Financial Innovations and Technological Innovations as Twin Engines of Economic Growth

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Abstract

This paper demonstrates the complementarities between financial and real innovations by developing a parsimonious model of the financial sector that is integrable into a growth model with endogenous technological progress. The financial sector comprises innovators who design new financial products and intermediaries which transform individual savings into funds for productive physical capital investment by firms. In addition, financial intermediaries also act as venture capitalists in financing risky R&D activities with potentially high payoffs. The rate of financial innovation is determined by labor resources devoted to the sector as well as by spillovers from existing financial products. Ultimately, financial innovations lead to long-run growth solely through the technological innovation channel. The intermediary role of the financial sector produces temporary growth effects on the transition path to the steady state. We also analyze the dynamic response of the model economy to financial liberalization and other government policy changes.

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1 Introduction

Is the financial sector a help or hindrance to the real economy? Judging from the media's intensive coverage of the finance industry, the man in the street may be forgiven for believing that the financial sector must somehow matter in creating wealth and sustaining economic prosperity. In the US, the finance industry attracts many of the best and brightest from each cohort of graduating college students. Worldwide enrollment in MBA programs have steadily increased in the last three decades.[1] To many non-financial economists, however, this phenomenon appears detrimental to economic growth as it represents a significant diversion of human capital away from activities that traditional growth theory emphasize as the engines of economic progress, such as scientific research and the engineering of new technologies. Many macroeconomic growth models exclude any meaningful role for the financial sector. In these models, savings by individuals are automatically and effortlessly transformed into productive investment by firms at every point in time. Investment in new plant and machinery then enable increased future production and consumption, especially when production technologies themselves improve through research and development efforts.

In this paper, we argue that the talent drain to the financial sector need not retard growth. While science and engineering graduates become involved in creating technological innovations, their business school counterparts are crafting innovations of a different but no less important nature. Financial innovations are new products and services created by the finance industry (including exchanges and securities firms) to satisfy the growing and ever more diverse needs of its clients, from the smallest private investor to the largest corporation seeking financing in money and capital markets for an ambitious merger or acquisition. Examples of important financial innovations include zero coupon bonds introduced by Merill Lynch and Salomon Brothers in 1982,

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[1] For example, the National Center for Education Statistics reports a quadrupling of enrolment in American MBA programs between 1970 and 2000.

collateralized mortgage obligations introduced by First Boston and Salomon Brothers the following year, and asset backed securities.

In our model, financial innovations serve two purposes. Firstly, financial innovations increase the variety of products offered by financial intermediaries as they mobilize and transform individual savings into funds allocated to firms for productive investment in new physical capital. The increasing array of financial products that are tailored and fine-tuned to the idiosyncratic needs of borrowers and savers, the users and suppliers of financial capital respectively, increases the efficiency of the intermediation process, fueling economic growth by increasing capital accumulation.[2] Secondly, financial innovations include products and services that have a positive impact on the rate of technological progress. The most obvious real-world example is the provision of venture capital services, where financial institutions develop the expertise to identify and fund highly risky research and development projects (most notably in the information technology and biotechnology sectors) with potentially huge future payoffs. Financial innovators and real technological innovators are therefore not simply competitors for scarce human resources, but also potential partners in producing economic growth.

Both of these *channels of growth*, as termed by Levine (1997) in his proposed framework for the study of finance and growth (see Figure 1), are grounded in solid empirical evidence. Benhabib and Spiegel (2000) find that financial development is positively correlated with total factor productivity growth. In particular, a proxy for the overall size of the formal financial intermediary sector (measured as the ratio of liquid liabilities of the financial sector to GDP) and the ratio of the financial assets of the private sector to GDP positively affect growth even after accounting for rates of factor accumulation.[3] In addition, Benhabib and Spiegel also find that the above measures of financial development as well as a variable included to emphasize the risk-sharing and information services provided by banks have positive effects on the rate of physical capital accumulation.[4]

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[2] The assumption of this paper is that financial intermediation turns prior savings into investible funds. There is, however, also a fairly large literature going back to Schumpeter which denies this and points to the banker as "manufacturer of credit".

[3] Both were developed by King and Levine (1993b).

[4] Other empirical studies that find a link between financial development and growth include Rajan

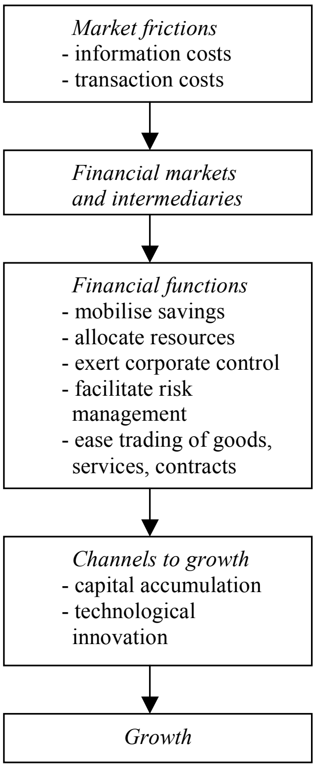

Figure 1: Levine's (1997) Theoretical Approach to Finance and Growth

Our model differs from existing theoretical work on finance and growth in significant ways. Firstly, financial development occurs endogenously as a result of financial innovation. Secondly, while most papers on growth and finance model the financial sector with considerable sophistication, the accompanying growth model is often rudimentarily sketched out.[5] We take the opposite approach: our parsimonious but meaningful model of the financial sector is embedded in a full-scale growth model with endogenous technological progress. Financial innovations spur technological progress but their creation drains precious resources away from the R&D activities that engender technological progress. Our approach suggests an optimal size of the financial sector, and permits a rich overview of the resource flows between various sectors (final goods, intermediate goods, real R&D, and financial) of the macroeconomy as well as the dynamic responses of these flows to perturbations in parameters characterizing preferences and

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and Zingales (1996), Demetriades and Hussein (1996), King and Levine (1993b), Berthelmy and Varoudakis (1996), and Levine and Zervos (1998).

[5] An exception is Morales (2003), which we discuss in the next paragraph.

technologies in each sector.[6]

By contrast, existing papers on the 'finance-growth nexus' focus primarily on the microeconomics underlying the processes through which financial intermediaries, by fulfilling the *functions of financial systems* in Levine's parlance, affect the rate of growth of production. For example, the impact of financial development on growth through its effect on borrowing constraints is studied by Bencivenga and Smith (1993), Japelli and Pagano (1994), and de Gregorio (1996).[7] Bencivenga and Smith (1991), and Obstfeld (1994) study the impact of financial development on growth through its facilitation of risk management. Acemoglu and Zilibotti (1997) look at savings mobilization, while King and Levine (1993b) construct a model in which financial systems evaluate prospective entrepreneurs and mobilize savings to finance the most promising productivity-enhancing activities.[8] Similarly, Saint-Paul (1992) looks at how capital markets facilitate the adoption of more specialized and productive technologies. A very recent paper by Morales (2003) incorporates financial intermediaries that reduce a researcher's moral hazard in an endogenous growth model with R&D.[9] However, the financial sector does not compete with the R&D sector for human capital. In addition, the paper focuses not on dynamic resource flows but on the welfare effects of taxes on capital, financial services and R&D.

There exists a separate strand of literature in economic theory that analyzes models

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[6] Santomero and Seater (2000) also derive the optimal size of the financial sector in the context of a growth model. However, their simple AK growth model cannot generate transition dynamics. In addition, because the model is solved only from a social planner's perspective, they cannot analyze the effects of financial regulations.

[7] In many of these models, financial development increases capital accumulation, which in turn raises the long-run growth rate via a 'learning-by-doing' externality a la Romer (1986).

[8] However, King and Levine (1999) do not model the impact of financial development on capital accumulation nor are they able to capture the dynamic resource flows between the financial and real technological sectors arising from shocks to preferences or technologies.

[9] In this paper, financial intermediaries choose the intensity of monitoring researchers, whose productivity is increasing in this intensity as they are assumed to dislike exerting effort in research. This assumption seems unrealistic since, in the real world, researchers in information technology and biotechnology are often so obsessed with their work that they neglect health and family. Certainly, few IT entrepreneurs choose venture capitalists based on the probability of slacking off and getting away with it.

of financial innovation and security design, with an excellent survey by Duffie and Rahi (1995). General equilibrium models of financial innovation emphasizing the 'spanning' role of securities include those by Allen and Gale (1989), Chen (1995), and Pesendorfer (1995). Other models such as Demange and Laroque (1995) incorporate a variable financial structure that exploit parametric assumptions of normality and constant absolute risk aversion. However, this literature does not deal with the implications of financial innovation on macroeconomic growth.

This paper is organized as follows: the next section discusses the nature of financial innovations and the ways in which they resemble yet differ from technological innovations. Section 3 describes our proposed financial sector. Section 4 links the financial sector to the rest of the economy, and explains the microeconomic foundations of the resulting three-sector endogenous growth model. Section 5 examines the social planner and competitive solutions to this model, and explores the comparative statics associated with its steady state as well as the transitional dynamics away from its steady state. In section 6, we use the model to examine the impact of financial liberalization, changes in accounting practices or alterations to the tax code. Section 7 concludes.

2 Financial Innovations

We first present a short discussion on financial innovations.[10] As Duffie and Rahi (1995) point out, financial securities are designed to suit many motives. For example, entrepreneurs and firms seek to raise capital efficiently. Market intermediaries hope to profit from offering transactions services in previously unavailable contingent claims. Regulators consider the role of financial innovation in promoting efficient allocation of risk and capital. Financial innovations may be motivated by the need to hedge some new economic risk, or by new regulation, a change in fiscal and monetary policies, or adjustments in accounting standards or tax codes. Other driving forces behind financial innovations include the demand for intertemporal or spatial wealth transfers, the need to lower transactions costs, and the desire to reduce agency costs due to asymmetric

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[10] Tufano (2002) presents an excellent survey of the literature on financial innovation from a wide variety of disciplines, including financial economics, history, law, and industrial organization.

information.

2.1 Financial versus Real Innovations

Llewellyn (1992) believes that the ultimate criterion when judging financial innovation is the extent to which it increases the *efficiency* of financial intermediation.[11] Moreover, he asserts that it is possible to draw a parallel between financial innovations and similar processes in other industries. A computer hardware company, for example, seeks to enhance its competitive position in the marketplace by offering fundamentally new products, or by improving upon the technical characteristics of existing products, and by combining into one machine the characteristics of various existing machines. In the process, the basic function of 'computing' becomes more efficient. Similarly for financial firms, which can invent a brand new class of products (financial instruments, techniques, and markets), modify existing products, or combine the characteristics of several different products, thereby making financial intermediation more efficient.[12] This unbundling of the characteristics and risks of individual instruments and their reassembly in different combinations results in 'spectrum filling', through which financial innovations can theoretically produce a range of instruments which encompasses all possible permutations of characteristics. As Merton (1992) argues, financial innovation drives the financial system towards the theoretically limiting goals of zero transaction costs and dynamically "complete" product markets. That is, the system moves closer

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[11] One can discuss the efficiency of the financial system in two different ways: *structural efficiency* (the range of choice offered in the system and its adaptability to changing circumstances and preferences of users) and *allocative efficiency* (the ability of the system to price risks accurately and to allocate funds to where the risk-adjusted rates of return are highest.)

