
Economics Working Paper 59

**Innovation, "Bank" Monitoring and
Endogenous Financial Development***

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Abstract

This paper develops a simple model to illustrate how capital accumulation, technological progress and financial development interact and mutually reinforce each other in a growing economy. As in a number of recent models, growth is sustained by the development of new varieties of intermediate goods. Innovation, however, is risky, and the probability of success depends on entrepreneurs' actions which can only be imperfectly observed by outsiders through the use of a costly monitoring technology.

In this context, financial intermediaries naturally emerge to avoid the duplication of monitoring activities. The existence of a moral hazard problem requires that contracts between intermediaries and innovating entrepreneurs be structured so as to induce optimal effort through a combination of incentive provision and monitoring. Banks actively seek information concerning the actions of borrowers. This allows them to offer better insurance terms and lowers the expected cost of the contract by reducing the risk premia required by risk-averse innovators. Moreover, the optimal degree of monitoring will be sensitive to factor prices. Hence, natural forward and backward links arise between finance and innovation. By allowing for better risk-sharing, closer monitoring yields a higher level of innovative activity in equilibrium. More research, in turn, brings faster productivity growth, larger incomes and larger and faster capital accumulation. Under plausible assumptions, the resulting changes in factor prices lower intermediation costs, leading to further increase in the efficiency of the financial sector.

I. Introduction

This paper develops a simple model to analyze how capital accumulation, technological progress and financial development interact in a growing economy. We extend a model of endogenous growth through new product development by incorporating informational asymmetries which give rise to the endogenous emergence of financial intermediaries. In this framework, we find that i) intermediaries contribute to growth by collecting information which, by improving their ability to provide risk-pooling services, facilitates the flow of resources to risky innovative activities, and ii) real sector growth feeds back into finance through changes in factor prices which increase the return to information-gathering by intermediaries. The model is therefore consistent with the growing evidence of a robust positive correlation between growth and financial indicators,¹ and may throw some light on the channels through which growth and finance interact.

Drawing on the work of Diamond (1983) and Williamson (1986), we use a set up in which intermediaries emerge endogenously as "delegated monitors" to collect information needed for efficient exchange in the presence of informational asymmetries. We, however, depart from the standard framework in three respects. The first one has to do with the nature of the informational asymmetry between lenders and borrowers. While most of the literature has relied on the costly state verification paradigm studied by Townsend (1979) and Gale and Hellwig (1985), we assume that entrepreneurs' actions, rather than the returns on their projects, are imperfectly observable. The second is that entrepreneurs are risk-averse in our model. Finally, whereas most work in this area has assumed that monitoring yields perfect information upon the payment of a set fee, we

¹ See for example King and Levine (1993) and the references therein.

introduce a monitoring technology which yields increasingly precise information about entrepreneurs' actions at a rising cost.

The combination of risk aversion and private information generates a moral hazard problem and calls for incentive contracts which do not provide for efficient risk sharing. This makes entrepreneurial activities relatively unattractive for risk averse agents, and tends to divert resources to less productive but safer areas. Following Arrow (1962), we argue that these considerations are particularly germane in relation with what we may broadly call innovative activities because would-be innovators often face greater uncertainty and have a greater informational advantage over outsiders than firms operating in established sectors. If, as assumed in some recent work on growth theory, such activities are also an important source of technological spillovers, their financing provides a natural channel through which intermediaries can contribute to growth. To formalize these ideas, we use a model of growth through new product development along the lines of those developed by Judd (1985), Grossman and Helpman (1989, 1991) and Romer (1990) but assume that innovation is risky and the probability of success depends on (imperfectly observable) actions taken by entrepreneurs. This framework allows us to highlight what we believe is a more plausible source of growth or "rate" effects for financial variables than the externalities *à la Romer* featured in most related papers.²

Finally, our specification of the monitoring technology allows us to study the optimal degree of investment in information gathering as part of the contract design problem. Banks have an incentive to supervise entrepreneurs' actions because it allows them to write contracts with better insurance terms. At an optimum, the marginal

² Most of the growth and finance literature has relied on "Ak" models with constant returns to reproducible inputs in order to turn what would have been temporary level effects in a standard neoclassical setting into permanent growth effects. The only two exceptions we are aware of are King and Levine (1992) and Blackburn and Hung (1993), both of which use R&D models similar in spirit to the one developed here. In the first paper, however, no incentive problems arise, and the stock market allows for perfect risk pooling. In the second, agents are risk neutral and the modelling of intermediation follows closely the costly state verification paradigm.

reduction in expected payments to agents due to improved risk sharing will be equated to the marginal cost of monitoring. Hence, the intensity of monitoring, and therefore the volume of resources absorbed by the financial sector, and its efficiency as a mechanism for risk pooling, are endogenously determined by the decisions of profit-maximizing agents. Moreover, since both the cost of monitoring and its benefits depend on factor prices, there emerges a feedback effect from factor accumulation to finance. We show that under plausible assumptions the optimal intensity of monitoring increases as a rising capital/labour ratio makes labour relatively more expensive, and is associated with an increase in the rate of innovation which tends to offset the tendency for growth to slow down with capital accumulation. Hence, real growth feeds upon and contributes to a smooth process of financial development which takes the form of a gradual improvement in the operation of capital markets, rather than the sudden jump from inexistent to fully developed banks or stock markets that we find in some of the literature (St. Paul, 1992; Levine, 1992, and Blackburn and Hung, 1993).

In the present model, informational problems retard growth by interfering with the flow of resources to innovative activities. These very problems, however, also generate profit opportunities that draw agents and resources into an intermediation sector which, by specializing in the supervision of risky entrepreneurial activities, helps overcome the frictions created by informational asymmetries. In these circumstances, the efficiency of the financial system --which determines its ability to channel resources to innovation-- is crucial for growth. However, since such efficiency is determined endogenously, we must look deeper when trying to explain differences in cross-country growth experiences in terms of financial variables.

In our view, the endogeneity of financial structure has two broad policy implications. The first is in some sense a negative one. While the combination of risk aversion and informational considerations may generate a bias against the financing of

innovation, this does not necessarily call for active public intervention through, e.g., selective or subsidized credit policies, for free markets may endogenously supply an efficient solution to the problem. Insufficient access to credit or risk-pooling services may indeed be a serious problem in some countries, and there certainly are circumstances in which government intervention may be appropriate. Before resorting to active measures, however, it seems prudent to ask ourselves whether there is anything in existing policies which has inhibited the development of appropriate markets or institutions.

The second "lesson" has to do with the importance of designing policy interventions in ways which do not interfere with private incentives. In the present model, for example, the existence of technological spillovers would call for a subsidy to innovation. Such a subsidy, however, would have to be designed so as not to reduce innovators' incentives to succeed or intermediaries' incentives to monitor them appropriately.

The remainder of the paper is organized as follows. To help put our model in the appropriate context, Section 1 contains a brief survey of the growth and finance literature. Section 2 outlines the model's structure and discusses briefly the channels through which the real and financial sectors interact. In section 3 we discuss equilibrium in the goods-producing sector and study the determination of factor prices as a function of the stocks of resources used in manufacturing and the existing number of product varieties. Section 4 analyzes the structure of the financial sector and characterizes the structure of contracts between profit maximizing banks and entrepreneurs when gathering information on the latter's actions is costly. In section 5, we discuss the equilibrium allocation of resources across the goods-producing and innovating sectors. Section 6 analyzes the dynamics of the system. Section 7 concludes with some brief comments on policy implications.

II. A Brief Review of the Literature

Economists have long been interested in the relationship between finance and development. A number of early works by Gurley and Shaw (1955), Patrick (1966), Cameron (1967), Goldsmith (1969) and McKinnon (1973), among others, documented the existence of a positive correlation between income levels and indicators of financial depth and the degree of intermediation in capital markets, and provided some basic elements for an understanding of the interaction between financial deepening and output growth as part of the development process. The consensus view that emerges from this work may be briefly stated: Finance contributes to growth to the extent that it increases the volume of investment or improves its allocation. Wealthier economies, in turn, will have a greater demand for financial services and will be better able to afford a costly financial super-structure.

Recent contributions formalize and extend these insights, drawing heavily on the results and techniques of two related lines of research: the "new" growth theory pioneered by Romer (1986) and Lucas (1988), and the literature on endogenous financial intermediation.³ The synthesis of these two literatures has led to the development of models in which financial markets or institutions, which emerge in response to capital market imperfections arising from the existence of informational asymmetries, can have an effect on the growth rate through the volume or composition of investment.

A number of models built along these lines investigate some of the channels through which finance affects real growth and viceversa. A common theme in this literature is that financial markets or institutions may, by providing risk pooling services, reduce or eliminate the need for inefficient forms of investment which may otherwise arise

³ See for example Leland and Pyle (1977), Diamond and Dybvig (1983), Diamond (1984), Bermanke and Gertler (1985) and Williamson (1986).

as a form of self insurance.⁴ A second group of papers focuses on the role of intermediaries as specialized collectors of information which helps improve the allocation of resources across investment opportunities⁵ or facilitates the flow of resources from savers to investors in the presence of informational symmetries.⁶ In both sets of models, financial markets and institutions play a non-trivial role in resource allocation. As a result, policies which interfere with the functioning of the financial system (e.g. different types of taxes and regulations) may have an adverse effect on the volume or efficiency of investment,⁷ and growth effects for financial variables are easily generated with the help of an Ak model with constant returns to reproducible inputs.⁸

⁴ Bencivenga and Smith (1991) and Levine (1991, 1992) use Diamond-Dybvig (1983) preferences to model idiosyncratic liquidity shocks. Agents have a choice between a safe and liquid storage technology and risky and illiquid projects with a larger expected return. Intermediaries eliminate the premature liquidation of long-lived capital and, provided agents are sufficiently risk-averse, reduce the overall holdings of unproductive liquid assets below what they would be in a situation in which agents must self-insure. In Greenwood and Jovanovic (1990), agents face a similar choice between a safe and a risky but more productive technology. In St. Paul (1992), producers self-insure against demand shocks by holding flexible but inefficient technologies. Existence of a stock market lets producers pool risks and therefore allows them to specialize, raising average productivity.

