta-\alpha},$$

where we have used the time derivative of (11) and the fact that factor prices are constant in the long-run equilibrium. This condition can be used to cancel X from the factor market clearing conditions thereby reducing the steady-state system to two equations:

$$g_L = \frac{\omega^{1-\beta}(1+\gamma)^{\beta-1}L - \alpha(\sigma-1)\rho}{\alpha(\sigma-1)+\beta}, \tag{23}$$

$$g_K = \frac{\omega^{-\beta}(1+\gamma)^{\beta-1}K - (1-\alpha)(\sigma-1)\rho}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\gamma)^{-1}}, \tag{24}$$

where g_L and g_K respectively denote the rates of innovation that clear the markets for labor and physical capital for a given ω.

[3] Alternatively, when production is relatively labor intensive, ω ensures that the output expansion path for production lies above the factor endowment ratio and the expansion path for innovation lies below it.

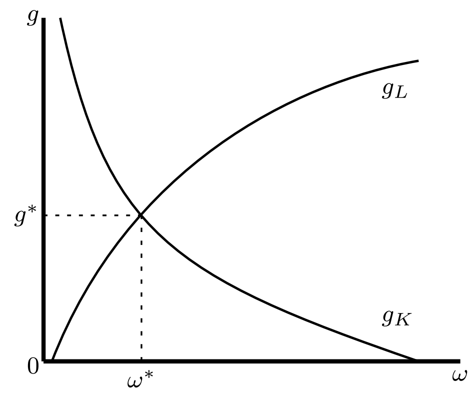


Figure 1: Long-run Equilibrium

Figure 1 illustrates the long-run equilibrium associated with Regime I. The steady-state condition for the labor market (23) has a horizontal intercept at $(1+\gamma)\left[\frac{\alpha(\sigma-1)\rho}{L}\right]^{1/(1-\beta)}$ and a strictly positive but diminishing slope. The condition for the physical capital market (24), on the other hand, has a strictly negative but increasing slope and a horizontal intercept at $\left[\frac{K}{(1-\alpha)(\sigma-1)\rho(1+\gamma)^{1-\beta}}\right]^{1/\beta}$. The intersection of these two curves determines the long-run rate of innovation g^* and the relative factor price ω^*. The following Lemma summarizes the parameter requirements for the existence of a unique long-run equilibrium, with a positive rate of innovation and an active manufacturing sector.

Lemma 1 *The existence of a unique long-run equilibrium with independent research projects requires* $\left[\frac{L}{\alpha}\right]^{\beta}\left[\frac{K}{(1-\alpha)(1+\gamma)}\right]^{1-\beta} > (\sigma-1)\rho$*, and either*
(i) for $\frac{(1+\gamma)\beta}{1-\beta} < \frac{\alpha}{1-\alpha}$, $\frac{\beta(1+\gamma)K}{(1-\beta)L} < \omega < \frac{\alpha K}{(1-\alpha)L}$ *or*
(ii) for $\frac{(1+\gamma)\beta}{1-\beta} > \frac{\alpha}{1-\alpha}$, $\frac{\beta(1+\gamma)K}{(1-\beta)L} > \omega > \frac{\alpha K}{(1-\alpha)L}$.

Therefore, in Regime I, sufficiently large endowments of labor and capital are the main requirements for a unique long-run equilibrium with a positive rate of innovation, and the relative factor intensity rankings for production and innovation determine the feasible range for ω, as discussed above.

Conditions (23) and (24) can be used to investigate the effects of changes in the financial regulations associated with loan default, μ. First on the long-run rate of innovation, we obtain:

Proposition 1 *(Financial regulations and growth): An increase in μ raises the innovation rate g^* through a decrease in γ.*

Proof: See Appendix A.

That is, an improvement in financial regulations (i.e., making them tougher and more complete) that raises the cost of debt evasion, by an increase in μ, unambiguously increases the rate of innovation. As shown in condition (9), an increase in μ decreases the lending rate γ and reduces the cost of financing physical-capital investment. This leads to an improvement in efficiency as financial market imperfections are corrected, and thus the rate of innovation rises.