[12] These characteristics include: (i) *price risk*, the extent to which the price of an asset or liability may change; (ii) *earnings risk*, such as the difference between equity and loan contracts; (iii) *credit risk*, or the possibility of a default; (iv) *pricing formula*; (v) *conversion characteristics*, such as the extent and circumstances in which the instrument can be converted into something else; (vi) the *size* of the facility; (vii) *exchange rate risk*; (viii) *discretion*, or the extent to which the instrument allows either the issuer or holder to exercise a discretion, for example an options contract; and (ix) *hedging* facility, the extent to which an instrument enables risks to be avoided (an example being a forward contract).

to the Arrow-Debreu ideal where all transactors can ensure for themselves delivery of goods and services in all future contingencies or states of nature [Arrow and Debreu (1954)].

However, a fundamental difference between financial innovations and technological innovations is that (at least until very recently) there are no protective patents in the financial industry.[13] In finance, the characteristics of innovation are immediately visible and can be almost simultaneously copied by competitors. Why then do financial innovations still occur? Vaaler (2001) argues that the 1980's and 1990's saw a flurry of new financial products and services despite such innovations being costly to develop by pioneers and easy to imitate by rivals. Examining one class of financial innovations (asset-backed securities) and one particular innovator (Citicorp), he suggests that the paradox might be explained by examining cumulative first-mover performance effects across related product and geographic market contexts. Tufano (1989) argues that the first-mover advantage for an investment bank is the expertise and reputation for expertise among potential issuers of securities. This expertise includes the ability to exploit the properties of the financial product to the benefit of the issuer, the ability to price the product in the market accurately, and knowledge of the market of potential investors in the product. Not only will the innovator gain reputation, it may also have lower costs as a result of its expertise. Herrera and Schroth (2001) show that investment banks may devote resources to producing unpatentable financial innovations because imitation of these products is often imperfect. The required disclosure of benchmark contracts (or terms-sheet) in innovative structured finance products (such as variations of credit derivatives and collateralized debt obligations) or the mere observation of the traded product do not reveal the underlying hedging mechanisms and the money making schemes that are concealed behind it.

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[13] Firms were not allowed to patent business methods until the July 1998 US Federal Circuit Court of Appeals decision in the *State Street Bank versus Signature* case, where the court found that the patent for a computerised method of administering mutual funds was valid, and that it was not necessary for the patent to be tied to a physical invention.

2.2 Types and Benefits of Financial Innovations

Financial innovations have occurred consistently at least since the Industrial Revolution and especially in the last several decades (see Miller (1986), who focuses on innovations from the 1960s to the 1980s). Clearly, they take many forms. A classification system for financial innovations developed by BIS (1986) separates them into: (i) *risk-transferring* innovations, which reduce the risk inherent in a particular instrument or enable the holder to protect against a particular risk; (ii) *liquidity-enhancing* innovations, such as securitized assets that enable loans to be sold in a secondary market which offers the lending institution the capacity to change the structure of its portfolio; and (iii) *equity-generating* innovations, which have the effect of giving an equity characteristic, where the rate of return on the asset is determined by the performance of the issuer, to assets where the nature of the debt-servicing commitment is predetermined, for example, a debt-equity swap. An alternative typology of financial innovations proposed by Perez (2002) is shown in Table 2.

The benefits of financial innovations are multi-fold. The costs of financial intermediation may be reduced by financial innovations as they give borrowers access to a wider range of markets and facilities and allow different institutions to exploit their comparative advantage. New instruments facilitate arbitrage between markets in different countries and instruments and in principle erode pricing anomalies, thus reducing market imperfections. In addition, some instruments widen the range of hedging possibilities and enable risks to be protected against, others allow risks to be priced and shifted to those willing and able to absorb them, while still others allow risks to be unbundled separately and 'sold'. If correctly priced, they enable the financial system to allocate resources more efficiently.

However, some financial innovations do not confer social benefits. Such innovations include those that defer and evade taxation, giving rise to loss of tax revenues, loss of confidence in government, and a sense of inequity. Critics of financial innovation also contend that it creates undue complexity that in turn leads to bad business decisions and social costs. In our model, we assume that the social benefits from financial innovation outweigh the social costs.

Type of Financial Innovation	*Examples*
A. Instruments to aid innovative real activities	Bank loans, venture capital, joint stock
B. Instruments to assist corporate growth or expansion	Bonds
C. Modernization of the financial services themselves	Telegraph transfers, personal checking accounts, ATMs, E-banking
D. Profit-taking and spreading investment and risk	Mutual funds, CDs, bonds, IPOs, junk bonds, derivatives, hedge funds
E. Instruments to refinance obligations or mobilize assets	Brady Bonds, swaps, acquisitions, mergers, takeovers, futures
F. Questionable innovations	Foreign exchange arbitrage, fiscal havens, off-the-record deals, pyramid schemes

Table 1: Perez (2000) Typology of Financial Innovations

3 The Financial Sector

In the tradition of many economic growth models, we adopt the representative agent framework. A representative financial intermediary uses the output from a financial innovator to transform the savings of the representative household into funds that the producer of the final consumption good taps into to finance new investment in physical capital. The technology used in producing the final good improves over time due to deliberate R&D efforts. We first explain the construction of the financial sector

3.1 Financial Innovators

The financial sector comprises financial innovators and financial intermediaries. The former produce new financial products and services using labor (and the embodied human capital) that is diverted from the production of the final consumption good and from real R&D activities. These include innovations of the forms discussed previously. We denote the stock of financial products (that is, old financial innovations) as τ.

3.1.1 Production Function for Financial Innovations

The development of the financial sector is characterized by an ever-expanding variety of financial products. For simplicity, there is no "creative destruction" of existing financial products by successively superior products. Moreover, the existing stock of financial products affects the production of new financial ideas according to

$$\dot{\tau} = F(u_\tau L)^\lambda \tau^\phi, \tag{1}$$

where $\dot{\tau}$ denotes the quantity of financial innovations per unit time, u_τ is the fraction of the labor force employed by the financial sector, L is the aggregate stock of labor (assumed to embody a fixed amount of human capital per unit of labor), F is a productivity parameter, $\lambda \in (0,1)$ is an elasticity parameter, and $\phi \in (0,1)$ measures the extent of spillovers from existing financial products. The idea is of a positive externality emanating from each financial innovation: financial innovators may build upon the ideas already introduced by other innovators. This idea that innovation begets innovation corresponds to Merton's well-known "innovation spiral".

For example, as suggested in Section 2.1, financial innovators may re-combine the characteristics of previous products to create new instruments that satisfy the contemporaneous needs of financial markets, which evolve with economic development. This positive externality is often called the "standing on the shoulders of giants" effect. Note that the production function for financial innovations exhibits diminishing marginal returns with respect to labor. As more and more individuals are engaged in designing new financial products, the probability of inefficient replication rises (the "stepping on toes" effect).

3.2 Financial Intermediaries

Financial intermediaries, on the other hand, are responsible for intermediating funds between borrowers and lenders. Borrowers are producers of the final consumption good while lenders are households with savings. Unlike conventional growth models, we do not assume that *all* household savings will automatically be transformed into funds that are utilizable by firms for investment in new plant and machinery. In particular, some risk-averse savers will continue to hold liquid but unproductive assets until offered a sufficient variety of financial products, while the financing needs of some firms will be left unfulfilled.

3.2.1 Efficiency of Financial Intermediation

The efficiency by which savings can be transformed into productive investment is measured by the intermediation coefficient,

$$\xi \equiv \tau / L^{\kappa}, \tag{2}$$

where $\xi \in (0,1)$, and $\kappa \in (0,1)$ is a parameter that measures the degree of rivalry in τ. ξ can be interpreted as a proxy for the state of development and sophistication of the financial sector.

Why does the efficiency of intermediation diminish as L increases? We argue that as the labor force or population increases, so does the volume and complexity of funds that have to be intermediated. A larger population (of both savers and corporate managers) may exhibit more diverse preferences and requirements for the risk, maturity and other characteristics of financial instruments. For some financial products and services (such as branch banking), the increase in population creates congestion that can only be relieved by financial innovation (such as phone and internet banking, in this example). However, other financial products (such as a new derivative of a pre-existing underlying security) may in fact become more useful when the customer base increases and the instrument becomes more widely traded.

By restricting κ to lie strictly between 0 and 1, we are saying that *in the aggregate,* financial innovations or products are neither fully rivalrous nor completely non-rivalrous.[14] In a later section, we will show that the model's steady-state conditions imply a restriction on κ.

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[14] If $\kappa = 1$, then all financial products are strictly rivalrous; if $\kappa = 0$, then all financial products are strictly non-rivalrous, so that the efficiency of financial intermediation is dependent only on the stock of financial products and independent of population size. Our model allows for κ to be infinitely small but not zero.

3.2.2 Capital Accumulation and Production

The capital accumulation process therefore takes the form:

$$\dot{K} = \xi (Y - C) - \delta K, \tag{3}$$

where K denotes the stock of capital, C is the level of aggregate consumption, and δ is the rate at which capital depreciates.[15] [16] The aggregate production function for the final good, Y, is of the Cobb-Douglas form:

$$Y = K^{\alpha} (A u_Y L)^{1-\alpha}, \tag{4}$$

where A denotes the level of technology, u_Y denotes the fraction of the labor force employed by the final goods sector, and $\alpha \in (0, 1)$ is capital's share of income from final goods production.

In the steady state, ξ must be constant by definition (and bounded from above at one in a closed economy). Therefore, if the labor force grows at the constant rate n, then the rate of financial innovations in the steady state must equal κn. From a practical perspective, financial innovations do not seem to have ceased even in the mature, developed economies of the OECD, which are arguably close to their steady states. Moreover, even as we observe unceasing innovative activities in the financial sectors of these countries, their efficiency cannot increase at the same rate forever.

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[15] Pagano (1993) specifies the saving-investment relationship as $\phi S = I$, where $1 - \phi$ is the flow of saving 'lost' in the process of financial intermediation. This exogenous fraction goes to banks as the "spread between lending and borrowing rates, and to securities brokers and dealers as commissions, fees and the like" (pp. 614-615). In our model, the unintermediated portion of savings is retained by financial intermediaries not as compensation for intermediary services rendered but as idle funds inaccessible to production firms.

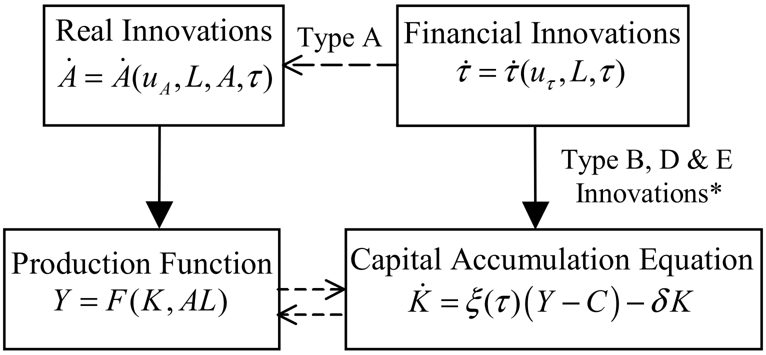
[16] This specification for the $\dot{K}$ equation is also related to the literature on investment-specific technological change. For example, in Greenwood, Hercowitz and Krusell (1997), $\dot{K} = qI_e - \delta K$, where I_e represents investment in equipment and q is the productivity of a new unit of equipment (or the inverse of the cost of producing a new unit of equipment in terms of final output).