⁵ In Greenwood and Jovanovic (1990), the productivity shock on a risky investment project is the sum of an idiosyncratic and an aggregate component. Financial intermediaries are coalitions of agents who pool their resources. One of the services they provide for their members consists in running trial projects in order to unscramble the aggregate shock; this information is then helpful in deciding whether to invest in the safe or the risky technology. In King and Levine (1992), banks screen applicants to determine whether they are capable of undertaking a research project with a positive probability of success.

⁶ In Sussman (1991), Sussman and Zeira (1993), and Blackburn and Hung (1993), information collection is part of optimal (second-best) trading arrangements in the presence of private information. In these papers, the returns on certain projects can be observed costlessly only by the agents that undertake them, and optimal contracts call for verification when borrowers claim bankruptcy. In these circumstances, intermediaries contribute to growth because they provide the most efficient channel for the flow of funds from savers to entrepreneurs in the presence of informational asymmetries.

⁷ See for example Levine (1992) and King and Levine (1992). Bernanke and Gertler (1985) make a similar point but do not focus on growth. Roubini and Sala i Martin (1992) use a reduced form model of the financial sector based on similar considerations to motivate an empirical study of the effects on growth of policies of financial repression.

⁸ This is easily illustrated with the help of a simple model which draws on Pagano (1992). Suppose aggregate output is given by a reduced form production function of the form

$$y_t = Ax_t + Bk_t$$

where x and k are the amounts of capital invested in two different technologies characterized by different (social) productivity factors, A and B , with $B > A$. Technology B is therefore more productive, at least on average, but agents may still want to invest some of their resources in A for some of the reasons sketched above. If we denote by q the fraction of total capital z allocated to the socially superior technology, and by s the savings rate, the growth rate of the economy is given by:

$$\frac{z_{t+1}}{z_t} = (1 - m) s [A + q(B - A)]$$

We

The feedback effects of growth on financial development have also received some attention in the literature. The key idea in most of this work is that although financial structures may increase the return on investment, they are also costly to build and maintain and will therefore not always be viable. If the cost of financial services has a significant fixed component, average costs will fall with the size and/or number of transactions, which should increase roughly in proportion with income levels or the capital stock. Thus, financial markets or institutions will emerge once some critical output level is reached [St. Paul (1992), Levine (1992)], or, given a non-degenerate income distribution, may be gradually joined by more and more individuals as each becomes rich enough [Greenwood and Jovanovic (1990)]. Blackburn and Hung (1993) suggest another possibility based on the observation that increasing diversification of bank portfolios reduces delegation costs [Diamond (1984) and Williamson (1986)]. Hence, if growth is accompanied by an increase in the number of entrepreneurs seeking loans, at some point it pays to switch from direct to intermediated lending. Finally, Sussman (1991) and Sussman and Zeira (1993) suggest an alternative mechanism based on the reduction of financial margins through increasing specialization and competition within the banking sector. They argue that an increase in the volume of funds flowing through the financial system will generate profit opportunities and attract new entrants. As each bank specializes in a smaller market segment and faces greater competition, both monitoring costs and mark-ups fall, contributing to faster growth through the reduction of the financial margin.

where m is the margin of intermediation absorbed by the financial sector.

In this framework, it is easy to see how finance may affect the growth rate. An improvement in the operation of financial markets which increases agents' ability to diversify the risks associated with the B technology may result in a higher value of q and faster growth. A reduction in the financial margin m will have a similar effect. Finally, devoting resources to the collection of information --an activity which is often best performed by a specialized institution in order to avoid duplication-- may allow agents to distinguish better among projects of different qualities, thus raising the average return on investment and the growth rate.

III. Model Set-Up and Overview

We consider an economy where two different kinds of goods are produced: a continuum of measure $m = n + \Delta$ of differentiated intermediate goods or "components," (x_s ; $0 \leq s \leq m$) and a single homogeneous final good ("output") that can be consumed directly or used as capital. Final output is assembled from components using a CES technology of the form:

$$(1) \quad Q = \left(\int_0^m (x_s)^\alpha ds \right)^{1/\alpha}$$

where $0 < \alpha < 1$ and x_s is the input of the s -th component. The production of intermediate goods requires capital (k) and labour (l), as described by a Cobb-Douglas production function common to all varieties:

$$(2) \quad x_s = (k_s)^\gamma (l_s)^{1-\gamma}$$

Over time, the number of component varieties increases as the result of costly research. Designs for new products are protected by a patent for one period and then go into the public domain.

The final goods sector is competitive. Firms maximize profits taking output, component and factor prices as given, and free entry ensures that profits are zero in equilibrium. The intermediate sector has a mixed market structure. Since patent protection lasts for only one period, firms are of two types: those which produce old varieties ($s \in [0, n]$) behave competitively and earn zero profits, while the rest ($s \in (n, n + \Delta]$) have some degree of market power and earn positive profits.

The possibility of extracting monopoly profits provides an incentive for agents to devote time to R&D activities. During a given period, a researcher has a probability p_e of success which depends on his effort in a way to be specified below. Successful innovators produce b_n new blueprints, and unsuccessful ones produce nothing. Normalizing the size

of the labour force to 1 and letting L denote employment in manufacturing, the fraction of the labour force engaged in research is $1-L$. The total output of new designs is therefore given by

$$(3) \quad \Delta = (1-L)p_e b n$$

where b is a productivity parameter and n the number of already existing product varieties at the beginning of the period. Notice that we have introduced a learning externality in the research technology, as the expected cost of a new blueprint (in units of labour time) is assumed to be inversely proportional to the economy's cumulative research experience, measured by n .⁹ For simplicity, we will assume that components can be produced during the same period they are invented, i.e.

$$(4) \quad n_{t+1} = n_t + \Delta_t = m_t$$

The productive structure we have just described is embedded in a standard OLG setup in which agents live for two periods, work in the first, and save for retirement. Each generation consists of a continuum of homogeneous agents of unit measure with a common utility function of the form

$$(5) \quad U(c_t, d_{t+1}) = \ln c_t + \beta \ln d_{t+1}$$

where c_t and d_{t+1} are first and second period consumption for an agent born at time t . Each agent makes consumption and saving decisions so as to maximize (5) given his income, y , and the interest factor $R = 1+r$. It is easy to show that the resulting indirect utility function is of the form

$$(6) \quad V(y, R) = \text{Max}_{c, x} \{ \ln c + \beta \ln x \quad \text{s.t.} \quad c = y - S, x = SR \} = (1+\beta) \ln y + v(R, \beta)$$

where S is the level of saving, whose optimal value is given by

⁹ Thus, innovation generates, in addition to new designs, knowledge which is useful in further research. This assumption, or something rather similar to it, is necessary in order for growth to be sustainable: if the cost of a new design remained constant, innovation would eventually stop, as increasing market saturation reduces the profits accruing to the inventor of a new product.

$$(7) \quad S^* = sy, \text{ with } s = \frac{\beta}{1+\beta}$$

Young agents face a non-trivial occupational choice. They may either take up employment in the industrial sector at a certain wage w , or become entrepreneurs and undertake a research project which, if successful, yields a number of blueprints for patentable new products. Successful entrepreneurs therefore have positive profits, while unsuccessful ones earn no income. Given their preferences, agents will not accept any gamble which implies a positive probability of starvation, and will therefore only engage in innovation if they can obtain at least some degree of insurance.

In the absence of private information, this would pose no problem. Agents would then be able to issue state contingent securities and, by holding a diversified portfolio, dispose of any idiosyncratic risk associated with their own project. However, the issuance of such securities will be prevented by the imperfect observability of entrepreneurs' actions. It will be assumed that a would-be innovator must pay a fixed entry cost of $1-\delta$ units of time, which may be interpreted as time spent searching for a potential project. Once his proposal has been accepted, he decides how much time to devote to his project. If he works full time in it ("exerts high effort"), he has a high probability of success, $p_H = p > 0$. If he shirks, however, he has a lower probability p_L (zero, for convenience) of coming up with any designs, but he can work in the manufacturing sector the remaining portion of his time, earning additional income δw . Entrepreneurs' actions are not freely observable by outsiders. Investors do, however, have access to a monitoring technology which reveals the researcher's true effort level with probability q at cost $\phi(q)$, and yields no information otherwise.

In this situation, it will be expensive for individual investors to hold diversified portfolios. Risk pooling may be achieved more efficiently by delegating on specialized financial intermediaries ("banks") in order to avoid the duplication of monitoring costs.

Banking is a competitive industry with free entry. Intermediaries have access to deposits at the market rate of interest and supply capital to firms through standard loans.

In addition, each bank holds a perfectly diversified portfolio of contracts with aspiring innovators.¹⁰ A contract specifies the intensity of bank monitoring, q , and a schedule of payments contingent on i) only the outcome of the research project (good or bad) when banks do not observe effort, and ii) both this variable and the agents' effort when the latter is observed. Taking the terms of the contract as given, researchers choose effort levels to maximize their expected utility. It is clear that if payments are the same in all states, agents will find it optimal to shirk. Since low effort yields no revenue, banks will design contracts so as to induce high effort at minimum cost through a combination of monitoring and the provision of incentives for success. The optimal combination of the two ingredients will be a function of existing factor prices, thus creating a link between the structure of financial contracts and factor accumulation.