Next, on the relative factor price ω, we obtain:

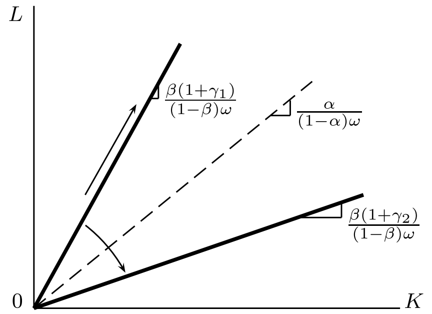
Proposition 2 *(Financial regulations and relative factor price): The relationship between μ and ω^* has an inverted-U shape with a maximum at $\gamma(\overline{\mu}) = \frac{(\alpha(\sigma-1)+\beta)g^*+(\alpha-\beta)(\sigma-1)\rho}{(1-\alpha)\beta(\sigma-1)\rho}$.*

Proof: See Appendix A.

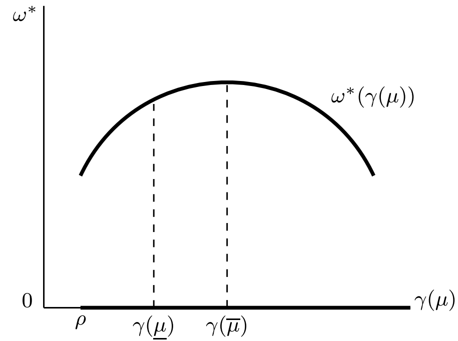
An increase in μ affects ω through two channels, as shown in Appendix A. The first is a substitution effect whereby a lower cost of financing physical-capital investment induces researchers to substitute capital for labor, putting downward pressure on ω:

$$g\left(\alpha(\sigma-1)+\beta\right).$$

The first term in paretheses is the value of an additional unit of labor employed in manufacturing, and the second term is the value of an additional unit of labor employed in innovation. The substitution effect is illustrated in panel (a) of Figure 2 by the arced arrow, that indicates the decrease in the relative labor intensity of innovation which coincides with a rotation of the output expansion path as the lending rate decreases from γ_1 to γ_2.



(a) Factor intensity ranking



(b) Relative factor price

Figure 2: Improvements in the Financial Regulations

The second channel is an output expansion effect whereby a higher level of innovation activity leads to a shift in factor employment from production to innovation that puts *upward* pressure on ω if product development is relatively *labor intensive*, and *downward* pressure if product development is relatively *capital intensive*:

$$(\sigma - 1)\rho\left[\alpha(1-\beta) - (1-\alpha)\beta(1+\gamma)\right].$$

The expansion effect is indicated in panel (a) of Figure 2 by the arrow running up the expansion path associated with a lending rate of γ_1.

The relationship between ω and γ is determined by the relative strengths of the substitution and expansion effects. Referring to panel (b) of Figure 2, suppose that initially the lending rate is high such that $\gamma_1 > \gamma(\overline{\mu})$, and product development is relatively labor intensive. In this case, a negative expansion effect dominates the substitution effect, and hence an improvement in financial regulations raises ω. Next, consider a lending rate between $\gamma(\underline{\mu}) = \frac{\alpha(1-\beta)}{\beta(1-\alpha)}$ and $\gamma(\overline{\mu})$. The expansion effect is still negative but now dominated by a positive substitution effect, and an increase in μ lowers ω (at $\gamma(\underline{\mu})$ the slopes of the expansion paths for innovation and production are the same and the expansion effect is zero). Lastly, for a lending rate below $\gamma(\underline{\mu})$, the substitution and expansion effects work in the same direction and an increase in μ lowers ω. Note that the lending rate γ converges to

ρ for a high level of μ, and consequently if $\frac{\alpha}{1-\alpha} < \frac{\beta(1+\rho)}{1-\beta}$, then $\frac{d\omega}{d\gamma}$ may be negative for all values of μ.