4 A Growth Model with Financial Innovations and Endogenous Technological Progress

We now examine a three-sector growth model with a financial sector of the kind discussed in the previous section as well as endogenous technological progress in the mold of Romer (1990) and Jones (1995). Technological progress is characterized by an increasing variety of producer durables that provide alternative methods of producing the final consumer good a la Dixit and Stiglitz (1977). Unlike the models of Aghion and Howitt (1992) and Grossman and Helpman (1991c), the producers of these intermediate goods never lose the monopoly rights to their production nor are they ever superseded by new producers. The blueprints for new intermediate goods are in turn created by a research and development sector.

We allow for the stock of financial innovations, τ, to influence the rate at which new designs for intermediate goods are produced in the R&D sector (which we denote as $\dot{A}$). Implicitly, we are using the stock of financial innovations as a proxy for the stage of development of an economy's financial sector: a more sophisticated financial sector is associated with a higher real innovation rate. This formulation attempts to capture the role that venture capitalists play in encouraging high-risk R&D activities with potentially large technological payoffs. Venture capitalists alone possess the expertise to identify, and subsequently fund, the most promising of these activities, as modelled in King and Levine (1993b). We argue that these venture capital firms are only ubiquitous in economies with a highly-developed and sophisticated financial sector, such as the US, where they are concentrated in technological corridors located in California, Massachusetts and Texas. Financial instruments favored by venture capitalists include convertible loan notes and redeemable convertible preference stock.

Perez (2002) also argues that a technological revolution requires deep and widespread transformations in finance. "These (financial) innovations condition the extent to which a technological revolution will deliver its potential..." (p.138). According to Hicks (1969), the Industrial Revolution in England was made possible by the rapid development of British financial markets in the first half of the 18th century. In the 19th century, the development of joint stock companies concentrated capital, spread



** from Perez (2002) typology*

Figure 2: The Impact of Financial and Real Technological Innovations

the risks and made the diffusion of railroad technology possible. The later 'Age of steel, railways and heavy engineering' was facilitated by the rise of investment banking and institutionalized financial capital.[17] Figure 2 makes clear the distinction (and symbiosis) between financial and real innovations in our model. According to the Perez typography shown in Table 2, type A financial innovations impact real innovative activities while innovations of types B, D and E affect capital accumulation and production.[18]

In the rest of this section, we present the decentralized, competitive model which explains the roles of different actors in the model (households, final goods firms, intermediate goods producers, real R&D firms, financial intermediaries and financial innovators) and their interactions. A flowchart of the model is illustrated in Figure 3.

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[17] By 1878, Thomas Edison was already receiving financial backing for his early project from the young J.P. Morgan's bank.

[18] In reality, the rate at which financial innovations are created may also depend on the level of real technology in the economy. That is, $\dot{\tau} = \dot{\tau}(u_\tau, L, A, \tau)$. De-emphasized in this paper, this feedback effect will be examined in a forthcoming paper of ours on financial innovations and technological revolutions.

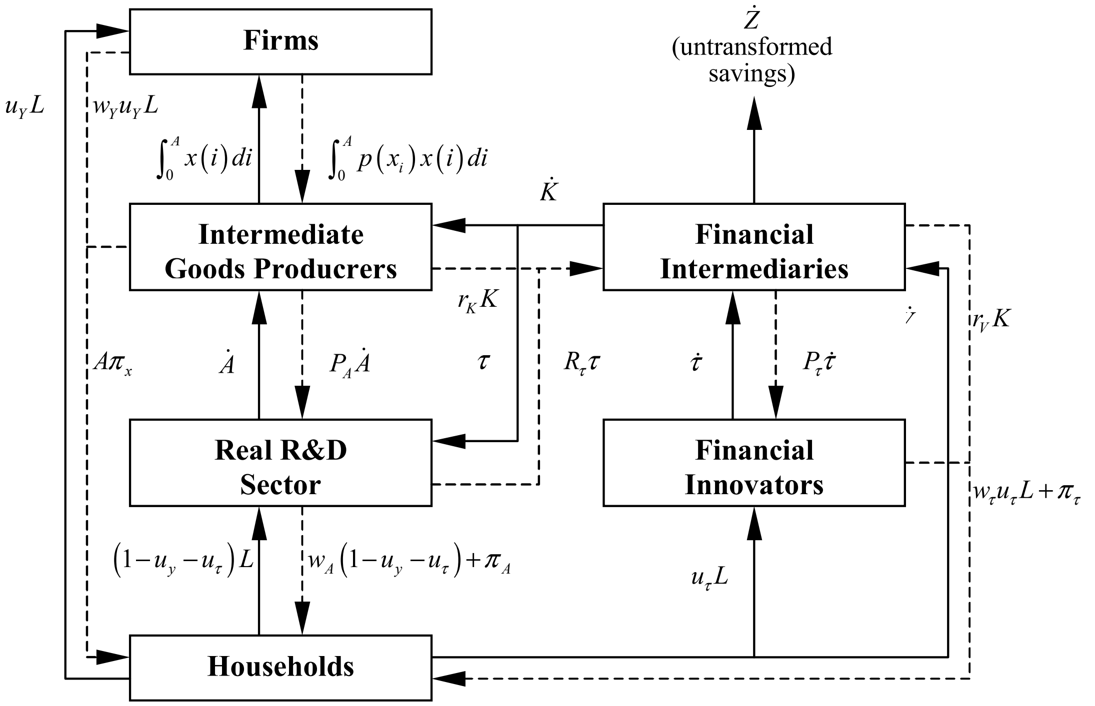

Figure 3: A Flowchart of the Economy

4.1 The Microeconomics of the Decentralized Model

4.1.1 The Financial Sector

Tufano (1989)'s empirical findings on the pricing behavior of financial innovators are consistent with the hypothesis of competitive innovation: investment banks that create new products do not charge higher prices in the brief period of monopoly before imitative products again. We therefore model financial innovators as competitive firms creating new financial products using labor (and its embodied human capital) as input, according to the production function

$$\dot{\tau} = \widetilde{F}\left(u_\tau L\right)^\lambda, \tag{5}$$

where $\widetilde{F} \equiv F\tau^\phi$. In the decentralized model, financial innovators do not internalize the spillover effect from the existing stock of financial products. They therefore treat $\widetilde{F}$ as exogenously given.

The profit of a representative financial innovator, to be maximized by its choice of $\dot{\tau}$, is

$$\pi_\tau = P_\tau \dot{\tau} - w_\tau u_\tau L, \tag{6}$$

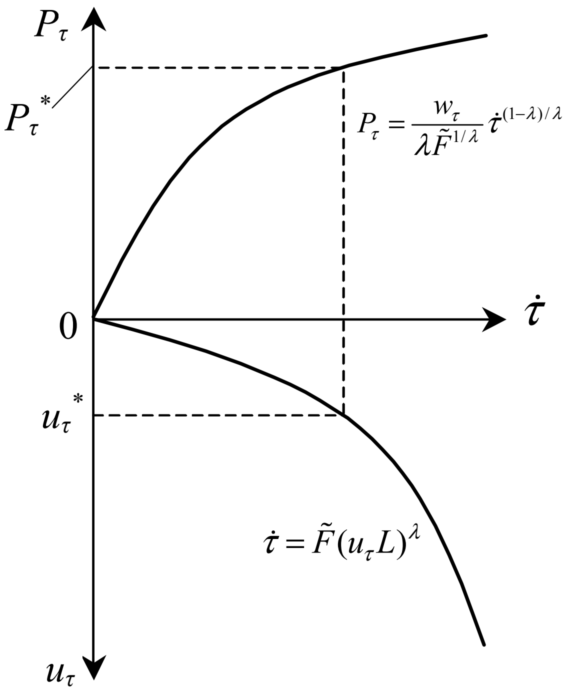

Figure 4: The Determination of the Price of Financial Innovations

where P_τ is the price of each financial innovation. The first order condition implies that

$$P_\tau = \frac{w_\tau}{\lambda\widetilde{F}^{1/\lambda}}\dot{\tau}^{\frac{1-\lambda}{\lambda}}. \tag{7}$$

This equation may be interpreted as the optimal pricing schedule for τ.

Downstream in the financial sector, financial intermediaries purchase innovations from financial innovators (which, in the real world, are probably sister divisions of the same financial firms) and use them in transforming savings into productive investment as well as in the funding of real R&D activities. As the focus of our model is on financial innovations, we model the financial intermediaries very simply. They are passive, price-taking entities engaged in perfect competition who derive their income from: (a) charging the R&D firms the rate R_τ for venture capital services rendered; and (b) charging firms in the (real) intermediate sector a higher interest rate (r_K) for renting capital than it pays out to households for their savings (r_V). The interest rate differential, $r_K - r_V$, may be thought of as the commission charged for intermediating funds. For simplicity, we assume that financial intermediation requires no labor input.

In each period, the representative financial intermediary ensures that revenues received from the real intermediate sector and R&D firms equal the cost of acquiring deposits from households and purchasing new financial products from financial innovators:

$$r_K K + R_\tau \tau = r_V K + P_\tau \dot{\tau}. \tag{8}$$

We will show later that, at each point in time, households optimally choose the allocation of labor between the final goods sector, the real R&D sector, and the financial innovations sector by equating the marginal value products of labor across these sectors. Equation (5) determines the number of units of financial innovations that is produced. Financial innovators then set the price of their innovations according to equation (7). This process is shown in Figure 3. Financial intermediaries, in turn, charge R&D firms for the venture capital services rendered according to the marginal value product of τ in producing real inventions, $\dot{A}$. With r_K equal to the marginal product of capital, the rate of return on savings, r_V, is then determined residually from equation (8).

4.1.2 The Real R&D Sector

Next, we examine the production of new designs in the real R&D sector. Here, the rate of innovation is governed by the following production function

$$\begin{aligned} \dot{A} &= \widetilde{B}\,(u_A L)^\eta \tau^\beta, \\ \widetilde{B} &\equiv BA^\psi, \end{aligned} \tag{9}$$

where $u_A = 1 - u_Y - u_\tau$ is the share of employment devoted to the production of new technical designs. As with the financial innovators, in the decentralized model, R&D firms do not take into account spillovers from existing designs, A^ψ, so they regard $\widetilde{B}$ as exogenously given. Moreover, as argued previously, a more sophisticated financial sector (with a greater stock of financial innovations, τ) is associated with a higher innovation rate. The parameter β measures the effectiveness of venture capitalists in identifying risky R&D projects and the impact of their funding on bringing these technological innovations to the market.