The contract design problem can be approached in two stages. First, banks choose payments to minimize expected payments to innovators for a given q , subject to appropriate participation and incentive compatibility constraints. This partial minimization yields a cost function of the form

$$C(q, w) = c(q)w$$

where $c(\cdot)$ is a decreasing and convex function of monitoring intensity. Thus, increased monitoring reduces the risk premium required to attract agents away from a safe job by allowing banks to offer better insurance terms. Second, q is chosen to minimize total cost,

$$\Phi(R, w) = \text{Min}_q \{c(q)w + \Psi(q, R, w)\}$$

¹⁰ We assume there is a continuum of agents. Hence, the return on banks' portfolios are certain and there is no need to monitor them.

where $\Psi(q, R, w)$ denotes the monitoring cost, a function of the prices of the inputs to the monitoring technology and the desired accuracy of information. Hence, the total cost of the contract is the sum of two components: the "pure labour cost" of attracting agents away from industrial employment, and a monitoring cost which depends, in general, on both factor prices. If monitoring takes any capital as an input, the optimal value of q increases as capital accumulation makes labour relatively more expensive.

In equilibrium, agents optimize, banks and other competitive firms earn zero profits, factor markets clear, and labour is allocated between current production and research in such a way that agents are indifferent between occupations. Over time, conditions change due to the accumulation of physical capital and technological progress. The savings of the young are used as productive capital next period, and R&D activity results in the development of new product varieties. In equilibrium, there emerges a positive correlation between the growth of real income and "financial development". As noted, factor accumulation induces changes in factor prices which increase the equilibrium monitoring intensity. Improved monitoring, by reducing the need for distorting incentives, lowers the risk premium required by researchers. Competition among banks ensures that this translates into better terms for innovators and an increase in the pace of research activity. More research brings faster productivity growth, larger incomes, and faster capital accumulation, thus closing a virtuous circle of growth that starts once a threshold level of accumulation, necessary to make monitoring viable, has been reached.

IV. Production Sector and Factor Prices

In this section we analyze the behaviour of producers of final and intermediate goods. For the time being, we will take as given the level of employment (L) and the stock of capital (K) in the manufacturing sector, as well as the existing number of old (n) and new (Δ) component varieties (x_s ; $0 \leq s \leq m$). We will derive a reduced form aggregate

production function linking final output to factor use and the number of components, and obtain expressions for equilibrium profits and factor prices as a function of K , n , Δ , and L . These results will be needed below in order to analyze the equilibrium allocation of resources across sectors and the determination of the level of research activity.

We will consider symmetric equilibria in which all component producers of a given type behave in the same way. Hence, there are only two prices and output levels to determine, corresponding to firms with and without market power. Denoting by (p_s, x_s) the price charged by and the output of the s -th component producer, we have:

$$\begin{aligned} (p_s, x_s) &= (p_0, x_0) \quad \text{for } s \in [0, n] \quad (\text{producers of old designs}) \\ &= (p_1, x_1) \quad \text{for } s \in (n, n+\Delta] \quad (\text{producers of new designs}) \end{aligned}$$

Final output is produced by competitive firms. Each firm minimizes the cost of producing the desired level of output Q taking as given the prices $\mathbf{p} = p(s) \Big|_0^{n+\Delta}$ of the different inputs $x(s)$:

$$\text{Min}_{x(s) \Big|_0^{n+\Delta}} \left\{ \int_0^{n+\Delta} p(s)x(s)ds \quad \text{s.t.} \quad Q = \left(\int_0^{n+\Delta} x(s)^\alpha ds \right)^{1/\alpha} \right\}$$

Using the first order conditions for this problem, we obtain the conditional demand for intermediate input $x(s)$ by a firm producing Q units of final output,

$$(7) \quad x_s(\mathbf{p}, Q) = \frac{Qp(s)^{-\varepsilon}}{\left(\int_0^{n+\Delta} p(t)^{1-\varepsilon} dt \right)^{1/\alpha}} = \frac{Qp_s^{-\varepsilon}}{\left(np_0^{1-\varepsilon} + \Delta p_1^{1-\varepsilon} \right)^{1/\alpha}}$$

where $\varepsilon = \frac{1}{1-\alpha} > 0$. Since component demand is linear in output, we can aggregate over all producers of final goods and interpret (7) as the total demand for the s-th component variety as a function of total output Q. Using (7), we obtain the firm's cost function:

$$(8) \quad C(\mathbf{p}, Q) = \left(np_0^{1-\varepsilon} + \Delta p_1^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} Q \equiv c(\mathbf{p})Q.$$

With free entry and perfect competition, the price of final output (p_Q) must be equal to its unit cost, i.e. $p_Q = c(\mathbf{p})$. Normalizing p_Q to 1 for all periods, we have, in equilibrium

$$(10) \quad np_0^{1-\varepsilon} + \Delta p_1^{1-\varepsilon} = 1$$

and substituting (10) into (7):

$$(11) \quad x_s(p_0, p_1, y) = Q p_s^{-\varepsilon}$$

Consider now the behaviour of component producers. Since they all share the same constant returns technology, cost minimization implies a common capital-labour ratio that we will denote by z. Thus,

$$(12) \quad \frac{k_1}{l_1} = z = \frac{k_0}{l_0}$$

and we can write, for any intermediate producer s,

$$(13) \quad x_s = k_s^\gamma l_s^{1-\gamma} = l_s z^\gamma$$

Competitive firms ($s \in [0, n]$) choose z to maximize profits per worker,

$$\text{Max}_z p_0 z^\gamma - Rz - w$$

yielding

$$(14) \quad R = \gamma p_0 z^{\gamma-1}$$

and earn zero profits in equilibrium. Thus

$$(15) \quad w = p_0 z^\gamma - Rz = (1-\gamma)p_0 z^\gamma$$

and the price they charge (p_0) is equal to the unit cost of production.

Producers of patent-protected goods ($s \in [n, n+\Delta]$) have the same unit costs of production as their competitive rivals (p_0) but enjoy some degree of market power. Each producer sets his own price so as to maximize profits taking as given factor prices (i.e. unit costs, p_0), the prices charged by all his competitors, and the market demand schedule for his product given by (7):

$$\text{Max}_p \Pi = p_s x_s - p_0 x_s = (p_s - p_0) x_s(p_s, p, Q) \quad \text{where } x_s(p_s, p, Q) = \frac{Q p(s)^{-\varepsilon}}{\left(\int_0^{n+\Delta} p(t)^{1-\varepsilon} dt \right)^{1/\alpha}}$$

Facing a constant-elasticity demand curve, monopolistic component producers apply a constant markup over cost. It is easy to check that the optimal price is given by

$$(16) \quad p_s = p_1 = \frac{p_0}{\alpha}, \quad \text{for all } s \in (n, n + \Delta], \quad (\alpha < 1)$$

and that each firm earns profits equal to

$$(17) \quad \pi_1 = (p_1 - p_0)x_1 = \frac{1-\alpha}{\alpha} p_0 x_1$$

The relative output levels of the different component producers can be determined from the ratio of their prices. Using the demand function (11) we find

$$\frac{x_1}{x_0} = \left(\frac{p_0}{p_1} \right)^\varepsilon = \alpha^\varepsilon \equiv \theta < 1 \quad \Rightarrow \quad (18) \quad x_1 = \theta x_0$$

i.e. monopolistic firms produce less than their competitive rivals in order to boost prices above marginal cost. From the supply side, we know that output per worker is the same in both types of firms, implying that the ratio of employment levels is the same as the ratio of outputs:

$$x_1 = l_1 z^\gamma \quad \text{and} \quad x_0 = l_0 z^\gamma \quad \Rightarrow \quad l_1 = \theta l_0$$

Finally, the sum of factor inputs by the different firms must equal total factor use in the manufacturing sector. (We can think of this as a pseudo-market clearing condition, since total factor use in the sector is endogenous). Hence,

$$nl_0 + \Delta l_1 = L \Rightarrow (n + \theta\Delta)l_0 = L \Rightarrow (20) \quad l_0 = \frac{L}{(n + \theta\Delta)}$$

and

$$nl_0z + \Delta l_1z = (n + \theta\Delta)l_0z = Lz = K \Rightarrow (21) \quad z = K/L$$

(i.e. since all firms have the same capital labour ratio, z is simply the aggregate capital-labour ratio in the sector). Using (20) and (21), we can solve for x_0 ,

$$(22) \quad x_0 = l_0z^\gamma = \frac{l}{n + \theta\Delta} \left(\frac{K}{L} \right)^\gamma = \frac{K^\gamma L^{1-\gamma}}{n + \theta\Delta}$$

Finally, we obtain p_0 from (10) and (16),

$$(23) \quad p_0 = \left(n + \Delta \frac{\theta}{\alpha} \right)^{(1-\alpha)/\alpha}$$

and recover p_1 and x_1 from (16) and (18).

We can now reconstruct a reduced-form aggregate production function relating final output to input use and derive expressions for factor prices as a function of input stocks and the number of components of each type. Substituting (18) into (17):

$$(24) \quad \pi_1 = \frac{1-\alpha}{\alpha} p_0 \theta l_0 z^\gamma$$

Next, the value of total output must be equal to total expenditure on components (profits are zero in the final goods sector). Thus, using (18) and (13):

$$(25) \quad Q = np_0x_0 + \Delta p_1x_1 = \left(1 + \frac{\theta\Delta}{\alpha n} \right) np_0x_0 = \left(1 + \frac{\theta\Delta}{\alpha n} \right) np_0l_0z^\gamma$$

Using (14), (15), (24) and (25), it is easy to see that

$$(26) \quad w = \frac{(1-\gamma)Q}{\left(1 + \frac{\theta\Delta}{\alpha n}\right)nl_0} \quad R = \frac{\gamma Q}{\left(1 + \frac{\theta\Delta}{\alpha n}\right)nl_0 z} \quad \pi_1 = \frac{(1-\alpha)\theta Q}{\alpha\left(1 + \frac{\theta\Delta}{\alpha n}\right)n}$$

Finally, substituting (22) and (23) into (25):

$$(27) \quad Q = \frac{\left(1 + \frac{\theta\Delta}{\alpha n}\right)^{1/\alpha}}{\left(1 + \frac{\theta\Delta}{n}\right)} n^{(1-\alpha)-1} K^\gamma L^{1-\gamma} = \frac{\left(1 - \frac{\Delta}{m}(1-\theta^\alpha)\right)^{1/\alpha}}{1 - \frac{\Delta}{m}(1-\theta)} m^{(1-\alpha)-1} K^\gamma L^{1-\gamma}$$

The reduced form aggregate production function displays constant returns in K and L for a given number of component varieties, m, and is increasing in m, capturing the idea that specialization may yield increasing returns. The first term, a complicated function of Δ/m , captures the fact that the asymmetric behaviour of the two types of component producers tends to reduce output, since the most efficient way to produce final goods involves the same quantity of all inputs.