4 Research Contracts

Now we characterize the long-run equilibrium for Regime C, where all innovation is undertaken by collaborations between researchers and venture capitalists. Again we examine the steady-state equilibrium where $\dot{w_L} = \dot{w_K} = 0$.

Combining the factor demands given in (6) and (17), the factor market clearing conditions (19) can be written as

$$L = \alpha\omega^{\alpha-1}X + \zeta\beta(1+\rho)^{1-\beta}\omega^{\beta-1}g, \quad K = (1-\alpha)\omega^{\alpha}X + \zeta(1-\beta)(1+\rho)^{-\beta}\omega^{\beta}g. \tag{25}$$

These conditions can be solved for aggregate production and the innovation rate as

$$X_C = \frac{1}{\omega^{\alpha}}\left[\frac{\beta(1+\rho)K - (1-\beta)\omega L}{(1-\alpha)\beta(1+\rho) - \alpha(1-\beta)}\right], \tag{26}$$

$$g_C = \frac{1}{\zeta}\left[\frac{(1-\alpha)\omega L - \alpha K}{(1-\alpha)\beta(1+\rho) - \alpha(1-\beta)}\right]\left[\frac{1+\rho}{\omega}\right]^{\beta}. \tag{27}$$

With the exception of the term $\zeta \equiv 1/\{\delta^{\beta}(1-\delta)^{1-\beta}\}$ in (27), which measures the inefficiency created by the holding problem in bargaining, these conditions are the same as those derived for Regime I in (21) and (22), with a lending rate of ρ rather than $\gamma > \rho$. Thus, the relative factor intensity ranking across sectors once again determines the feasible range for ω over which both the production and innovation sectors are active.

The no-arbitrage condition for Regime C can be obtained using (18) with the production market clearing condition $pnx = 1$ and the price $p = w_L^{\alpha}w_K^{1-\alpha}/\theta$:

$$X = \zeta(\rho + g)(\sigma - 1)(1+\rho)^{1-\beta}\omega^{\beta-\alpha}.$$

Substituting this into the factor market clearing conditions yields:

$$g_L = \frac{\omega^{1-\beta}(1+\rho)^{\beta-1}\zeta^{-1}L - \alpha(\sigma-1)\rho}{\alpha(\sigma-1)+\beta}, \tag{28}$$

$$g_K = \frac{\omega^{-\beta}(1+\rho)^{\beta-1}\zeta^{-1}K - (1-\alpha)(\sigma-1)\rho}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}}. \tag{29}$$

These conditions provide combinations of the innovation rate and ω that clear the labor and physical capital markets.

The long-run equilibrium in Regime C can be similarly depicted as in Figure 1, with g^* and ω^* now determined by the intersection of (28) and (29). The horizontal intercepts of the g_L and g_K curves are respectively $\left[\frac{\zeta\alpha(\sigma-1)\rho(1+\rho)^{1-\beta}}{L}\right]^{1/(1-\beta)}$ and $\left[\frac{K}{\zeta(1-\alpha)(\sigma-1)\rho(1+\rho)^{1-\beta}}\right]^{1/\beta}$. Once again the respective slopes of the g_L and g_K curves are positive and negative, and thus the following Lemma summarizes the parameter values necessary for the existence of a unique long-run equilibrium.

Lemma 2 *The existence of a unique long-run equilibrium with research contracts requires* $\left[\frac{L}{\alpha}\right]^{\beta}\left[\frac{K}{(1-\alpha)(1+\rho)}\right]^{1-\beta} > \zeta(\sigma-1)\rho$, *and either*

(i) $\frac{\beta(1+\rho)K}{(1-\beta)L} < \omega < \frac{\alpha K}{(1-\alpha)L}$ *for* $\frac{(1+\rho)\beta}{1-\beta} < \frac{\alpha}{1-\alpha}$, *or*

(ii) $\frac{\beta(1+\rho)K}{(1-\beta)L} > \omega > \frac{\alpha K}{(1-\alpha)L}$ *for* $\frac{(1+\rho)\beta}{1-\beta} > \frac{\alpha}{1-\alpha}$.