Each R&D firm derives revenue $P_A \dot{A}$ from the sale of blueprints to intermediate goods producers, and incurs costs $w_A u_A L$ from labor hired, and $R_\tau \tau$ from services rendered by financial intermediaries. Its profits are therefore

$$\pi_A = P_A \dot{A} - w_A u_A L - R_\tau \tau, \tag{10}$$

and L and τ are both compensated according to their marginal productivities in R&D production:

$$w_A = P_A \tilde{B} \eta \left(u_A L\right)^{\eta-1} \tau^{\beta}, \tag{11}$$

$$R_\tau = P_A \tilde{B} \left(u_A L\right)^{\eta} \beta \tau^{\beta-1}, \tag{12}$$

where w_A is the prevailing wage in the real R&D sector, R_τ is the 'rental rate' of τ charged by financial intermediaries, and P_A is the price of each new technical design.

4.1.3 The Final Goods Sector

As in Romer (1990) and Jones (1995), the final goods sector produces the consumption good Y using labor $u_Y L$ and a collection of intermediate inputs x, taking the available variety of intermediate inputs A as given:

$$Y = \left(u_Y L\right)^{1-\alpha} \int_0^A x\left(i\right)^{\alpha} di. \tag{13}$$

A representative producer of final goods solves the following profit maximization problem

$$\max_{u_Y, x(i)} \pi_Y = \left(u_Y L\right)^{1-\alpha} \int_0^A x\left(i\right)^{\alpha} di - w_Y u_Y L - \int_0^A p\left(x\left(i\right)\right) x\left(i\right) di, \tag{14}$$

where w_Y is the prevailing wage in the final goods sector and $p\left(x\left(i\right)\right)$ is the price of intermediate good i. The price of the final good is normalized to unity. The first-order conditions dictate that

$$w_Y = \left(1-\alpha\right) \frac{Y}{u_Y L}, \tag{15}$$

and

$$p\left(x\left(i\right)\right) = \alpha \left(u_Y L\right)^{1-\alpha} x\left(i\right)^{\alpha-1} \quad \forall i. \tag{16}$$

4.1.4 Intermediate Goods Producers

The intermediate sector comprises an infinite number of firms on the interval $[0, A]$ that have purchased a design from the real R&D sector, who then behave as monopolists in the production of their specific variety. Each firm rents capital at rate r_K and, using the previously purchased design, effortlessly transforms each unit of capital into a single unit of the intermediate input. (For simplicity, producer durables are transformed costlessly back into capital at the end of the period and no depreciation takes place.) Each intermediate firm therefore solves the following problem period-by-period:

$$\max_x \pi_x = p(x)\,x - r_K x. \tag{17}$$

Being monopolists, they see the downward-sloping demand curve for their producer durables generated in the final goods sector. This results in a standard monopoly problem with constant marginal cost and constant elasticity of demand, giving rise to the following solutions:

$$\bar{p}(i) = \bar{p} = \frac{r_K}{\alpha} \quad \forall i, \tag{18}$$

$$\bar{x}(i) = \bar{x} = \left[\frac{\alpha\,(u_Y L)^{1-\alpha}}{\bar{p}}\right]^{\frac{1}{1-\alpha}} \quad \forall i, \tag{19}$$

and

$$\pi_{x(i)} = \bar{\pi}_x = (1-\alpha)\,\bar{p}\bar{x} = \alpha(1-\alpha)\frac{Y}{A} \quad \forall i. \tag{20}$$

Each intermediate firm thus sets the same price and sells the same quantity of its produced durable. Moreover, since

$$K = \int_0^A \bar{x}\,di = A\bar{x}, \tag{21}$$

we can rewrite the aggregate final goods production function as

$$Y = K^{\alpha}\,(A u_Y L)^{1-\alpha}. \tag{22}$$

4.1.5 Households

Finally, to close the model, we examine the consumption decision of households. We assume that this decision may be characterized by a representative consumer maximizing an additively separable utility function subject to a dynamic budget constraint. We use a conventional CRRA utility function and assume that households are ultimate owners of all capital and shareholders of final goods firms, real intermediate firms, R&D

firms, financial intermediaries and financial innovators. The optimization problem is thus:

$$\max_{C,u_Y,u_\tau} \int_0^\infty \frac{C^{1-\theta}-1}{1-\theta} e^{-\rho t} dt, \tag{23}$$

subject to

$$\begin{aligned} \dot{V} &= r_V K + w_Y u_Y L + w_\tau u_\tau L + w_A u_A L \\ &\quad + A\bar{\pi}_x + \pi_\tau + \pi_A - P_A \dot{A} - C, \qquad (24) \\ \dot{K} &= \xi \dot{V}, \qquad (25) \\ 1 &= u_Y + u_\tau + u_A, \qquad (26) \end{aligned}$$

where $\dot{V}$ represents the flow of households' stock of assets (i.e. saving), $\bar{\pi}_x$, π_τ and π_A are the profits from the real intermediate sector, the financial sector and the R&D sector. In equilibrium, wages are equal across all labor markets, i.e. $w_Y = w_\tau = w_A$. These conditions together with equation (8) yield the following household budget constraint

$$\begin{aligned} \dot{K} &= \xi \Big(r_K K + \bar{w} u_Y L + \bar{w} u_A L + R_\tau \tau \\ &\quad + A\bar{\pi}_x + \pi_A - P_A \dot{A} - C \Big). \qquad (27) \end{aligned}$$

We can show that the following arbitrage equations for R&D blueprints and financial products must hold:

$$\begin{aligned} \xi r_K &= \frac{\bar{\pi}_x}{P_A} + \frac{\dot{P}_A}{P_A} \qquad (28) \\ \xi r_K &= \frac{\dot{V}}{P_\tau \tau} + \frac{\dot{P}_\tau}{P_\tau} \qquad (29) \end{aligned}$$

Equation (28) states that the opportunity cost to an intermediate producer of investing in a R&D blueprint, $\xi r_K P_A$, must equal the flow of profits that it generates, $\bar{\pi}_x$, and its associated capital gain, $\dot{P}_A$. Equation (29) similarly indicates that the opportunity cost to a financial intermediary of purchasing a financial innovation, $\xi r_K P_\tau$, must be equal to the average flow of savings intermediated by a unit of financial product, $\dot{V}/\tau$, and the associated capital gain, $\dot{P}_\tau$.

5 The Model's Solutions and Implications

We now derive the solution for the social planner's version of the model, which has the advantage of being simpler for the reader to follow. Recall that, unlike private agents in the competitive model, the social planner internalizes the spillover effects of current (financial and technological) innovation on future innovative activities. We will then explain how the competitive solution differs from the social planner's.

5.1 The Planner's Problem

The representative agent in the economy seeks to

$$\max_{c(t),u_Y(t),u_\tau(t)} \int_0^\infty \frac{c^{1-\theta}-1}{1-\theta} e^{-(\rho-n)t} dt, \tag{30}$$

subject to

$$\begin{aligned}
\dot{K} &= \xi\left[K^\alpha \left(Au_Y L\right)^{1-\alpha} - C\right] - \delta K, && (31)\\
\dot{\tau} &= F\left(u_\tau L\right)^\lambda \tau^\phi, && (32)\\
\dot{A} &= B\left(u_A L\right)^\eta \tau^\beta A^\psi, && (33)\\
1 &= u_Y + u_\tau + u_A, && (34)
\end{aligned}$$

The model is solved using the standard optimal control approach. The Hamiltonian is:

$$\begin{aligned}
\mathbf{H} \equiv\ & \frac{c^{1-\theta}-1}{1-\theta} e^{-(\rho-n)t} + \nu\left\{\xi\left[K^\alpha \left(Au_Y L\right)^{1-\alpha} - C\right] - \delta K\right\}\\
& + \mu F\left(u_\tau L\right)^\lambda \tau^\phi + \upsilon B\left(u_A L\right)^\eta \tau^\beta A^\psi,
\end{aligned}$$

where the control variables are c, u_Y and u_τ, the state variables are K, τ and A, and ν, μ and υ are the costate variables associated with K, τ and A respectively. The first-order conditions $\partial\mathbf{H}/\partial c = 0$, $\partial\mathbf{H}/\partial u_Y = 0$, $\partial\mathbf{H}/\partial u_\tau = 0$, $\partial\mathbf{H}/\partial K = -\dot{\nu}$, $\partial\mathbf{H}/\partial \tau = -\dot{\mu}$ and $\partial\mathbf{H}/\partial A = -\dot{\upsilon}$ yield the following equations

$$\begin{aligned}
\frac{\dot{c}}{c} &= -\frac{1}{\theta}\left(\rho + \frac{\dot{\nu}}{\nu} + \frac{\dot{\xi}}{\xi}\right),\\
\frac{\nu}{\upsilon} &= \frac{\eta}{1-\alpha} \frac{B\left(u_A L\right)^\eta \tau^\beta A^\psi}{\xi K^\alpha \left(Au_Y L\right)^{1-\alpha}} \frac{u_Y}{u_A},\\
\frac{\upsilon}{\mu} &= \frac{\lambda}{\eta} \frac{F\left(u_\tau L\right)^\lambda \tau^\phi}{B\left(u_A L\right)^\eta \tau^\beta A^\psi} \frac{u_A}{u_\tau},
\end{aligned}$$

$$\begin{aligned}
-\frac{\dot{\nu}}{\nu} &= \xi\alpha\hat{k}^{\alpha-1}u_Y^{1-\alpha}-\delta, \\
-\frac{\dot{\mu}}{\mu} &= \frac{\lambda}{1-\alpha}\frac{F\left(u_\tau L\right)^{\lambda}\tau^{\phi-1}}{\hat{k}^{\alpha}{u_Y}^{1-\alpha}}\frac{u_Y}{u_\tau}\left(\hat{k}^{\alpha}{u_Y}^{1-\alpha}-\frac{\hat{c}}{\hat{k}}\right) \\
&\quad +F\left(u_\tau L\right)^{\lambda}\tau^{\phi-1}\left(\phi+\frac{\lambda\beta}{\eta}\frac{u_A}{u_\tau}\right), \\
-\frac{\dot{\upsilon}}{\upsilon} &= \left(\psi+\eta\frac{u_Y}{u_A}\right)B\left(u_A L\right)^{\eta}\tau^{\beta}A^{\psi-1}\left(\psi+\eta\frac{u_Y}{u_A}\right),
\end{aligned}$$

where $\hat{k}\equiv K/AL$ and $\hat{c}\equiv C/AL$. Finally, the transversality conditions are

$$\lim_{t\rightarrow\infty}\nu\left(t\right)K\left(t\right) = 0, \tag{35}$$

$$\lim_{t\rightarrow\infty}\mu\left(t\right)\tau\left(t\right) = 0, \tag{36}$$

$$\lim_{t\rightarrow\infty}\upsilon\left(t\right)A\left(t\right) = 0. \tag{37}$$

Definition 1 *The economy is on its balanced growth path (or its steady state) when all variables grow at constant rates. In addition, the variables* $\hat{y}\equiv Y/AL$, $\hat{c}$, $\hat{k}$, ξ, u_Y, u_τ, u_A *and* $\gamma_A\equiv\dot{A}/A$ *are all constant.*

This definition implies that output per worker, y, consumption per worker, c, and capital per worker, k, must all grow at rate γ_A^* in the steady state, where γ_A^* is the steady-state value of γ_A, while the growth rate of τ will be equal to κn.