V. Financial Sector and Contracts with Innovators

In order for the economy we have just described to function smoothly, financial markets must accomplish two things. One is channeling savings from workers to firms for use as capital in production; the other is providing some insurance so that risk-averse individuals will be willing to undertake risky research projects. The first involves only riskless production loans and therefore poses no special difficulties. The second can also be achieved, in the absence of transactions costs, through unintermediated securities markets, but not always efficiently. This is the reason why intermediaries emerge in this model.

Let us, for the time being, rule out the possibility of monitoring. Then, constrained-optimal allocations can be implemented through the direct sale of securities

which mimic the incentive compatible contracts characterized below. Such securities must specify payments contingent on publicly observable events and provide incentives for entrepreneurs to exert effort. As we will see, this requires innovators to receive some payment (y_G) when their project is successful, and a lower, but strictly positive, payoff (y_B) when it fails. Such a payments scheme could be implemented through the direct sale by entrepreneurs, at price y_G , of (perfectly divisible) securities which entitle the holder to the resulting monopoly profits when the project succeeds, and to a partial rebate from the issuer equal to $y_G - y_B$ when it fails. Savers would then hold a diversified portfolio of such securities yielding a certain return equal, in equilibrium, to the interest rate on riskless loans.

When we allow for the existence of a monitoring technology, agents may find it worthwhile to hold relatively few securities and monitor their issuers. This situation, however, is likely to involve a double inefficiency: monitoring costs will be duplicated, and agents who invest only on their own behalf will not be fully diversified, for they would not find it worthwhile to monitor projects in which they hold an infinitesimally small stake. Since both savers and entrepreneurs are risk averse and would bear some risk in this situation, both will require an expected return higher than that available to them through safe options -- one in order to hold risky securities rather than a riskless loan, and the other in order to undertake an uncertain research project rather than hold a safe job in the industrial sector. In equilibrium, this is only sustainable if monopoly profits are "high," i.e. if the level of innovative activity is "low." In such circumstances, however, positive profits can be earned by an agent who holds a perfectly diversified portfolio and specializes in monitoring, for he avoids the duplication of monitoring costs and can, moreover, offer a lower return to both sides in exchange for better insurance terms. Hence, under certain conditions, intermediaries will emerge endogenously. If there is free entry into the sector, competition among banks will eventually drive profits down to zero but, in the process,

the required return on research projects falls, leaving us, in equilibrium, with a rate of innovation higher than the one we would observe in an economy where intermediaries are exogenously excluded.

For the sake of concreteness, we will assume from now on that all financial transactions are conducted through intermediaries which we will call banks. (We should keep in mind, however, that equilibrium allocations which involve no monitoring can also be supported by alternative institutional arrangements). Banking will be assumed to be a competitive industry with free entry. Each bank has access to deposits at the market-determined interest rate, and holds a perfectly diversified portfolio of production loans to firms and state contingent contracts negotiated with would-be innovators.

The remainder of this section deals with the optimal design of such contracts and their comparative statics with respect to factor prices. Recall that an entrepreneur pays an entry cost of $1-\delta$ units of his labour time. If he exerts high effort (spends all his time on research), he succeeds and produces bn designs for new intermediate goods with probability $p_H = p > 0$. If he shirks, however, he has a zero probability of success ($p_L = 0$) but earns outside income δw . Hence, the probability of success increases with effort ($p_e, e = H, L$). Successful bank-researcher pairs then establish new firms and earn monopoly profits equal to $bn\pi_1$, while unsuccessful ones earn zero revenue. The optimal contract maximizes expected bank profits subject to the appropriate participation and incentive compatibility constraints for entrepreneurs. Since bank profits will be at most zero if agents shirk, contracts will always induce high effort. If entrepreneurs' actions are freely observable banks can condition payments on them and the optimal contract adopts a very simple form. If effort can be observed only imperfectly through the use of a costly monitoring technology, however, things are slightly more complicated, as contracts will now have to specify the intensity of monitoring in addition to a schedule of payments contingent on jointly observable events. Banks will seek the combination of incentives and

monitoring which minimizes the cost of inducing high effort for given factor prices. We will show that under reasonable assumptions monitoring intensity increases as labour becomes more expensive relative to capital. This result provides a link between factor accumulation and financial variables. Its implications in general equilibrium will be analyzed in later sections.

V. A. Observable Effort

As a benchmark we first characterize the optimal contract when banks can freely observe both the agent's effort level and the success or failure of his project. Under such conditions, a contract is a schedule of payments contingent on both events: $\{y_{eO}; e = H, L \text{ and } o = G, B\}$, where "e" denotes the effort level (High or Low) and "o" the outcome of the project (Good or Bad). Taking as given the wage and interest rates, the optimal contract maximizes expected bank profit subject to the participation constraint that the agent's expected utility exceed its reservation level, given by the utility of a worker in the industrial sector, U_w . As noted above, contracts must induce high effort. Hence, the expected surplus ($pbn\pi_1$) is given, and the bank's problem reduces to that of minimizing the expected cost of the contract. Dropping the e subscript, this may be written:

$$C_0(w) = \min_{y_G, y_B} py_G + (1-p)y_B \quad s.t. \quad EU_H > U_w \Leftrightarrow p \ln y_G + (1-p) \ln y_B \geq \ln w$$

Graphically, the bank takes as given the indifference curve in the plane (y_G, y_B) yielding expected utility U_w , and seeks the lowest isocost compatible with it. Bank isocosts are straight lines with slope $-\frac{1-p}{p}$ while indifference curves are convex and

have slope $\left. \frac{dy_G}{dy_B} \right|_{IC} = -\frac{(1-p)y_G}{py_B}$. Hence, indifference curves and bank isocosts have the

same slope at the certainty line, and the optimal contract (y_G^*, y_B^*) corresponds to a

tangency point on the 45° line. In words, since agents are risk averse and banks are effectively risk neutral, optimal contracts involve complete insurance; that is $y_G^* = y_B^* = y^*$. The participation constraint then requires $y^* = w$. Hence, $C_0(w) = w$ and expected bank profits are given by $E\Pi_0 = pnb\pi_1 - w$.

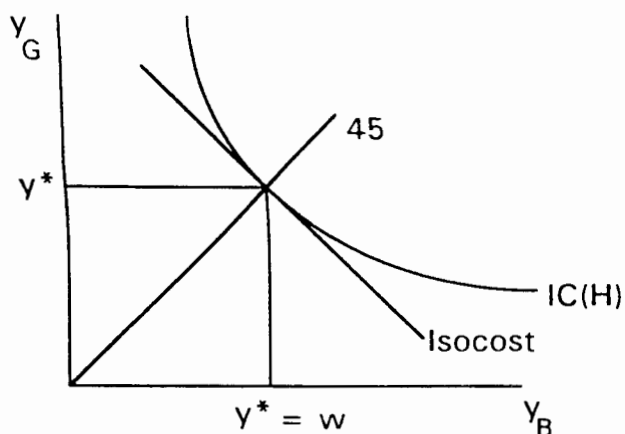


Figure 1: Optimal Contracts with Public Information

V. B. Contracts with Private Information

We now consider a situation in which effort is not freely observable but banks have access to a monitoring technology which, taking $\phi(q)$ units of capital as input,¹¹ reveals the agent's true effort level with probability q , and nothing otherwise. We will find it convenient to break up the contract design problem into two sequential steps. Taking the value of q as given, we will first characterize the payoff schedule which minimizes expected payments to entrepreneurs subject to the appropriate incentive compatibility and participation constraints. The envelope function for this problem, $C(q, w)$ is decreasing in q because better monitoring enables banks to induce high effort while relying less on incentives which interfere with efficient risk sharing. In a second stage, banks trade off this

¹¹ The case where monitoring also takes labour as an input will be discussed below.

marginal cost reduction against the cost of monitoring, choosing q so as to minimize the sum of "labour" and monitoring costs, $C(c, w) + \varphi(q)R$.

V.B. (i) Optimal Payments given q

Let us assume, then, that banks observe effort with probability q , and nothing (N) otherwise. In the first case, payments can be conditioned on the success (G) or failure (B) of the research and on the effort level (y_{eo} ; $e = H, L$; $o = G, B$). In the second, they can be a function only of the outcome of the research project (y_{NG}, y_{NB}).

In principle, then, there are six possible payments. It is easy to see, however, that they reduce to only three, one of which is always zero. First, notice that one payment, y_{LG} , will never be made, since projects always fail when agents shirk. Second, it is clearly optimal to pay the same amount in all events which have positive probability only when agents exert high effort, for anything else would introduce unnecessary risks for the agent without adding to his incentives. Thus $y_{HG} = y_{HB} = y_{NG} \equiv y_H$. Finally, the contract will specify the lowest possible payment to detected shirkers (y_{LB}) in order to discourage such behaviour. In fact, if fines are allowed, the optimal value of y_{LB} is negative and the first best can be implemented.¹² It seems more realistic to assume, however, that the worst thing banks can do to lazy researchers is not to pay them, so we constrain y_{LB} to be non-negative --a constraint which will clearly be binding.