The key requirement is again sufficiently large labor and capital endowments, although the factor requirement may be smaller or larger than that for Regime I depending on the level of inefficiency generated by contract negotiations and the difference in the lending rates. The relative factor intensity ranking continues to determine the relevant range for ω.

Next we use conditions (28) and (29) to examine the effects of changes in the contracting environment on g^* and ω^*. A quick examination of the outcome of Nash bargaining (13) indicates that the research team's share of created value $\delta(o_L, o_K)$ is an increasing function of the researchers' outside option o_L and a decreasing function of the venture capitalists' outside option o_K. We can then establish

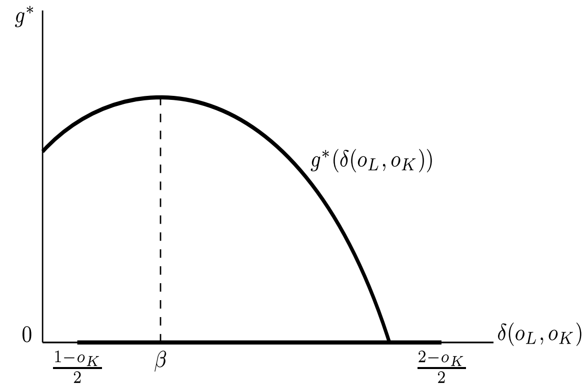


Figure 3: Improvements in the Contract Environment

Proposition 3 *(Outside option and growth): The relationship between o_L and g^* has an inverted-U shape with a maximum at $\beta = \delta$.*

Proof: See Appendix B.

Figure 3 provides an illustration of Proposition 3, where the rate of innovation is measured on the vertical axis and the research team's share of created value on the horizontal axis. The outside option for the research team, o_L, determines the contract environment through (13), as shown by the bold line $\delta(o_L, o_K)$, holding the outside option of the venture capitalist fixed. The contract environment, in turn, determines the long-run rate of innovation, as depicted by the curve labelled g^*. The highest point on this curve occurs where $\delta(o_L, o_K) = \beta$.

The economic intuition behind this result is made clear through an examination of (16). The holdup problem, and its impact on the efficiency of the innovation process, arises directly from the influence of the contractual environment on the investment incentives of entrepreneurs and venture capitalists. As each party foresees the inevitability of renegotiation of ownership rights over created value before a new product design can be brought to market, neither party has an incentive to make the optimal investment in any given contract environment. The inefficiency thus generated leads to an increase in the cost of product development and hinders the innovation rate. As shown in Figure 3, however, this ineffi-

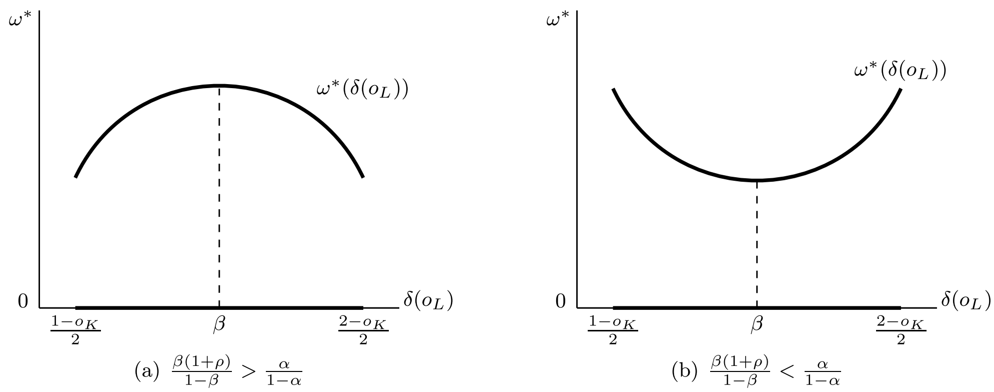


Figure 4: Improvements in the Contract Environment

ciency can be mitigated through adjustments in the outside options, and is minimized when $\delta(o_L, o_K) = \beta$. [4] This suggests that a contract environment which provides entrepreneurs with a either a smaller larger share of created value than the contribution of labor to innovation will inhibit economic growth.