Proposition 2 *There exists a balanced growth path as defined above if and only if* $\kappa=\lambda/\left(1-\phi\right)$.

Proof. Let $\gamma_\tau\equiv\dot{\tau}/\tau=F\left(u_\tau L\right)^{\lambda}\tau^{\phi-1}$. Differentiating the logarithm of γ_τ with respect to time yields

$$\frac{\dot{\gamma}_\tau}{\gamma_\tau}=\lambda\left(\frac{\dot{u}_\tau}{u_\tau}+n\right)-\left(1-\phi\right)\gamma_\tau.$$

Since γ_τ and u_τ are, by definition, constant on the balanced growth path, $\gamma_\tau^*=\lambda n/\left(1-\phi\right)$. In addition, as $\dot{\tau}/\tau=\kappa n$ in order for $\xi\equiv\tau/L^{\kappa}$ to be constant in the steady state, the solution γ_τ^* implies that $\kappa=\lambda/\left(1-\phi\right)$.

Proposition 3 *The steady-state growth rate of the economy,* γ_A^*, *must be equal to* $\left(\eta+\beta\kappa\right)n/(1-\psi)$.

■

Proof. Since $\dot{A} = B\left(u_A L\right)^{\eta} \tau^{\beta} A^{\psi}$, the growth rate of A is given by:

$$\gamma_A = B\left(u_A L\right)^{\eta} \tau^{\beta} A^{\psi-1}.$$

Differentiating the logarithm of the above equation with respect to time yields

$$\eta\left(\frac{\dot{u}_A}{u_A} + n\right) + \beta\frac{\dot{\tau}}{\tau} - (1-\psi)\gamma_A = 0.$$

Since $\dot{u}_A = 0$ and $\dot{\tau}/\tau = \kappa n$ in the steady state, it must be that

$$\gamma_A^* = \frac{(\eta + \beta\kappa)\, n}{1-\psi}.$$

■

The financial sector therefore has a direct impact on the growth rate of technology and, consequently, on aggregate output. The growth rate of Y, given by $\gamma_A + n$, is a monotonically increasing function of the parameters λ, ϕ, η, β and ψ which govern the production of financial innovations $\dot{\tau}$ and real technological innovations $\dot{A}$.

5.2 Steady-State Solutions

We can use the definition of the balanced growth path to generate a system of five steady-state equations (given by $\dot{\hat{k}}/\hat{k} = 0$, $\dot{\hat{c}}/\hat{c} = 0$, $\dot{\xi}/\xi = 0$, $\dot{u}_Y/u_Y = 0$, and $\dot{u}_\tau/u_\tau = 0$) which enable us to solve analytically for the five key variables of the model. Expressed sequentially, the solutions are:

$$\begin{aligned}
u_\tau^* &= \frac{\Lambda + \Gamma\Psi}{\Phi + \Lambda + \Gamma\left(\Phi + \Psi\right)}, \\
u_Y^* &= \frac{\Gamma\Phi}{\Phi + \Lambda + \Gamma\left(\Phi + \Psi\right)}, \\
\xi^* &= \left(\frac{F u_\tau^{*\lambda}}{\gamma_\tau^*}\right)^{\frac{1}{1-\phi}}, \\
\hat{k}^* &= \left(\frac{\xi^* \alpha}{\rho + \delta + \theta\gamma_A^*}\right)^{\frac{1}{1-\alpha}} u_Y^*, \\
\hat{c}^* &= \frac{\rho + \delta + \theta n - \alpha\left(n + \delta + \gamma_A^*\right)}{\alpha}\frac{\hat{k}^*}{\xi^*},
\end{aligned}$$

where

$$\begin{aligned}
\Gamma &\equiv \frac{\rho+(\theta-1)n-\psi\gamma_A^*}{\eta\gamma_A^*}, \\
\Phi &\equiv \rho+(\theta-1)n-\gamma_A^*+(1-\phi)\gamma_\tau^*, \\
\Psi &\equiv \frac{\alpha\lambda\gamma_\tau^*\left(n+\delta+\gamma_A^*\right)}{(1-\alpha)(\rho+\theta n+\delta)}, \\
\Lambda &\equiv \frac{\lambda\beta\gamma_\tau^*}{\eta}, \\
\gamma_\tau^* &= \frac{\lambda n}{1-\phi}, \\
\gamma_A^* &= \frac{\eta n+\beta\gamma_\tau^*}{1-\psi}.
\end{aligned}$$

u_τ^* therefore describes the optimal steady-state size of the financial sector in terms of employment. The solution for the decentralized, competitive model differs from the above planner's solution in the following ways:

$$\begin{aligned}
u_\tau^{*DC} &= \frac{\Lambda+\Gamma^{DC}\Psi^{DC}}{\Phi^{DC}+\Lambda+\Gamma^{DC}\left(\Phi^{DC}+\Psi^{DC}\right)}, \\
u_Y^{*DC} &= \frac{\Gamma^{DC}\Phi^{DC}}{\Phi^{DC}+\Lambda+\Gamma^{DC}\left(\Phi^{DC}+\Psi^{DC}\right)}, \\
\xi^{*DC} &= \left(\frac{F\left(u_\tau^{*DC}\right)^\lambda}{\gamma_\tau^*}\right)^{\frac{1}{1-\phi}}, \\
\hat{k}^{*DC} &= \left(\frac{\xi^*\alpha^2}{\rho+\delta+\theta n}\right)^{\frac{1}{1-\alpha}} u_Y^{*DC}, \\
\hat{c}^{*DC} &= \frac{\rho+\theta n-\alpha^2\left(n+\delta+\gamma_A^*\right)}{\alpha^2}\frac{\hat{k}^{*DC}}{\xi^{*DC}},
\end{aligned}$$

where γ_A^*, γ_τ^* and Λ are as before, and

$$\begin{aligned}
\Gamma^{DC} &\equiv \frac{\rho+(\theta-1)n}{\alpha\eta\gamma_A^*}, \\
\Phi^{DC} &\equiv \rho+(\theta-1)n-\gamma_A^*+\gamma_\tau^*, \\
\Psi^{DC} &\equiv \frac{\alpha^2\lambda\gamma_\tau^*\left(n+\gamma_A^*\right)}{(1-\alpha)(\rho+\theta n+\delta)},
\end{aligned}$$

Although we can write down the difference between the two solutions analytically, for example $\xi^{*DC}-\xi^*$, the expressions are too complicated to be signed. Using numerical techniques, we can demonstrate that the steady-state levels of u_A and u_τ, the shares of labor devoted to the real R&D sector and the financial innovations sector respectively, are lower in the decentralized model compared to their counterparts in the social planner's solution. The sources of divergence are the externalities arising from existing R&D designs and financial products (which are only internalized by the social planner), as well as the monopoly power of intermediate good producers (which is eliminated by the social planner).[19]

5.3 Model Implications: Comparative Statics

5.3.1 Calibration

Due to the complexity of the model's analytical solutions, we utilize numerical methods to investigate the comparative statics of the model. Specifically, we analyze the impact of a change in five different parameters on the steady-state allocation of labor. The comparative statics are performed with respect to a particular parameter holding the other parameters constant. The chosen baseline values for the various parameters are:

α	δ	ρ	θ	n	λ	ϕ	η	ψ	β
$\frac{1}{3}$	0.0	0.02	1.5	0.01	$\frac{2}{3}$	0.2	$\frac{2}{3}$	0.2	0.2

The share of capital in the value of final goods produced is set equal to one-third, the discount rate is 0.02, the coefficient of risk-aversion (or desire for consumption smoothing) is 1.5, the labor force grows by 1 percent each period, while the rest of the table shows the chosen values for the input elasticity parameters in the production of real R&D designs and financial innovations. It can be shown that our results are robust to different choices for the baseline values. Moreover, the comparative statics for the decentralized model are qualitatively identical to that of the planner's version.

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[19] Pesendorfer (1995) also demonstrate that some innovations may not be undertaken because decentralized financial firms cannot coordinate their activities. The reason for this inefficiency is that although a simultaneous issue of all complementary products may be profitable, a single issue of one new product is not.

5.3.2 The Impact of Changes in Preferences and Technologies

Figure 5 shows the impact of variations in ϕ, ρ, θ, ψ and β on u_{τ}^{*}, u_{Y}^{*} and u_{A}^{*}. The results of our exercise are summarized in the following table:

	ϕ	ρ	θ	ψ	β
u_{τ}^{*}	$\uparrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\uparrow$
u_{Y}^{*}	$\downarrow$	$\uparrow$	$\uparrow$	$\downarrow$	$\downarrow$
u_{A}^{*}	$\downarrow$	$\downarrow$	$\downarrow$	$\uparrow$	$\uparrow$

We find that a rise in ϕ increases u_{τ}^{*} but decreases u_{Y}^{*} and u_{A}^{*}. The explanation for this is straightforward. An increase in ϕ (which, we recall, measures the spillover effects from existing financial products on financial innovations) raises the marginal product of labor in the financial innovations sector. Labor thus moves from the final goods sector and the R&D sector into the financial innovations sector until the productivity of labor (and hence the real wage) are once again equal in the three sectors.

A rise in β increases the importance of τ on the production of new R&D designs (the ultimate source of growth in this model) as well as raises the marginal product of labor in that sector. The former creates a higher demand for financial products which leads to a rise in u_{τ}^{*} while the latter induces a rise in u_{A}^{*} in order to bring wages across the sectors back to equilibrium again. Similarly, an increase in ψ raises the productivity of labor in the R&D sector, thereby inducing u_{A}^{*} to rise at the expense of u_{Y}^{*} and u_{τ}^{*} to equalize wages.

The impact of ρ and θ on the shares of labor in the three sectors are similar. An increase in either ρ or θ increases u_{Y}^{*} but decreases u_{τ}^{*} and u_{A}^{*}. An increase in either ρ or θ indicates a rise in households' preference for current consumption. Consequently, more labor is devoted to the production of the final consumption good at the expense of the other two sectors.