Thus, it remains to determine only two payments, which we will call $y_H (= y_{HG} = y_{HB} = y_{NG})$ and $y_B (= y_{NB})$. An agent who exerts high effort earns the first payment with probability $1-(1-p)(1-q)$, --that is, in all cases except when the bank does not observe

¹² Notice that it is enough to set $y_{LB} = -\delta w$; then, shirkers who are caught have zero net income and minus infinity utility. Since no agent will embark on a course of action which yields this outcome with positive probability, the mere threat of such punishment will suffice to prevent shirking whenever there is some chance of detection. As a result, the contract can specify complete insurance, which is the cheapest way to satisfy the participation constraint.

effort and the project fails-- while a shirker earns a total (including outside) income of $y_H + \delta w$ if he is not detected (with probability $1-q$) and just δw if he is caught.

The optimal payment schedule thus solves

$$C(q, w) = \underset{y_H, y_B}{\text{Min}} [1 - (1-p)(1-q)] y_H + (1-p)(1-q) y_B$$

subject to the constraints that the expected utility of a hard working researcher weakly exceed both those of an industrial worker (participation), and a shirker (incentive compatibility constraint); that is:

$$(P) EU_H \geq U_w : [1 - (1-p)(1-q)] \ln y_H + (1-p)(1-q) \ln y_B \geq \ln w$$

$$(IC) EU_H \geq EU_L : [1 - (1-p)(1-q)] \ln y_H + (1-p)(1-q) \ln y_B \geq q \ln \delta w + (1-q) \ln (y_B + \delta w)$$

Normalizing all payments by the safe wage, we can write the cost function $C(q, w) = c(q)w$, where

$$C(q) = \underset{\theta_H, \theta_B}{\text{Min}} [1 - (1-p)(1-q)] \theta_H + (1-p)(1-q) \theta_B$$

$$\text{s.t. } (P) [1 - (1-p)(1-q)] \ln \theta_H + (1-p)(1-q) \ln \theta_B \geq 0$$

$$(IC) [1 - (1-p)(1-q)] \ln \theta_H + (1-p)(1-q) \ln \theta_B \geq q \ln \delta + (1-q) \ln (\theta_B + \delta)$$

with $\theta_H = y_H/w$ and $\theta_B = y_B/w$.

Figure 2 illustrates the shape of the feasible set. The constraints require that we choose a point on or above the curves labeled P and IC. It is easy to show that IC lies above P if and only if

$$(28) \theta_B \geq B(q) = \delta^{-q/(1-q)} - \delta$$

where $B()$ is an increasing function of q and that

$$(29) B(q) \geq 1 \Leftrightarrow q \geq q_0 \equiv \frac{\ln(1+\delta)}{\ln(1+\delta) - \ln \delta} < 1 \text{ (since } \delta < 1)$$

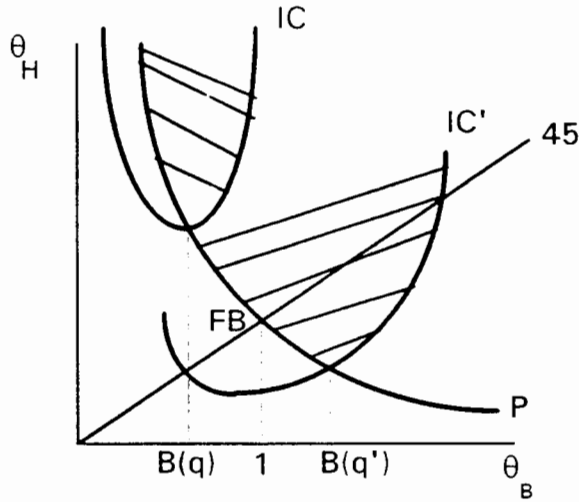


Figure 2: Feasible Contracts

Depending on the value of q , there are two possibilities,¹³ as illustrated in figure 2. For $q' \geq q_0$, IC' and P cross to the right of 1, and the first best contract (FB) is incentive compatible: If the probability that high effort will be observed is high enough, risk-averse agents prefer a certain income of 1 (in wage units) to a lottery which pays $1+\delta$ with probability q and $\delta < 1$ with probability $1-q$. Thus, for $q \geq q_0$, we have equal payments in both states, and the labour cost of the contract is equal to the salary:

$$c(q) = 1 \quad \text{and} \quad \theta_B^* = \theta_G^* = 1$$

For $q \leq q_0$, the incentive compatibility constraint is binding and we have $\theta_H^* > 1 > \theta_B^*$. Under certain assumptions, the lowest attainable isocost curve goes through the intersection of the two constraints, and the optimal contract is given by:¹⁴

$$(30) \quad \theta_B^* = B(q) < 1, \quad \theta_H^* = H(q) \equiv B(q)^{-(1-p)(1-q)/[1-(1-p)(1-q)]} > 1$$

¹³ Possibly three, see the following footnote.

¹⁴ We have not been able to rule out the possibility that the IC curve may be downward sloping and steeper than the isocost curve at the point where it crosses P . In this case, the optimal contract lies somewhere on IC between the intersection and the lowest point on the curve, and the participation constraint is not binding. Equilibrium then involves a form of rationing, as some agents willing to try their luck in research will be unable to find funding, and the number of innovators is determined by the zero profit condition for banks. Equilibrium such as this, if they exist, will tend to disappear with high values of q (i.e. with capital accumulation) and, in any event, do not change the thrust of the story. To avoid further complications, we will rule out this possibility. A sufficient (but not necessary) condition for the solution to be the one given in (30) is $\delta \leq p$. This ensures that IC is upward sloping at the intersection with P for all $q \geq 0$.

Figure 3 illustrates shows the optimal payments and the expected cost of the contract, which can be read off the intersection of the corresponding isocost with the certainty line. Notice that incentive provision now precludes complete insurance. As a result, the expected labour cost of the contract now contains a risk premium over the safe wage, i.e. $c(q) > 1$.

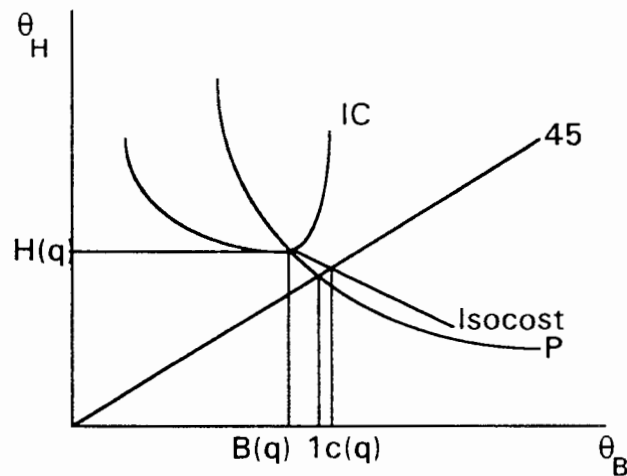


Figure 3: Optimal Payments with Private Information

Figure 4 shows how the optimal payments change with q : as monitoring becomes increasingly precise, the lower payment increases and the higher one falls (more than proportionately). As we are getting closer to complete insurance case, the risk premium required to meet the participation constraint falls, reducing the expected labour cost of the contract. Substituting the optimal payment functions back into the objective function, we obtain the minimum direct cost of the contract as a function of q ,

$$C(q, w) = c(q)w, \text{ where } c(q) = \begin{cases} [1 - (1-p)(1-q)] H(q) + (1-p)(1-q) B(q) & \text{for } q \leq q_0 \\ 1 & \text{for } q > q_0 \end{cases}$$

Direct computation then yields, after some laborious sign checking, the following result, which tells us that the "wage" cost of the optimal contract is a decreasing and convex

function of q (see figure 5). Better monitoring reduces the need for distorting incentives and hence the expected cost of the contract, but does so at a decreasing rate.

o **Proposition 1:** Expected payments to entrepreneurs under the optimal contract are given by $C(q, w) = c(q)w$, where $c()$ is a decreasing and convex function with $c'(q_0) = 0$ and $c'(0) < 0$ and bounded.

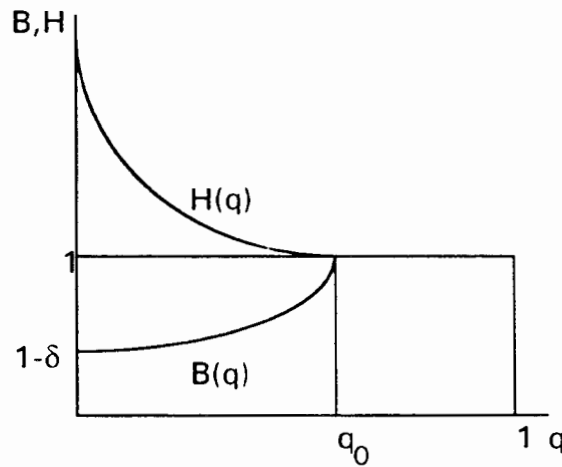


Figure 4: Optimal payments as a function of q

V.B. (ii) Optimal Monitoring Intensity

The optimal value of q minimizes the sum of monitoring costs and expected payments to entrepreneurs. Assuming for concreteness that the monitoring technology is linear in capital, so that monitoring costs are given by $\varphi(q) = \lambda q R$, and writing $r = R/w$ for the rental/wage ratio, the expected total cost of the optimal contract is given by:

$$\Phi(R, w) = \text{Min}_q \{c(q)w + \varphi(q)R\} = w(\text{Min}_q \{c(q) + \lambda q r\}) = \phi(r)w$$

Since $c()$ is convex and λq linear in q , the first order condition

$$\begin{aligned} -c'(q) &\leq \lambda r && \text{with equality if } q > 0 \\ q &\geq 0 && \text{with equality if } -c'(0) < \lambda r \end{aligned}$$

is sufficient for a minimum. Figure 6 illustrates the determination of the optimal level of monitoring and its comparative statics. At an interior solution the principal sets q so as to equate the marginal reduction in expected payments due to increased monitoring with the

marginal cost of the latter, assumed constant. A decrease in r lowers the cost of monitoring relative to incentive provision and therefore increases the optimal q . Since $c'(0)$ is bounded, corner solutions may arise: for a sufficiently high value of r , it is optimal not to monitor at all. On the other hand, $c'(q_0) = 0$ implies $q^* \leq q_0$, and it is clear that $q^* \rightarrow q_0$ as $r \rightarrow 0$. Finally, the function $f()$ (the multiplicative risk premium) is increasing in r and concave,¹⁵ with $\phi \rightarrow 1 = c(q_0)$ as $r \rightarrow 0$.