Proposition 4 *(Outside option and relative factor price): The relationship between o_L and ω^*, (i) has an U shape with a minimum at $\beta = \delta$ for $\frac{\beta(1+\rho)}{1-\beta} < \frac{\alpha}{1-\alpha}$; and (ii) has an inverted-U shape with a maximum at $\beta = \delta$ for $\frac{\beta(1+\rho)}{1-\beta} > \frac{\alpha}{1-\alpha}$.*

Proof: See Appendix B.

The two possible cases are depicted in Figure 4. In either case, for $\delta < \beta$ an improvement in the contractual environment *reduces inefficiency* and creates incentives for further investment in innovation that will attract more labor and capital to this sector, increase the innovation rate (g_C), and decrease manufacturing output (X_C). In contrast, for $\delta > \beta$ an improvement in the contractual environment *raises inefficiency*, causing a contraction of the innovation sector and an expansion of the manufacturing sector.

The effect of shifts in factor employment on ω depends on the factor intensity ranking. Panel (a) illustrates the case where innovation is labor intensive compared to the manufacturing sector. An expansion of the innovation sector requires more labor than capital and

[4]It is straightforward to show that $d\zeta^2/d^2\delta > 0$ and setting $d\zeta/d\delta = \zeta(\frac{1-\beta}{1-\delta} - \frac{\beta}{\delta}) = 0$ gives $\delta = \beta$, which minimizes the inefficiency.

therefore drives up ω. Alternatively, panel (b) describes the case where innovation is capital intensive. Then an expansion of the innovation sector increases the demand for capital relative to labor, and drives down ω.

5 Optimal Innovation Regimes

In this section we make a comparison of the long-run growth rates associated with each innovation regime, and investigate the R&D incentives of entrepreneurs. For a given created value, entrepreneurs choose the regime that requires the lowest product development cost, and the government prefers the regime that provides the greatest rate of growth in welfare, as measured in instantaneous utility (2). In the steady-state equilibrium a constant factor allocation requires $\dot{X} = 0$, and the long-run growth rate is therefore $\dot{Y}/Y = g/(\sigma - 1)$. Accordingly, we focus on the innovation rate when comparing the growth rates associated with each regime.

In deciding between whether to undertake independent innovation, or to conduct research collaboration with a venture capitalist, entrepreneurs make a simple comparison of product development costs and choose the best option, given factor prices and the cost of financing physical-capital investment. Referring to the free entry conditions for each innovation regime, i.e., (11) and (16), an entrepreneur will be indifferent when

$$\gamma_v = (1+\rho)\zeta^{\frac{1}{1-\beta}} - 1, \tag{30}$$

where $\zeta \equiv 1/\{\delta^{\beta}(1-\delta)^{1-\beta}\}$ continues to represent the inefficiency of the holdup problem in Regime C. This condition clearly shows the tension between the higher financing costs of Regime I, and the lower retention rate of created value in Regime C. It is convex in the contract environment δ with a minimum at $\beta = \delta$, as depicted by the $v_I = v_C$ locus in Figure 5. For combinations of γ and δ above (respectively below) this locus, venture capital provides a lower (higher) development cost, and accordingly entrepreneurs choose

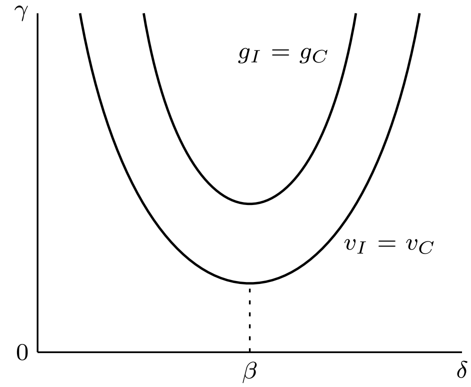


Figure 5: Research Incentives

Regime C (I).