5.4 Transitional Dynamics

In view of the relatively large dimensionality of the model (with three control variables and three state variables), we use two different approaches to study its transitional

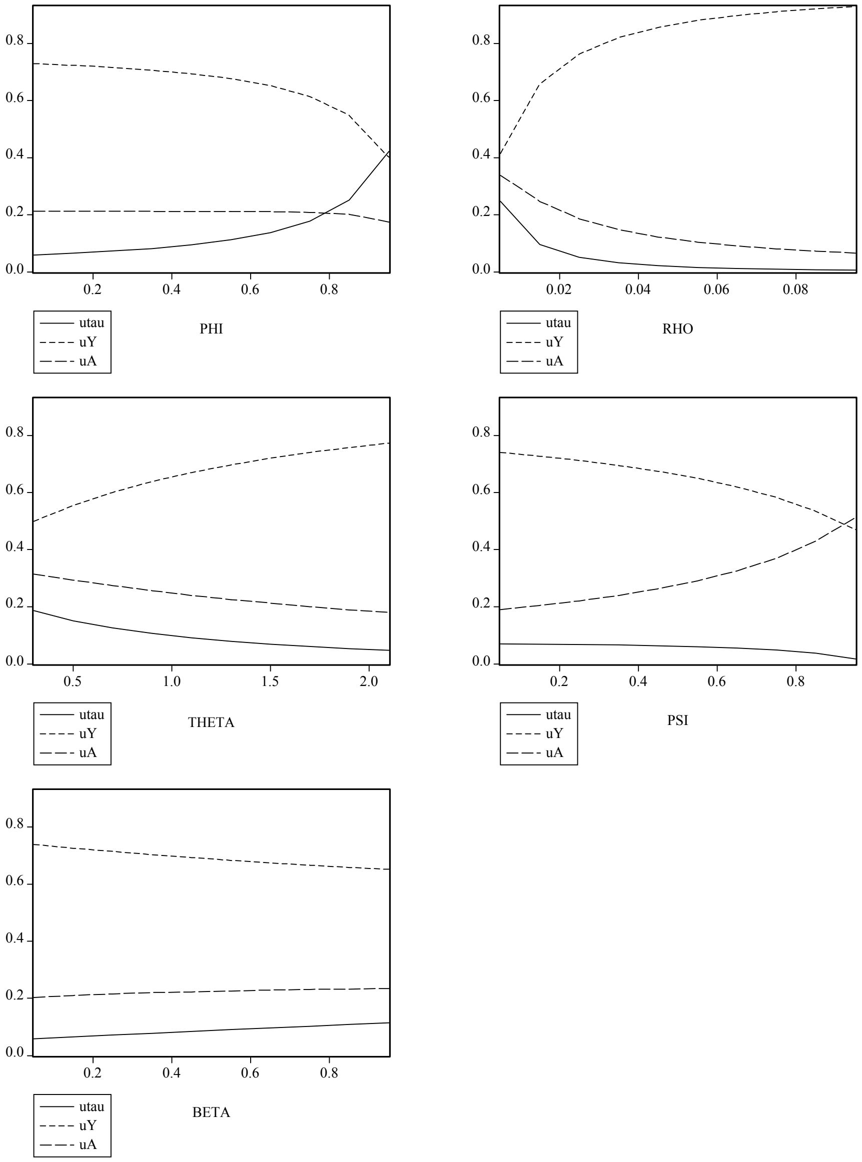

Figure 5: Comparative Statics using Numerical Solutions

dynamics. The first approach, commonly adopted in the growth literature, entails making the employment shares in the various sectors as well as the saving rate exogenous, while the second makes use of numerical methods to produce impulse-response diagrams corresponding to the full model.

5.4.1 Dynamics of the Reduced Model

In the simplified model with exogenous labor shares and saving rate (denoted $\bar{s}_K$), the equations describing the $\dot{\xi} = 0$, $\hat{k} = 0$ and $\dot{\gamma}_A = 0$ schedules are:

$$\begin{aligned} \xi &= \left[\frac{F u_T^{\lambda}(1-\phi)}{\lambda n}\right]^{\frac{1}{1-\phi}} u_Y, \\ \hat{k} &= \left[\frac{\tilde{a}\xi}{\tilde{b} + \tilde{c}\xi^{\phi-1}}\right]^{\frac{1}{1-\alpha}}, \\ \gamma_A &= \tilde{d} + \tilde{c}\xi^{\phi-1}, \end{aligned}$$

where $\tilde{a} \equiv \bar{s}_K(1-\psi)$, $\tilde{b} \equiv n\eta + (1-\psi)(n+\delta)$, $\tilde{c} \equiv \beta F u_T^{\lambda}$, and $\tilde{d} \equiv n\eta/(1-\psi)$. The phase diagrams of the reduced model, in $\hat{k} - \xi$ space and $\gamma_A - \xi$ space respectively, are shown in the top panels of Figure 6.

As shown in the lower panels of Figure 6, a rise in the productivity parameter of financial innovators F (due to, say, government deregulation of the financial sector) causes the $\dot{\xi} = 0$ schedule to shift to the right, the $\dot{\hat{k}} = 0$ schedule to shift down, and the $\dot{\gamma}_A = 0$ schedule to shift up. $\hat{k}$ decreases before recovering and eventually surpasses its original level. The growth rate of technology, γ_A, rises temporarily before returning to its original level. The increase in F therefore produces temporary growth effects but only level effects in the long run.

5.4.2 Simulated Impulse-Responses of the Full Model

Preserving the endogeneity of the labor shares and saving rate of the original model necessitates the use of numerical methods when investigating its transitional dynamics. Specifically, we convert the model from continuous to discrete time and use the 'shooting' method (implemented in a C-language computer program) to guess the magnitude of the jumps in the control variables c, u_Y, and u_T occurring in the instant a shock impacts the system. 'Correct' jumps ensure the system moves along the stable manifold

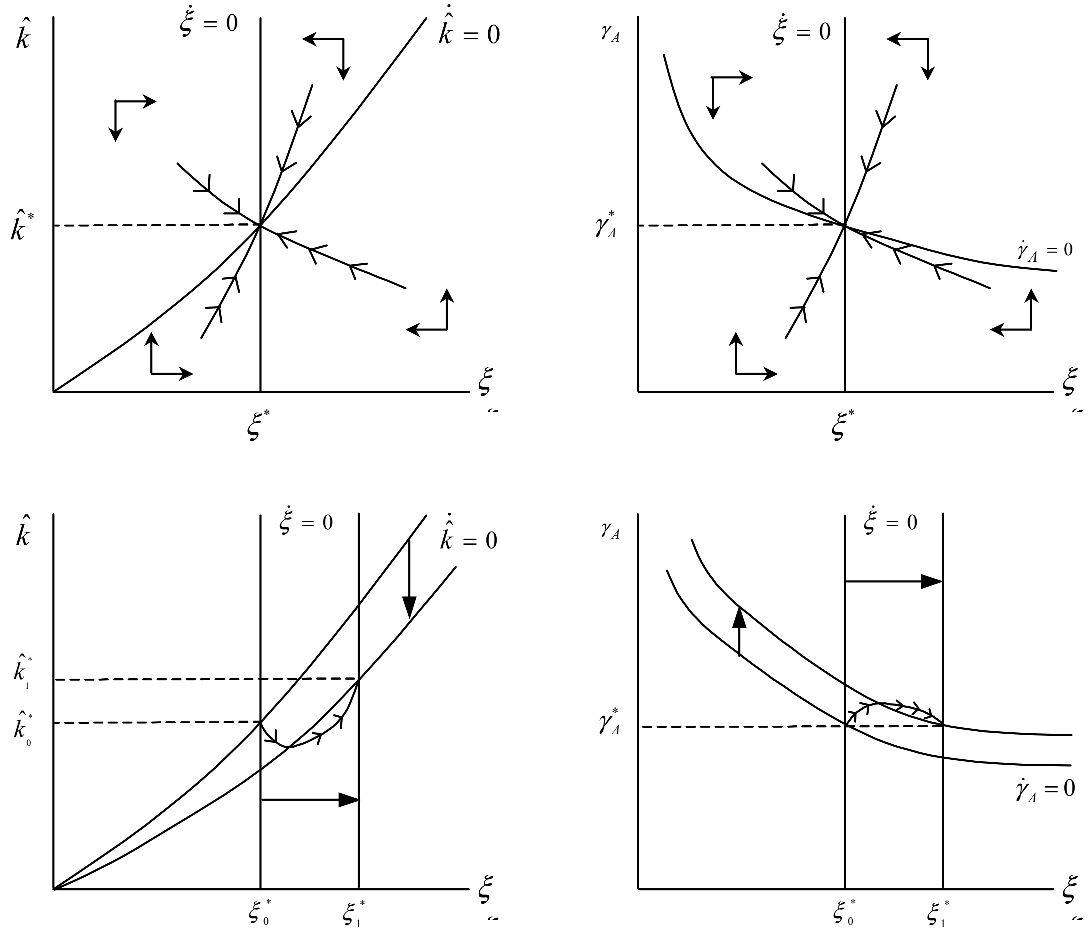

Figure 6: Phase Diagrams Depicting the Impact of a Rise in F

until the new steady state is reached while incorrect jumps lead to dynamic paths that eventually violate the transversality conditions.[20] The system of difference equations describing the dynamic evolution of the state and control variables are shown in the Appendix.

We now report the response of the state and control variables to a positive innovation in F. These are illustrated in Figure 7, which for clarity's sake is not drawn to scale. A rise in F raises the marginal product of labor of financial innovators, causing the share of employment in the financial sector, u_τ, to jump upwards. Conversely, this causes the share of employment in the final goods and real R&D sectors, u_Y and u_A, to jump downwards in order for the marginal productivity of labor in these sectors to match that of the financial innovators. (Recall that both final goods and R&D production exhibit diminishing returns with respect to labor.) u_Y and u_τ then slowly converge to their original levels as a change in F has no impact on the economy's long run growth rate or the distribution of labor across the three sectors. The share of employment in the R&D sector, u_A, at first continues to decline after the initial jump as u_Y recovers faster than the decline in u_τ, and then rises gradually back to its original level.

By affecting the marginal product of labor of financial innovators, the increase in F raises the wages received by households, causing consumption to jump up instantaneously. As more labor is channelled into the financial innovations sector and less into the final goods sector, final goods consumption and capital accumulation decline until the increased efficiency of the financial intermediaries (due to a rising ξ, in turn arising from u_τ being above its steady state level) increases the rate of accumulation of capital and hence output. Consumption eventually reaches its new, higher steady-state level. Since the behavior for $\hat{y} \equiv Y/AL$ mirrors that of $\hat{k}$ (whose path corresponds to that in the simplified model - see Figure 6), the model predicts that output per effective unit of labor dips below its pre-shock trajectory before recovering and then rising above it.

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[20] The simulation program is available upon request.