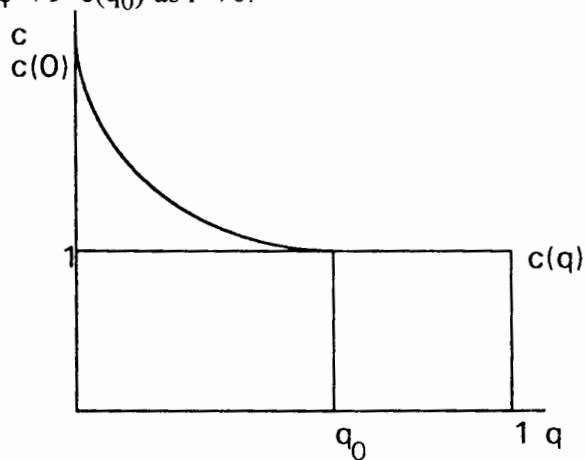


Figure 5: Labour Cost of the Contract as a Function of Monitoring Intensity

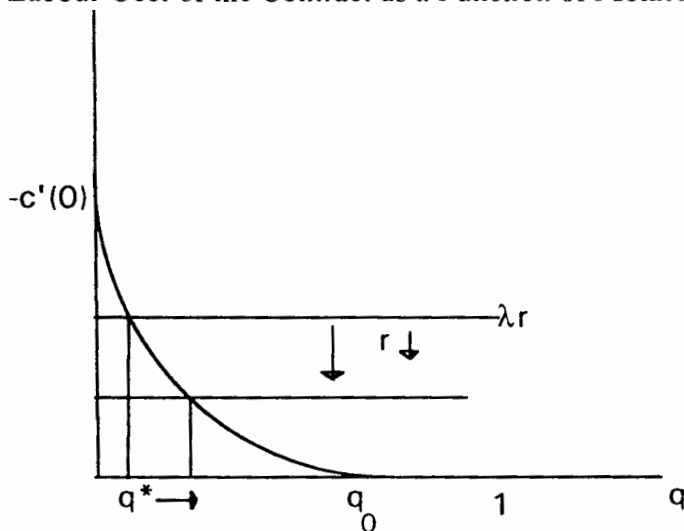


Figure 6: Determination of the Optimal Level of Monitoring

¹⁵ By the envelope theorem $\phi'(r) = \lambda q^* > 0$, and $\phi''(r) = \lambda q'(r) < 0$.

V.C. Optimal Monitoring and Capital Intensity

Our results so far imply that the optimal intensity of monitoring is a simple function of factor prices. It is now easy to proceed one step further and relate the structure of financial contracts to factor endowments. We will find it convenient to write the (minimized) cost of a monitoring contract and the optimal value of q as functions of the capital intensity in production, z , rather than the rental/wage ratio, r . We can see that:

$$r = \frac{R}{w} = \frac{\gamma}{(1-\gamma)z} \quad \text{hence, } r'(z) = \frac{-\gamma}{(1-\gamma)z^2} < 0$$

Abusing notation somewhat, we will write $q^* = q(z)$ and $\phi(z)$. Notice that (at an interior solution)

$$q'(z) = q'(r)r'(z) = \frac{\lambda\gamma}{c''(q^*)(1-\gamma)z^2} > 0$$

$$\phi'(z) = \phi'(r)r'(z) = -\lambda q^* \frac{\gamma}{(1-\gamma)z^2} < 0.$$

Moreover, since $r \rightarrow \infty$ as $z \rightarrow 0$ and $r \rightarrow 0$ as $z \rightarrow \infty$, we have $q^* \rightarrow q_0$ as $z \rightarrow \infty$ and $q^* = 0$ for all z lower than some threshold value, z_0 , defined by

$$-c'(0) = \lambda r_0 \Leftrightarrow -c'(0) = \lambda \frac{\gamma}{(1-\gamma)z_0} \Leftrightarrow z_0 = \lambda \frac{\gamma}{c'(0)(1-\gamma)}$$

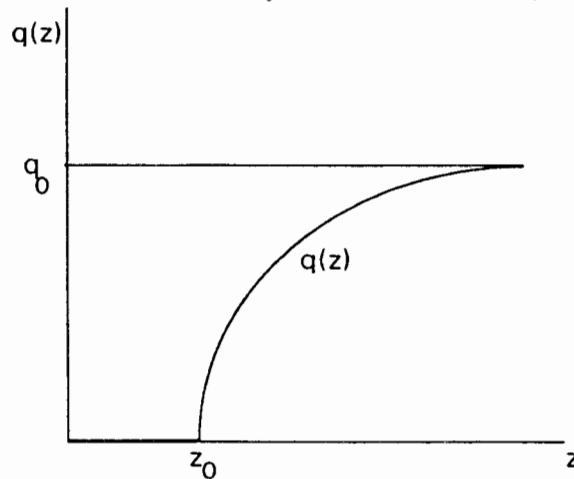


Figure 7: Optimal Level of Monitoring as a Function of Capital Intensity

We summarize some useful properties of the solution and envelope functions for this problem in the next proposition.

o **Proposition 2:** The optimal level of monitoring q^* is an increasing function of z with $q^* \rightarrow q_0$ as $z \rightarrow \infty$ and $q^* = 0$ for all $z \leq z_0 = \frac{\lambda\gamma}{c'(0)(1-\gamma)}$

The minimum expected cost of the contract may be written $\Phi(z) = \phi(z)w$ where the function $\phi(z)$ is decreasing, with $\phi(z) = c(0) > 1$ for all $z \leq z_0$, and $\phi(\infty) = 1$.

Since z can be expected to be an increasing function of the total stock of capital, the proposition implies that capital accumulation makes monitoring more attractive and leads to an increase in the efficiency of the financial system. At the same time, an increase in z lowers $\phi(z)$, the total cost of attracting risk-averse agents away from safe employment, and should therefore yield a higher rate of innovation.

Hence, proposition 2 is an important part of the story. It may therefore be worth it to pause for a second to examine more closely what is driving this result and whether or not it is as robust to the specification we have chosen. Notice that the total cost of a monitoring contract,

$$TC_m(q) = c(q)w + \phi(q)R$$

is the sum of two components, a monitoring cost proportional to the interest factor, and an expected payment to entrepreneurs which is proportional to the wage rate in manufacturing. Clearly, a decrease in R relative to w makes monitoring more attractive relative to incentive provision. What matters, then, is R/w , the rental/wage ratio. Under our technological assumptions, R/w turns out to be a decreasing function of z alone. In general, things are not quite that simple, but it is true that the rental/wage ratio will tend to fall with capital accumulation (and possibly also with technical progress).

A second thing to worry about is that we have assumed the monitoring technology uses only capital as an input, whereas research uses only labour. At first sight, it might look as if the result turns on the relative factor intensities of the research and labour technologies. This is not the case, however. The main reason is that $c(q)w$ is the expected cost of a contract designed to "lure researchers away" from alternative occupations that pay a safe salary. Hence, this component of cost is the result of adding an appropriate risk premium to an agent's opportunity cost, given by the wage rate. The addition of capital to the research technology would not change this: the bank would simply have to supply the necessary capital in addition to paying the researcher, but the contract with the latter, and the degree of monitoring would not be affected. On the other hand, total bank profits would change, and cheaper capital would, other things equal, increase the equilibrium level of research activity reinforcing the effects working through the monitoring channel.

On the other hand, the introduction of labour in the monitoring technology (as would be reasonable to do) will tend to weaken the feedback effect of capital accumulation on the intensity of monitoring, but it will not disappear unless we make the extreme assumption that monitoring requires no capital whatsoever. For example, with a Cobb-Douglas monitoring technology of the form $q = Bk^a l^{1-a}$, the cost of monitoring is given by

$$M(q, R, w) = \frac{q}{(1-a)} w \left(\frac{1-a}{a} \right)^a = wqm(r)$$

and, provided $a \neq 0$, we can still factor out the wage to write the bank's problem

$$\Phi(R, w) = \text{Min}_q \{c(q)w + \phi M(q, R, w)\} = w \{ \text{Min}_q c(q) + qm(r) \} = \phi(r)w$$

yielding a solution function with the same qualitative properties as before.

VI. Allocation of Resources between Sectors

In this section we study the equilibrium allocation of given stocks of capital (Z) and labour (1) between sectors at a given point in time. In equilibrium, i) banks and households optimize, ii) free entry implies zero profits for banks and other competitive firms, iii) agents are indifferent between occupations whenever any research is undertaken and iv) factor markets clear. The optimization and indifference conditions are already embedded in the expressions for factor prices and the characterization of optimal contracts obtained above. Thus, we are left with three additional equilibrium conditions:

i) Bank profits are zero, implying the expected cost of a contract must be equal to expected monopoly profits:

$$(31) E\Pi = 0 \Leftrightarrow pbn\pi_1 = \phi(z)w$$

ii) The labour market clears. i.e. employment in research and manufacturing adds up to one, implying that the rate of innovation is given by

$$(32) \frac{\Delta}{n} = (1-L)pb$$

iii) Total demand for capital is equal to total manufacturing employment, L , times the common capital/labour ratio in production, z , plus the demand for monitoring capital, given by $(1-L)\lambda q(z)$. In equilibrium this quantity must be equal to the aggregate capital stock, Z :

$$(33) Lz + (1-L)\lambda q(z) = Z$$

We will show that, as may be expected, the partial equilibrium correlation between capital intensity in production on one hand and the optimal level of monitoring and the cost of the optimal financial contract on the other, translates into a similar correlation between the aggregate capital stock and the two financial variables. Hence, capital accumulation does indeed lead to increased monitoring and, through an increase in the ability of intermediaries to provide efficient risk sharing, to a decrease in the expected cost

premium of innovators' contracts. Competition among banks, however, ensures that this cost reduction leads to improved terms for entrepreneurs, rather than increased bank profits. As a result, the equilibrium level of employment in R&D will increase with the stock of capital, yielding a higher rate of productivity growth which, in turn, leads to higher incomes and faster capital accumulation.