Our comparison of the long-run growth rates associated with each regime, allows factor prices to adjust with changes in financial regulations and the contract environment. In particular, we consider a $g_I = g_C$ locus to describe the preference of the government. The slope of this locus is $\frac{dg_I}{d\gamma}/\frac{dg_C}{d\delta}$, and thus, evoking the results obtained in Propositions 1 and 3, the locus is convex in the contract environment with a minimum at $\beta = \delta$, as illustrated by the $g_I = g_C$ curve in Figure 5. Setting the innovation rates derived in (23) and (28) equal, the $g_I = g_C$ locus can be expressed as a function of the relative factor prices associated with each regime.

$$\gamma_g = \frac{\omega_I}{\omega_C}(1+\rho)\zeta^{\frac{1}{1-\beta}} - 1. \tag{31}$$

Above (below) this locus Regime C (I) has the greater innovation rate. A quick comparison of (30) and (31) reveals that the position of the $g_I = g_C$ locus depends on the ratio of relative factor prices for each regime. In Appendix C we show that $w_I/w_C > 1$ for $g_I = g_C$ and obtain the following:

Lemma 3 *The $g_I = g_C$ locus always lies above the $v_I = v_C$ locus.*

Proof: See Appendix C.

The $g_I = g_C$ locus provides a convenient means of ranking the growth rates of each regimes at different lending rates. The result is summarized in the following Proposition.

Proposition 5 *(Growth comparison): (i). Regime I has the higher growth rate for* $\rho < \gamma < \gamma_g$*; (ii). Regime C has the higher growth rate for* $\gamma_g < \gamma$*.*

Proof. Reorganizing $\rho < \gamma_v$ yields the inequality $1 < \zeta$, which holds for all feasible values of δ. Thus, ρ lies below the $v_I = v_C$ locus and, from Lemma 3, the $g_I = g_C$ locus as well. ■

Consider first the case where financial regulation is well developed, or μ is high, and the lending rate is the same for both regimes ($\gamma = \rho$). In this case, the difference in product development costs stems solely from the holdup problem of Regime C and the growth rate of Regime I is higher ($g_I > g_C$). Next, a deterioration in financial regulation, or a decrease in μ, raises the lending rate and increases the product development cost of Regime I. If the lending rate rises above the threshold rate γ_g indicated by (31), the product development cost of Regime I will become more expensive than that of Regime C, and accordingly the growth rate of Regime C will be higher ($g_C > g_I$).

Lemma 3 yields an interesting comparison concerning the alignment of R&D incentives and economic policy. In the region between the $g_C = g_I$ and $v_C = v_I$ curves, although Regime I provides a greater long-run rate of innovation, Regime C has the lower product developments cost. Thus, while the optimal innovation regime is I, the R&D incentives of investors (including entrepreneurs and venture capitalists) pull the economy towards Regime C. We summarize this result in the following Proposition.

Proposition 6 *(Regime conflicts): (i). Entrepreneurs choose the regime with the lower growth rate for* $\gamma_g > \gamma > \gamma_v$*; (ii). For other values of* γ*, they choose the regime with the higher growth rate.*

These results suggest that countries with poor financial systems but relatively better contractual environments should encourage research collaboration. Furthermore, in some developing countries where the overall financial system is poor, lending is often done among close relatives and the lending rate is very low. Our model predicts that business startups in such environments more often occur in Regime I.

6 Conclusion

This paper has examined incentives for R&D in a model featuring financial market imperfections and incomplete contracts in the product development process, and how these affect the rate of innovation and endogenous growth. In particular, new products can be developed by either independent entrepreneurs or through research collaborations between entrepreneurs and venture capitalists. While independent entrepreneurs retain full ownership over created value, they face financial market imperfections that make physical-capital investments costly. In contrast, entrepreneurs that enter into research contracts with venture capitalists can avoid costs associated with market imperfections, but only retain a reduced share of equity in their research projects.