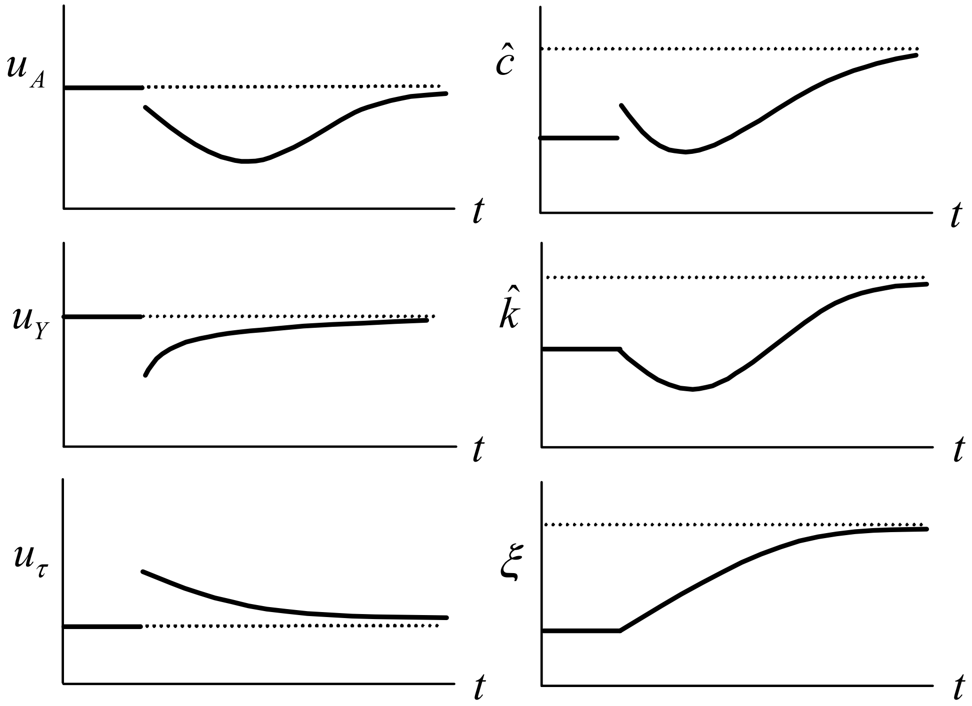

Figure 7: Impulse Responses of Variables to a Rise in F

6 Brief Policy Analysis

Our model indicates that there is an optimal size for the financial sector in the steady state (at least in terms of employment), as given by u_τ^*. There is some evidence that suggests the financial sector in the US has reached a high degree of maturity by the 1990s. Figure 8 shows that the financial sector's share in US total private non-farm employment rose quite consistently from 4.5 percent to 7.5 percent between 1950 and the late 1980s.[21]. From 1990 to 2002, however, the figure has hovered between 7 to 7.5 percent. This observation is consistent with the steady state behavior of our model. The increase in the financial sector's share of US total private non-farm employment prior to 1990 may indicate convergence to a fixed steady state or responses to a series

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[21] Financial activities are defined by the BLS as those associated with the monetary authorities, credit intermediation and related activities (depository credit intermediation plus commercial banking), activities related to securities/commodity contracts/investments, insurance carriers and related activities, and activities related to funds/trusts/other financial vehicles.

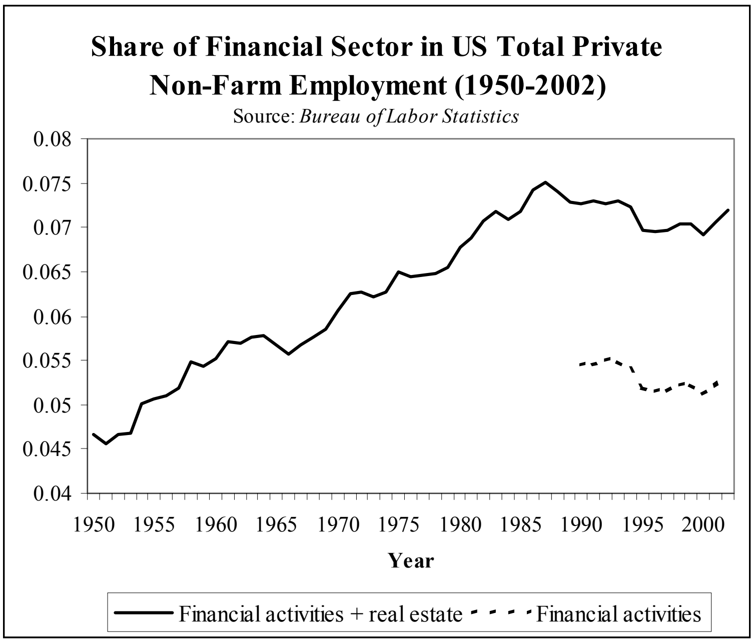

Figure 8: Evolution of the Employment Share of the Financial Sector in the US

of positive financial policy shocks.[22] We intend to conduct a deeper investigation into this potentially interesting issue.

Our model also suggests that policies governing the financial sector may raise the steady-state growth rate of capital and output per capita through their ultimate effects on the rate of technological innovations. This is, however, contingent on the policies affecting the elasticity of spillovers from existing financial products on the rate of financial innovations and on the elasticity of spillovers from the stock of financial products on the production of R&D designs. The financial sector then develops more rapidly (its maturity being measured by the stock of financial products) and assists the real R&D sector more capably through its venture capital role.

6.1 Financial Liberalization

In general, policies that change the environment in which financial firms operate and their incentives to innovate, such as liberalizing the financial sector or lifting financial repression, will likely lead to changes in the productivity parameter of financial inno-

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[22] These may include legislation establishing a regulatory body that increased public confidence in the financial sector in the earlier years, or efficiency-boosting financial deregulation in the later years.

vators (captured in our model by a rise in F), which raises the steady-state per-capita capital stock and output but not their growth rates. We can show that when F is too low, the economy may never achieve a hundred per cent transformation of savings into investment, i.e. $\xi < 1$ in the steady state. Our model may therefore be classified as 'semi-endogenous' in the Jones (1995) sense.[23]

Similarly, opening the financial sector of a less developed economy to leading-edge financial firms from advanced countries will enable a transfer of financial expertise from these countries to the less developed one, allowing the latter to raise its F parameter and thereby attain its steady-state more rapidly while achieving a higher level of GDP per capita. Figure 9 shows the impact of liberalization on the rate of financial innovation and the pricing of these innovations in the old and new steady states. The rise in F shifts the $\dot{\tau}$ schedule to the right and the P_τ schedule downwards. $\dot{\tau}$ increases while P_τ falls. The transitional dynamics of u_τ was discussed in the previous section, as were the adjustment paths of $\hat{k}$ and $\hat{y}$.

6.2 Other Changes in Regulations, Accounting Standards or Tax Codes

We can also analyze the consequences of changes in regulations, accounting standards or tax codes on innovative activities in the financial sector. Such changes may render some of the existing financial products obsolete. This is depicted as a negative exogenous shock to ξ in Fig. 10 (reproduced from Section 5.4.1) and Fig. 11. The growth rate of financial innovations jumps upwards at the time of the shock, then slowly returns to its steady state value. As the impulse response diagrams in Fig.12 show, ξ also gradually returns to its original level after the initial jump caused by the shock. $\hat{k}$ first declines and then recovers as the initial fall in ξ causes to capital stock to increase less rapidly relative to the level of technology (recall that $\hat{k} \equiv K/AL$). The growth rate of the

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[23] That is, a growth model where government policy affects only the steady state levels of variables but not their growth rates. If $\dot{\tau} = F\left(u_\tau L\right)^\lambda \tau$, that is $\phi = 1$, then the model exhibits scale effects as in Romer (1990). However, this is not a desirable property as OECD growth rates have remained steady even as the number of workers involved in creating financial innovations has increased in the last several decades.

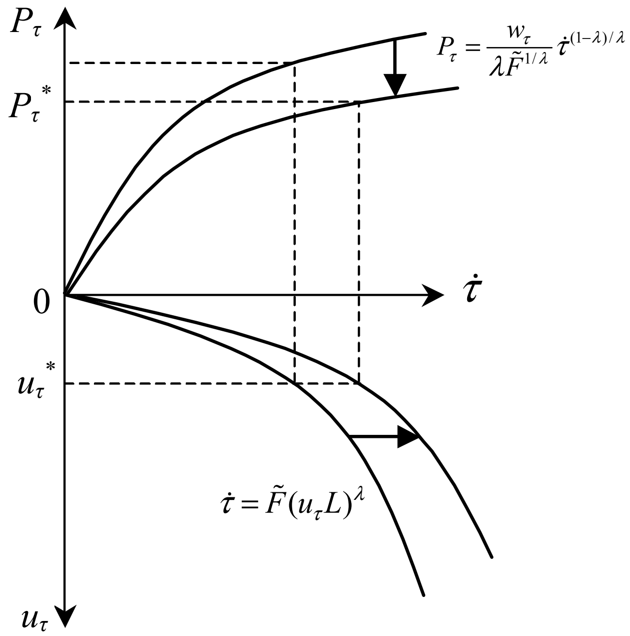

Figure 9: The Impact of Financial Liberalization on the Rate and Pricing of Financial Innovations

economy, γ_A, follows a trajectory that is the mirror image of that for $\hat{k}$. As the shock stimulates intense innovative activities in the financial sector (to replace the financial products made obsolete), their effects spill over into the real R&D sector through the β parameter in the $\dot{A}$ equation. Eventually γ_A returns to its long run value.

6.3 Patenting of Financial Innovations

Historically, the US Patent Office has taken a dim view of the patentability of most financial products. However, in 1998, the Federal Circuit Court of Appeals decision in the case of *State Street Bank v. Signature Financial* 47 U.S.P.Q.2d (BNA) 1596 (Fed. Cir. 1998) seemed to open the door for patents on financial products. Signature had sued State Street for violating its patent for a new asset management system. The Court of Appeals' upholding of Signature's patent is considered by some to be a watershed event in financial innovation. Can our model shed any light on the macroeconomic ramifications of this decision?

The patenting of financial innovations has two effects in our model. Firstly, it reduces the spillover effect of financial innovation undertaken in one firm on that of

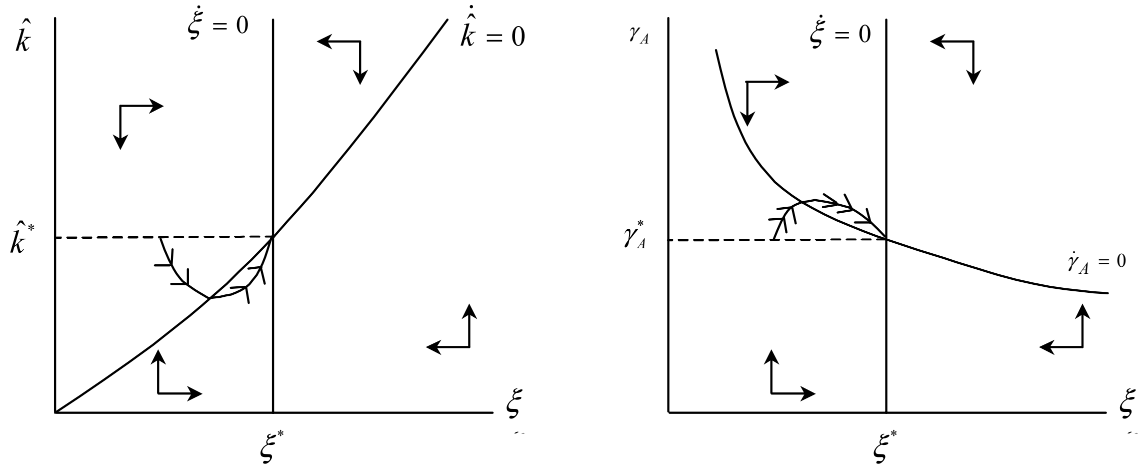

Figure 10: Impact of a Change in Regulation, Accounting Standard or Tax Code

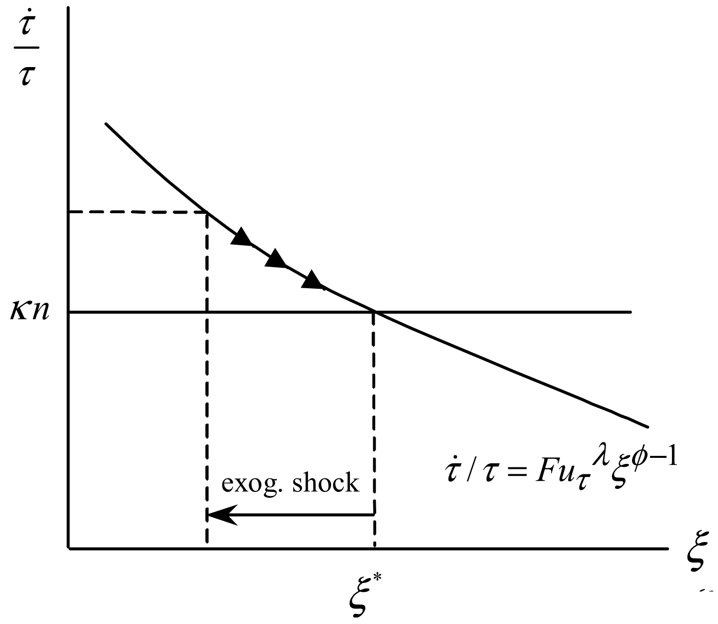

Figure 11: Growth Rate of Financial Innovations due to a Change in Regulation, Accounting Standard or Tax Code