Using the expressions for w and π_1 given in (26) we obtain

$$\frac{\pi_1}{w} = \frac{(1-\alpha)\theta L}{\alpha(1-\gamma)(n+\theta\Delta)}$$

which shows that an increase in manufacturing employment (i.e. a reduction in R&D employment) increases profits relative to wages. Substituting this expression in the condition for zero bank profits (31) and using (32), we obtain the following relation between L and z :

$$(34) \quad L = L_1(z) \equiv \frac{1 + \frac{1}{\theta b p}}{1 + \frac{(1-\alpha)}{\alpha(1-\gamma)\phi(z)}}$$

Given z , and therefore the expected cost premium of the research contract over the wage, measured by $\phi(z)$, $L_1()$ gives the level of manufacturing employment such that bank profits are zero and the labour market clears with agents indifferent between occupations. An increase in z lowers the expected cost premium of the contract over the wage and enables banks to offer better terms to entrepreneurs for a given wage rate and profit levels. In order for equilibrium to be maintained, labour must flow from manufacturing to research until the balance between wages and profits is restored and agents are again indifferent between occupations. Hence, $L_1()$ is a decreasing function of z .

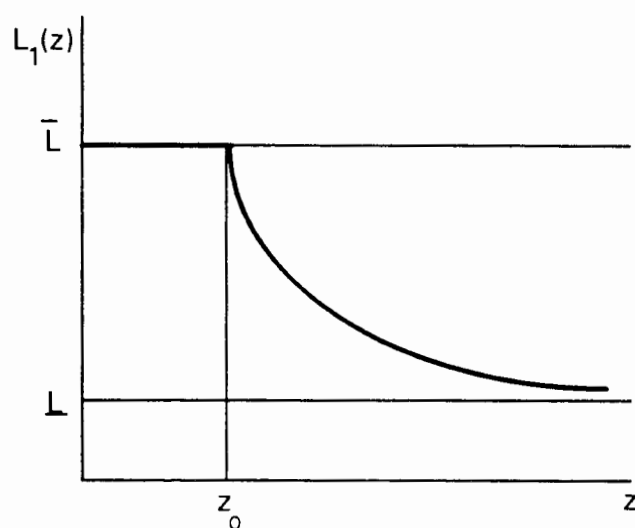


Figure 8: Equilibrium Industrial Employment as a Function of z

Recall that $\phi(z) = c(0) > 1$ for all $z \leq z_0$, and $\phi(\infty) = 1$; thus, $L_1(z)$ ranges between two positive values, $\bar{L} = L_1(z_0)$ and $\underline{L} = L_1(\infty)$ as shown in figure 8. For concreteness, we will assume that parameter values are such that $\bar{L} < 1$, i.e. that there is some employment in research even when z is too low to permit monitoring.¹⁶

A second relation between z and L emerges from the capital market clearing condition,

$$(33) \quad Lz + (1-L)z\lambda q(z) = Z \Rightarrow z = \frac{Z - (1-L)\lambda q(z)}{L}$$

¹⁶ Notice that $1-L = \frac{1-\alpha}{\alpha(1-\gamma)\phi(z)} - \frac{1}{\theta p}$. Thus, $1-L > 0$ iff $\theta p > \frac{\alpha(1-\gamma)}{\theta(1-\alpha)}\phi(z)$. That is, we have an interior

equilibrium with positive R&D iff the expected productivity of labour in research is sufficiently high relative to the cost premium of the financial contract. We are assuming that this condition holds for $\phi(z) = c(0)$ and therefore for all z . If this were not the case, we could have corner equilibria with $L = 1$ and no R&D, particularly at low z 's. This raises the possibility of development traps for economies where research is not highly productive, or for initially poor economies which may get stuck at a low-level steady state before they can accumulate enough capital for research and monitoring to start.

This expression implicitly defines a function of the form $z = z_k(L, Z)$. We observe that

$$z_k(L, Z) = \frac{Z - (1-L)\lambda q(z)}{L} \leq \frac{Z}{L} = \bar{z}(L, Z)$$

where $\bar{z}(1, Z) = Z$ and $\bar{z}(\underline{L}, Z) < \infty$. Moreover, in the region where $z \leq z_0$, there is no monitoring, so $q(z) = 0$, implying that $z_k(L, Z)$ coincides with $\bar{z}(L, Z)$, and $\frac{\partial z_k(L, Z)}{\partial L} < 0$ when evaluated at z_0 . Thus, even though $z_k(\cdot)$ may not be decreasing as a function of L throughout its domain, its graph is broadly as shown below: it is downward sloping for $z \leq z_0$, crosses a vertical line through z_0 just once, and the horizontal line through \underline{L} at a value of z between z_0 and Z/\underline{L} . We can conclude therefore that the graph $z_k(L, Z)$ crosses that of $L_1(z)$ from above at least once. Since an increase in Z shifts the graph of $z_k(\cdot)$ to the right, an increase in the capital stock yields a higher z and a lower L whenever both lines cross just once.

There are two possibilities, depending on the relative positions of z_0 and Z/\bar{L} . If $Z < \bar{L}z_0$, then the equilibrium corresponds to a point on the flat portion of $L_1(z)$ with $L^* = \bar{L}$ and no monitoring. Otherwise, we have $L^* < \bar{L}$ and $q^* > 0$. We have, then:

o **Proposition 3:** For any given stock of capital, Z , there exists at least one equilibrium allocation of resources across sectors. There also exists a level of capital, $Z_0 = \bar{L}z_0$ such that

- For $Z \leq Z_0$, there is a corner equilibrium with $L^* = \bar{L}$ and no monitoring.
- For $Z > Z_0$, there is an interior equilibrium with $L^* < \bar{L}$ and $q^* > 0$.

If the equilibrium is unique, increases in the capital stock beyond Z_0 lead to a greater intensity of monitoring and a higher level of employment in R&D.

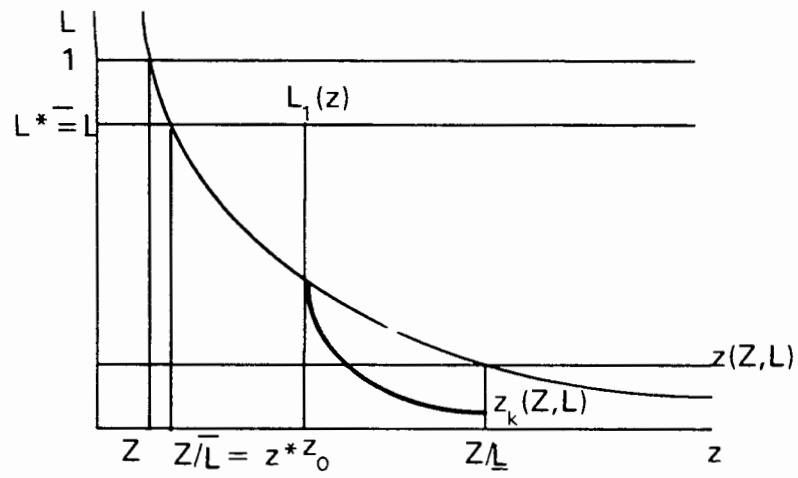


Figure 9: Corner Equilibrium without Monitoring

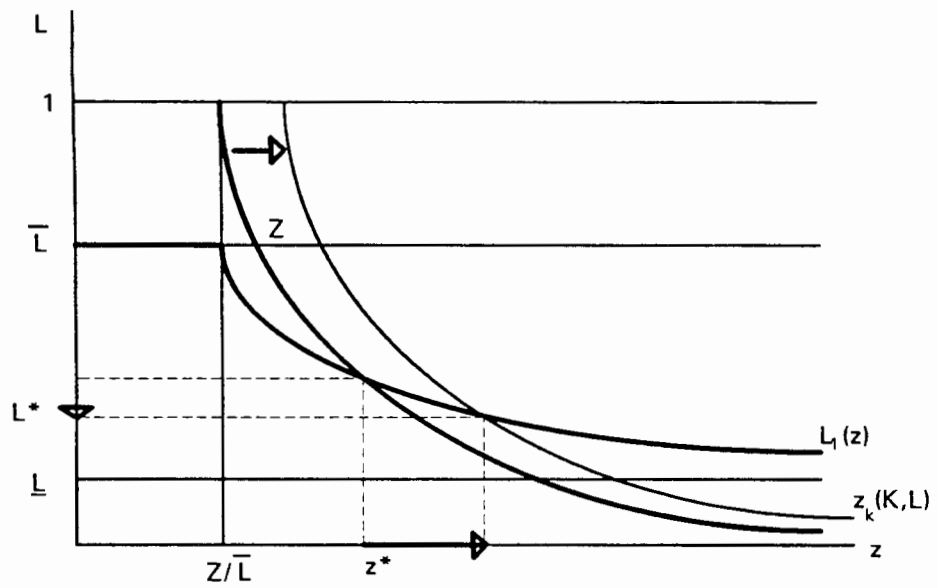


Fig. 10: Interior Equilibrium with Monitoring

VII. Dynamics

There are two sources of change from one period to the next in the model: technological progress induced by R&D, and the accumulation of physical capital through saving. The "rate of innovation" may be measured by

$$(35) \quad \frac{n_{t+1}}{n_t} = 1 + \frac{\Delta_t}{n_t} = 1 + (1 - L_t)pb$$

and the growth of the capital stock is described by

$$(36) \quad Z_{t+1} = sW_t = s \{L_t + (1 - L_t)c(z_t)\}w_t$$

That is, next period's capital stock is equal to the savings of the current young, a fixed fraction s of their first period income. Notice that the total income of young workers is the sum, weighted by employment in each sector, of the industrial salary w and the expected labor cost of the research contracts $c(z_t)w_t$.