Investigating long-run equilibria for both regimes, we obtain the following results: (i) An increase in the R&D incentives for entrepreneurs always raises the long-run innovation rate in Regime I, but may raise or lower it in Regime C. (ii) Improvements in the contract environment may cause an increase or a decrease in the relative factor price for labor and physical capital depending on the contract environment and the factor intensities of production and innovation. (iii) Regime I provides the higher growth rate when financial markets are well functioning, and it is Regime C if legal environments for contracting are relatively more developed and the inefficiency stemming from the holdup problem is kept low.

Our model has implications for the alignment of economic policy and R&D incentives for entrepreneurs. In some cases, although an innovation regime with independent entrepreneurs developing new products provides the greatest long-run rate of innovation, short-run incentives for entrepreneurs lead to an innovation regime with venture capitalists and a lower innovation rate.

Appendix A: Propositions 1 and 2

The total differentials of (23) and (24) with respect to g^*, ω^*, and γ can be written in matrix form as

$$\begin{bmatrix} 1 & -\frac{(1-\beta)\omega^{-\beta}(1+\gamma)^{\beta-1}L}{\alpha(\sigma-1)+\beta} \\ 1 & \frac{\beta\omega^{-(1+\beta)}(1+\gamma)^{\beta-1}K}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\gamma)^{-1}} \end{bmatrix} \begin{bmatrix} dg^* \\ d\omega^* \end{bmatrix} = \begin{bmatrix} -\frac{(1-\beta)\omega^{1-\beta}(1+\gamma)^{\beta-2}L}{\alpha(\sigma-1)+\beta} \\ \frac{1-\beta}{(1+\gamma)^2}\left[\frac{g^*-\omega^{-\beta}(1+\gamma)^{\beta}K}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\gamma)^{-1}}\right] \end{bmatrix} d\gamma,$$

Using Cramer's rule we obtain

$$\begin{aligned} \frac{d\omega^*}{d\gamma} &= \frac{(1-\beta)\left[g\left(\alpha(\sigma-1)+\beta\right)+(\sigma-1)\rho\left(\alpha(1-\beta)-(1-\alpha)\beta(1+\gamma)\right)\right]}{(1+\gamma)^2\left[\alpha(\sigma-1)+\beta\right]\left[(1-\alpha)(\sigma-1)+(1-\beta)(1+\gamma)^{-1}\right]\Omega_I}, \\ \frac{dg^*}{d\gamma} &= -\frac{(1-\alpha)(1-\beta)(\sigma-1)(\rho+g)(1+\gamma)^{\beta-2}\omega^{-\beta}L}{\left[\alpha(\sigma-1)+\beta\right]\left[(1-\alpha)(\sigma-1)+(1-\beta)(1+\gamma)^{-1}\right]^2\Omega_I} < 0. \end{aligned}$$

where

$$\Omega_I = \frac{(1-\beta)\omega^{-\beta}(1+\gamma)^{\beta-1}L}{\alpha(\sigma-1)+\beta} + \frac{\beta\omega^{-(1+\beta)}(1+\gamma)^{\beta-1}K}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\gamma)^{-1}} > 0,$$

and we have used ((23) and (24). While the comparative static $dg^*/d\gamma > 0$ proves Proposition 2, the sign of $d\omega^*/d\gamma$ depends on the term

$$g\left(\alpha(\sigma-1)+\beta\right)+(\sigma-1)\rho\left(\alpha(1-\beta)-(1-\alpha)\beta(1+\gamma)\right), \tag{A1}$$

which is a decreasing function of γ. The relative factor price is therefore concave in γ with a maximum occurring where (A1) equals zero.