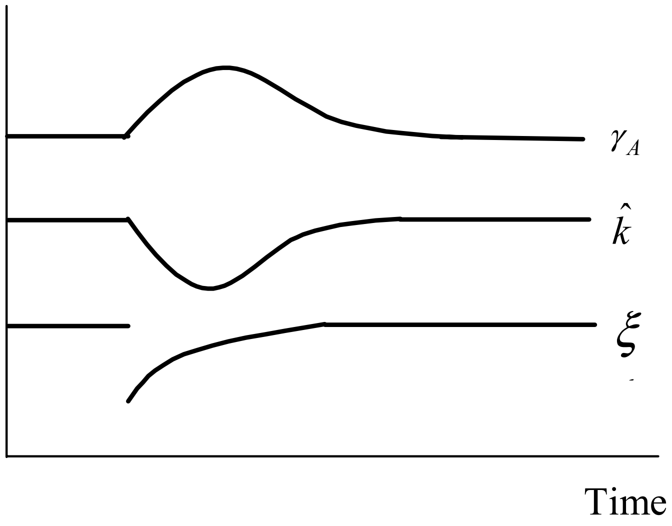

Figure 12: Impulse Responses of Variables to a Change in Regulation, Accounting Standard or Tax Code

another as well as the intertemporal spillovers on future innovation. This may be captured in the model by a reduction in ϕ. From propositions 2 and 3 in Section 5.1, we see that a reduction in ϕ lowers the steady state growth rate of the economy. The top left panel in Figure 5 also indicates that the steady state share of the labor force engaged in financial innovation will decrease. In addition, the patenting of financial innovations may conceivably change the market structure of the financial innovation sector. The sector may become less competitive, which will exacerbate the under-production of financial innovations. This will reduce social welfare if financial innovations are of the desirable rather than questionable kind.

Finally, the divergence of the decentralized solution from the planner's in this model possibly suggests a reason for the desirability of mergers in the finance industry. As firms in the industry become fewer in numbers but stronger in market power, they may begin to internalize the spillovers from current to future financial innovations. (If the industry consists of only one monopolistic firm, it would in effect behave like the social planner with regards to such externalities.) This perhaps accounts for the spate of consolidations and mergers observed in the finance industry in the 1990s. As a corollary, the model suggests that, as a result of complementarities among innovations, regulations that force financial firms to specialize in a subset of potential financial products may be harmful for the financial innovation process.

7 Conclusion

In this paper, we set out to investigate the impact of financial innovations on the macroeconomy by developing a formulation of the financial sector and embedding it in a growth model with endogenous technological progress. The motivation for this research is the observation that, in recent years, there has been a rapid proliferation of financial products and an enormous amount of human capital being channelled into the creation of these products. The key question that we seek to answer is whether financial innovations complement real technological innovations, the traditional source of economic growth, or merely divert precious resources away from real R&D activities.

The financial sector in our model comprises financial innovators and financial intermediaries. Financial innovators utilize labor (and the embodied human capital) as well as the existing catalog of financial products to develop new financial products and services. Financial intermediaries then purchase these innovations to improve their efficiency in transforming household savings into funds for productive investment by firms. In addition, we model the activities of venture capitalists by allowing spillovers from financial innovations into the real R&D sector.

In solving for the steady state values of the model's key variables and analyzing the resulting comparative statics, we showed that financial innovations ultimately affect the long run growth rate only through the technological innovation channel, thus highlighting the symbiosis between financial and real innovations. The model's solution also reveals the optimal allocation of labor to competing uses in the financial, final goods and real R&D sectors, and how this allocation depends on the model's parameters. In addition, we traced the path of the optimal allocation in the aftermath of a shock to the economy and examined the other transitional dynamics of the model.

We demonstrated that while financial innovations initially raise the efficiency of financial intermediation between borrowers and savers, this process slows and comes to an eventual halt in the steady state, so that an increase in the productivity of the financial sector leads to growth effects on the transitional path to the steady state but only level effects in the long run. We also discussed how the competitive solution to the model differed from that of a hypothetical social planner. Finally, we used the model to study the effects of financial liberalization, changes in regulations or tax codes, and changes in patent laws that will permit the patenting of financial innovations.

Extensions to be explored and future research plans include incorporating capital inflows and outflows into the model, and using this augmented model to study in depth the dynamic macroeconomic effects of financial liberalization. We also intend to test the model empirically by collecting time series and cross-country data on measures of efficiency of the financial sector.

A Difference Equations in Transitional Dynamics Simulation

The system of difference equations describing the dynamic evolution of the control variables $\widehat{c}$, u_Y and u_τ and state variables $\widehat{k}$ and ξ (referred to in Section 5.4) are as follows:

$$\begin{aligned}
\hat{c}_{t+1} &= \left[\frac{1}{\theta}\left(\xi_t \alpha \hat{k}_t^{\alpha-1} u_{Y,t}^{1-\alpha} - \delta - F u_{\tau,t}^{\lambda} \xi_t^{\phi-1} + \kappa n - \rho\right) - \gamma_{A,t}\right] \hat{c}_t + \hat{c}_t, \\
u_{Y,t+1} &= \frac{u_{A,t}\left[(1-\eta)\,u_{\tau,t} + (1-\lambda)\,u_{A,t}\right]}{\left[(1-\eta)\,u_{Y,t} + \alpha u_{A,t}\right]\left[(1-\eta)\,u_{\tau,t} + (1-\lambda)\,u_{A,t}\right] - (1-\eta)^2 u_{\tau,t} u_{Y,t}} \\
&\quad \times \left[\Upsilon_t - \frac{(1-\eta)\,u_{\tau,t}}{(1-\eta)\,u_{\tau,t} + (1-\lambda)\,u_{A,t}} \Lambda_t\right] u_{Y,t} + u_{Y,t}, \\
u_{\tau,t+1} &= \frac{u_{A,t}}{(1-\eta)\,u_{\tau,t} + (1-\lambda)\,u_{A,t}} \left[\Lambda_t - \frac{(1-\eta)\,u_{Y,t}}{u_{A,t}} \frac{u_{Y,t+1} - u_{Y,t}}{u_{Y,t}}\right] u_{\tau,t} + u_{\tau,t},
\end{aligned}$$

where

$$
\begin{aligned}
\gamma_{A,t+1} &= \left[\eta\left(\frac{u_{A,t+1}-u_{A,t}}{u_{A,t}}+n\right)+\beta F u_{\tau,t}^{\lambda}\xi_t^{\phi-1}-(1-\psi)\,\gamma_{A,t}\right]\gamma_{A,t}+\gamma_{A,t},\\
\Upsilon_t &\equiv \eta\left(\gamma_{A,t}\frac{u_{Y,t}}{u_{A,t}}-n\right)-\alpha\xi_t\frac{\hat{c}}{\hat{k}}+(1-\beta)\,F u_{\tau,t}^{\lambda}\xi_t^{\phi-1}-\kappa n+(1-\alpha)\left(n+\delta+\gamma_{A,t}\right),\\
\Lambda_t &\equiv \eta\left(\gamma_{A,t}\frac{u_{Y,t}}{u_{A,t}}-n\right)-\frac{\lambda}{1-\alpha}F u_{\tau,t}^{\lambda-1}\xi_t^{\phi-1}\left[u_{Y,t}-\left(\frac{u_{Y,t}}{\hat{k}_t}\right)^{\alpha}\hat{c}_t\right]\\
&\quad -\beta F u_{\tau,t}^{\lambda}\xi_t^{\phi-1}\left(1+\frac{\lambda}{\eta}\frac{u_{A,t}}{u_{\tau,t}}\right)+\lambda n,
\end{aligned}
$$

and

$$
\begin{aligned}
\hat{k}_{t+1} &= \left[\xi_t\left(\hat{k}_t^{\alpha-1}u_{Y,t}^{1-\alpha}-\frac{\hat{c}_t}{\hat{k}_t}\right)-\delta-\gamma_{A,t}-n\right]\hat{k}_t+\hat{k}_t,\\
\xi_{t+1} &= \left(F u_{\tau,t}^{\lambda}\xi_t^{\phi-1}-\kappa n\right)\xi_t+\xi_t.
\end{aligned}
$$

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B Mathematical Notation

C = consumption

ρ = subjective discount rate

θ = coefficient of risk-aversion in the utility function

δ = rate of depreciation

t = time

K = physical capital

L = labor

n = rate of growth of the labor force

u_Y = share of employment devoted to production of final consumption good

u_τ = share of employment devoted to production of financial innovations

u_A = share of employment devoted to R&D of new technological designs

τ = stock of financial innovations

$\xi \equiv \tau / L^\kappa$ = efficiency of intermediation between savings and investment

$\hat{c} \equiv C/AL$ =technology-augmented consumption-labor ratio

$\hat{k} \equiv K/AL$ = technology-augmented capital-labor ratio

γ_τ^* = steady-state growth rate of the stock of financial innovations

γ_A^* = steady-state growth rate of the number of intermediate goods

i = index of intermediate goods

A = number of intermediate goods

x = quantity of any intermediate

w_j = wage rate in sector j

r_V = interest rate on transformed savings earned by households

r_K = interest rate paid by financial intermediaries by borrowers (firms)

$p(x_i)$ = price of intermediate good i

P_τ = price of a financial innovation

R_τ = cost of venture capital services rendered by financial intermediaries

π_x = profits earned by a producer of an intermediate good

π_τ = profits earned by a financial innovator

α = capital's share of income generated in final goods production

λ = elasticity of financial innovation production with respect to labor

ϕ = elasticity of financial innovation production with respect to the existing stock of financial products

κ = a measure of the average degree of rivalry in financial products

η = elasticity of R&D production with respect to labor

ψ = elasticity of R&D production with respect to the existing stock of R&D designs

β = elasticity of R&D production with respect to the stock of financial innovations