All the endogenous variables in these equations are functions of n and Z . Hence, the motion of the system will be described by a two-dimensional system in these variables. Since this system is rather complicated, we will limit ourselves to a partial analysis which is, however, sufficient to give us some idea of the qualitative features of the system's evolution.

For this purpose, we will start by considering what happens in two extreme cases: those of an economy in which there is perfect information, and another one with private information but no monitoring. The second is indeed an equilibrium for a low enough stock of capital, while the first situation is approached asymptotically if capital accumulation proceeds without bound to the point where the interest rental/wage ratio is close to zero.

With public information (p), the cost of research contracts is equal to the wage ($c^p = 1$) and employment in R&D is at its maximum possible value ($L^p = \bar{L}$). With private information and no monitoring (i), on the other hand, we have a large risk premium and

low employment in research ($c^i = c(0) > 1$ and $L^i = \underline{L}$). In both cases, employment levels and the rate of innovation are constant over time, and z is given by Z/L -- all three features which considerably simplify the analysis.

Using,

$$(26) \quad w = \frac{(1-\gamma)y}{\left(1 + \frac{\theta\Delta}{\alpha n}\right)nl_0}; \quad R = \frac{\gamma y}{\left(1 + \frac{\theta\Delta}{\alpha n}\right)nl_0 z}; \quad \pi_1 = \frac{1-\alpha}{\alpha} \frac{\theta y}{\left(1 + \frac{\theta\Delta}{\alpha n}\right)n}$$

$$(27) \quad y = \frac{\left(1 + \frac{\theta y}{\alpha n}\right)^{1/\alpha}}{1 + \frac{\theta\Delta}{n}} n^{(1/\alpha)-1} K^\gamma L^{1-\gamma}$$

the growth rate of income is given by

$$\frac{y_{t+1}}{y_t} = \left(\frac{n_{t+1}}{n_t}\right)^{(1/\alpha)-1} \left(\frac{z_{t+1}}{z_t}\right)^\gamma$$

and that of capital accumulation can be written

$$\frac{z_{t+1}}{z_t} = \frac{w_t}{w_{t-1}} = \frac{y_t}{y_{t-1}}$$

Defining $g_{t+1} = \frac{y_{t+1}}{y_t} g$, we obtain a single difference equation in the growth rate of output:

$$(37) \quad g_{t+1}^j = [1 + (1-L^j)pb]^{(1/\alpha)-1} (g_t^j)^\gamma, \quad j = p, i$$

where g_1^j is fixed by the initial values of n and Z .

Figure 11 displays the phase diagram for (37) for both polar cases and illustrates that the existence of private information tends to lower growth rates through the lower equilibrium level of research activity.

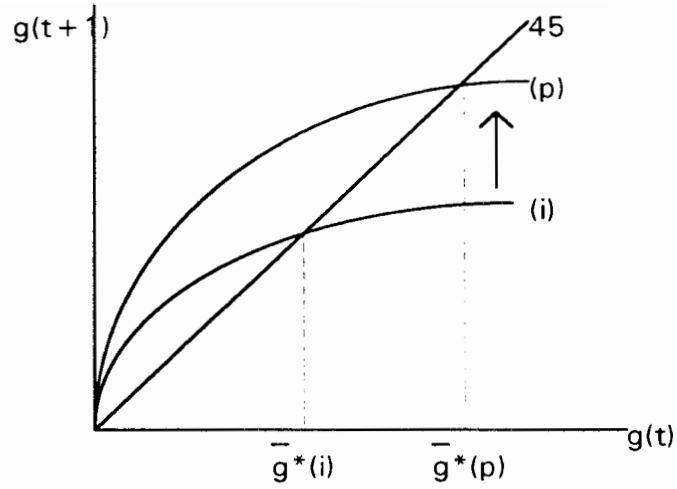


Figure 11: Growth Rates with Public vs. Private Information

We can think of financial deepening as a gradual shifting from the lower to the higher phase line as increased monitoring brings us progressively closer to the full information equilibrium. Given our assumptions concerning parameter values, an initially capital-poor economy with imperfect information starts out with no monitoring and grows along the lower of the two paths described above. Eventually, it accumulates enough capital that monitoring begins to take place (i.e. $Z \geq Z_0$). At this point, the law of motion of the economy becomes more complicated. We have now:

$$(38) \quad Z_{t+1} = s\{L_t + (1 - L_t)c(z_t)\}w_t = s\{L_t + (1 - L_t)c(z_t)\} \frac{(1 - \gamma) \left(1 + \frac{\theta \Delta_t}{\alpha n_t}\right)^{(1/\alpha) - 1}}{1 + \frac{\theta \Delta_t}{n_t}} n_t^{(1/\alpha) - 1} z_t^\gamma$$

It is not possible to reduce this to a neat expression involving only growth rates, but we can show that capital grows without bound (although perhaps not monotonically) and this implies that we asymptotically reach the higher phase line.

Suppose capital accumulation along the lower growth path has proceeded to the point where $Z_t \geq Z_0$; then $z_t \geq z_0$ and since the product of the first two terms in the right hand side of (38) is bounded away from zero, there exists a positive number x such that

$$(39) \quad Z_{t+1} \geq xn_t^{(1/\alpha)-1} z_0^\gamma$$

Now, if $Z_{t+1} \geq Z_t$ we remain in the monitoring zone forever thereafter. However, it may not be so and we could in principle fall back into the no-monitoring region. In that case, however, capital begins to accumulate once more following the no-monitoring law of motion until we eventually have $Z_t \geq Z_0$ again, but now with a larger n . Since n grows without bound, it will eventually be true that $Z_{t+1} \geq Z_t$. Finally, let T be the time at which we cross into the monitoring region for good. Then,

$$Z_{T+\tau} \geq xn_{T+\tau}^{(1-\alpha)-1} z_0^\gamma \geq x(n_T[1+(1-\underline{L})pb]^t)^{(1/\alpha)-1}$$

and, since the last term goes to infinity with t , so does Z .

VIII. Concluding Comments

One of the central implications of the recent growth literature is that the key to sustained growth may lie not so much in a high overall rate of investment as in a country's ability to channel sufficient resources into activities associated with the accumulation of technical knowledge and its incorporation into productive processes. In this paper, we have argued that such "growth promoting" activities have certain peculiarities which interfere with their financing through direct securities markets. In particular, would-be innovators often face greater uncertainty and have a greater informational advantage over outsiders than firms which operate in well established lines of business. As Arrow (1962) has pointed out, this combination of factors interferes with the efficient sharing of the risks associated with innovation, and may have an adverse effect on growth.

In these circumstances, resources do not flow costlessly into the uses where their expected marginal return is highest --as they would in a standard neoclassical setting-- and

there is room for costly institutions which help overcome informational frictions. Hence, financial intermediaries play an important role in the development process as a channel for the flow of funds from savers to innovators. This, however, is only half the story. A growing literature suggests that the key to the emergence of intermediaries lies precisely in informational problems of the type we have emphasized. In fact, the same factors which interfere with the financing of innovation can also generate profit opportunities for agents willing to specialize in the financing and monitoring of entrepreneurs. To the extent that monitoring, like other productive activities, requires resources, there emerges a second link from factor accumulation to finance.

The model we have developed formalizes some of these ideas and provides a framework for analyzing the interaction between real growth and financial development in a context in which both are endogenous. Financial development takes the form of an endogenous increase in the intensity of monitoring in response to factor price changes that accompany "real growth." Increased monitoring, in turn, improves the ability of intermediaries to provide risk pooling services, and stimulates growth by facilitating the flow of resources into innovative activities. Thus, the model generates a positive correlation between income growth and financial deepening which is consistent with the results of a fair amount of empirical work, and may throw some light on the mechanisms which generate it.

Understanding the nature of such links may be important when it comes to policy formulation. If innovation is indeed a crucial engine of growth, and if there are reasons to expect that free markets will not provide sufficient incentives for its optimal provision, then it is certainly important to think about what may be done to increase the flow of resources into such activities. Although we have not introduced policy parameters explicitly, we may perhaps draw some useful policy implications from the analysis.

The economy we have described has two features which tend to make the rate of innovation suboptimally low. One is the existence of technological spillovers --the public good aspect of knowledge emphasized in the recent literature--, the other is the problem caused by the existence of asymmetric information. From the point of view of what to do about them, the two problems are very different: While markets cannot make agents internalize spillovers, they may indeed provide incentives for private initiative to deal efficiently with informational frictions. Given our assumptions, the financial contracts characterized above provide the most efficient feasible mechanism for the sharing of the risks associated with innovation. There are no reasons to expect that governments can do better. Hence, the existence of capital market imperfections arising from informational problems do not necessarily justify active policies in the form of subsidized or directed credit programmes, even in circumstances in which appropriate targets can be easily identified. This does not mean that such policies can never be appropriate, but their need must be based on a careful analysis of the problem one is trying to solve.¹⁷

The existence of positive spillovers, however, would still call for a Pigouvian subsidy to innovation. The model suggests, however, that such subsidies must be carefully designed so as not to interfere with private incentives. Thus, an unconditional subsidy to innovating entrepreneurs will almost certainly increase their number, but it will also have an adverse effect on bank incentives to monitor appropriately, and on the incentives of entrepreneurs to succeed in their projects.

¹⁷ For example, the difficulty of borrowing against a non-collateralizable asset may prevent agents from investing as much as they want in education. Guaranteed student loan programs which provide access to credit, even at market rates, may then have a positive effect, both on efficiency and equity grounds. Coupled with realistic tuition fees, such programmes may also increase students' motivation by forcing them to bear the cost of their education.

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