Appendix B: Propositions 3 and 4

The total differentials of (28) and (29) with respect to g^*, ω^*, and δ can be written in matrix form as

$$\begin{bmatrix} 1 & -\frac{(1-\beta)\omega^{-\beta}(1+\rho)^{\beta-1}\delta^{\beta}(1-\delta)^{1-\beta}L}{\alpha(\sigma-1)+\beta} \\ 1 & \frac{\beta\omega^{-(1+\beta)}(1+\rho)^{\beta-1}\delta^{\beta}(1-\delta)^{1-\beta}K}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}} \end{bmatrix} \begin{bmatrix} dg^* \\ d\omega^* \end{bmatrix} = \begin{bmatrix} \frac{\omega^{1-\beta}(\beta-\delta)(1+\rho)^{\beta-1}L}{\delta^{1-\beta}(1-\delta)^{\beta}[\alpha(\sigma-1)+\beta]} \\ \frac{\omega^{-\beta}(\beta-\delta)(1+\rho)^{\beta-1}K}{\delta^{1-\beta}(1-\delta)^{\beta}[(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}]} \end{bmatrix} d\delta.$$

Using Cramer's rule we obtain

$$\begin{aligned} \frac{d\omega^*}{d\delta} &= \frac{(\beta-\delta)\omega^{-\beta}(1+\rho)^{\beta-1}}{\delta^{1-\beta}(1-\delta)^{\beta}\Omega_C}\left[\frac{K}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}} - \frac{\omega L}{\alpha(\sigma-1)+\beta}\right], \\ \frac{dg^*}{d\delta} &= \frac{(\beta-\delta)(1+\rho)^{2(\beta-1)}\delta^{2\beta-1}(1-\delta)^{1-2\beta}\omega^{-2\beta}LK}{[(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}]\,[\alpha(\sigma-1)+\beta]\,\Omega_C}, \end{aligned}$$

where

$$\Omega_C = \frac{\beta\omega^{-(1+\beta)}(1+\rho)^{\beta-1}\delta^{\beta}(1-\delta)^{1-\beta}K}{(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}} + \frac{(1-\beta)\omega^{-\beta}(1+\rho)^{\beta-1}\delta^{\beta}(1-\delta)^{1-\beta}L}{\alpha(\sigma-1)+\beta} > 0.$$

The comparative static for the relative wage depends on the sign of

$$[\alpha(\sigma-1)+\beta]\,K - \left[(1-\alpha)(\sigma-1)+(1-\beta)(1+\rho)^{-1}\right]\omega L, \qquad \text{(B1)}$$

which is increasing in $(1+\rho)$ and, using Lemma 2, equals zero when $(1-\alpha)\beta(1+\rho) = \alpha(1-\beta)$. Thus, (B1) is greater than zero for $(1-\alpha)\beta(1+\rho) > \alpha(1-\beta)$ and less than zero for $(1-\alpha)\beta(1+\rho) < \alpha(1-\beta)$. This result in combination with the term $\beta-\delta$ determines the effects of an increase in δ on the relative factor price as summarized in Proposition 3. The comparative static for the rate of innovation depends solely on the sign of $\beta-\delta$ as stated in Proposition 4.

Appendix C: Lemma 3

First, we use (23) and (24) to solve for the relative factor price of Regime I as

$$\omega_I = \left[\frac{g_I \left[\alpha(\sigma - 1) + \beta \right] + \alpha(\sigma - 1)\rho}{g_I \left[(1 - \alpha)(\sigma - 1) + (1 - \beta)(1 + \rho)^{-1} \right] + (1 - \alpha)(\sigma - 1)\rho} \right] \frac{K}{L}.$$

Second, (28) and (29) are combined to obtain the relative factor price of Regime C:

$$\omega_C = \left[\frac{g_C \left[\alpha(\sigma - 1) + \beta \right] + \alpha(\sigma - 1)\rho}{g_C \left[(1 - \alpha)(\sigma - 1) + (1 - \beta)(1 + \gamma)^{-1} \right] + (1 - \alpha)(\sigma - 1)\rho} \right] \frac{K}{L}.$$

A comparison of these relative factor prices indicates that $\gamma > \rho$, which is true by definition, is a sufficient condition for $\omega_I/\omega_C > 1$ when $g_I = g_C$.

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