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TECHNOLOGICAL REVOLUTIONS AND FINANCIAL INNOVATIONS

by

Yuan K. Chou

Department of Economics
The University of Melbourne
Melbourne Victoria 3010
Australia.

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Yuan K. Chou[1]

Department of Economics, University of Melbourne

Abstract
In this paper, we study the symbiotic relationship between financial innovation and technological innovation. In particular, we construct a theoretical macroeconomic growth model that correspond to the thesis presented in Perez (2002) that all the technological revolutions and their associated development surges since the Industrial Revolution have been both beneficiaries and stimulants of financial development. We explain the microeconomic foundations of the model and present its steady state solution, emphasizing how the growth rate of the economy depends on parameters characterising the R&D and financial sectors. We then analyze the impact of specific types of financial innovations that predominate in each phase of the technological cycle on the optimum allocation of resources in the economy.

JEL Codes:G20, O31, O33, O41
JEL Keywords: Financial Innovation, Technological Revolutions, Economic Growth

1. Introduction

The symbiotic and intimate relationship between technological progress and financial development, as well as the strategic complementarity between financial markets and technology, have been recognized by economists for at least some time now, although theoretical explorations into this research area has been sporadic and tentative at best. For example, Santarelli (1995) asserts that the process of technological change cannot be fully understood without identifying its relationship with the features of the financial instruments and institutions that characterize any given historical period. Hicks (1969) believes that the capital market improvements that mitigated liquidity risk were primary causes of the industrial revolution in England. Perez (2002) argues that financial innovations have been responsible for not just this technological revolution, but also in the subsequent four major revolutions (those associated with steam engines and railways, steel and electricity, automobiles and mass production, as well as information and telecommunications). Technological progress in turn stimulates modernization of the financial sector and the development of new financial products and services. The invention of the telex transfer, automated teller machines and Internet banking are examples that spring readily to mind. Theoretical models, however, have hitherto considered the relationship between technological progress and growth and that between financial development and growth largely in isolation. Even when financial development and technological progress are considered together, such as in the model of King and Levine (1993), the relationship is portrayed as one where the former influences the latter. The feedback effect from technological advancement to financial development is ignored.

[1] Address: Department of Economics, University of Melbourne, VIC 3010, Australia. Phone: +61 3 8344 5287 Fax: +61 3 8344 6899 Email: ychou@unimelb.edu.au. The author would like to thank Martin Chin for his research assistance.

In this paper, we develop a three-sector macroeconomic growth model that captures the inter-relationship between real and financial innovations. 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, fuelling economic growth by increasing capital accumulation. 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. The real R&D sector that invents new technologies is modelled along the lines of Romer (1990) and Jones (1995), where technological progress results in an increasing array of intermediate goods that do not suffer from obsolescence. However, our modelling of the R&D sector allows it to influence the rate at which financial innovations are created.

The paper is organized as follows. Section 2 gives an overview of the Perez (2002) theory of the inter-linkages between technological revolutions and financial innovations. In section 3, we present the key equations and microeconomic foundations of our model, as well as its steady state solution and comparative statics. In Section 4, we use the model to analyze the impact of different types of financial innovations on the optimal allocation of resources to the various sectors of the economy. Section 5 concludes.

2. Technological Revolutions and Development Surges

Why does technical change occur by revolutions? Perez (2002) argues that the clustering of innovations is associated with bursts of entrepreneurship, which arise in response to opportunity explosions. The bunching of opportunities occurs with the appearance of a new techno-economic paradigm, which defines a new design, product and profit space that can set alight the imagination of potential innovators. The favorable conditions for the next revolution are created when the potential of the previous one approaches exhaustion.[2]

Perez defines a technological revolution as a powerful and highly visible cluster of new and dynamic technologies, products and industries, capable of engendering an upheaval of the entire fabric of the economy and of propelling a long-term upsurge of development. “It is a strongly related constellation of technological innovations, generally including an important all-pervasive low-cost input, often a source of energy, sometimes a crucial material, plus significant new products and processes and a new infrastructure.” (p.8) The sets of technological breakthroughs spreads far beyond the industries and sectors where they originate, providing a set of interrelated generic technologies and organizational principles that fosters a quantum leap in productivity for almost all economic activities.

2.1 The Phases of a Development Surge

The development surge or technological revolution may be separated into two halves ('deployment' and 'installation') on either side of a turning point (see Fig.1). Within the deployment stage, the revolution may be further divided into two separate phases: *irruption* and *frenzy*. The installation period is the time when new technologies irrupt in a previously maturing economy, disrupting the established fabric and spreading new and superior ways of

[2] Others, for example Mensch (1974), have also provided strong evidence that basic innovations do tend to arise in clusters.

doing things. In the deployment period, the fabric of the entire economy is rewoven and reshaped by the modernizing power of the new triumphant paradigm, which becomes the new best practice and norm, enabling the full unfurling of its wealth generating possibilities.

2.1.1 Irruption

The *irruption* phase occurs just after the ‘big bang’. New products and technologies, backed by financial capital, are revealing their future potential and carving strong inroads in a world still predominantly shaped by the previous paradigm. There is a large quantity of potential investment funds in the market still generated by the firms of the old paradigm. The amazing growth and productivity increases of the new industries attract new investors, consumers and new competing entrepreneurs.

2.1.2 Frenzy

Frenzy is the subsequent phase of the installation period, when financial capital reigns supreme. The paper economy decouples from the real economy as finance becomes divorced from production. It is a time characterized by speculation, corruption and worship of wealth such as that witnessed during the IT bubble of the late 1990s. Most of the excess money is used to further the revolution, especially its infrastructure (canal mania, railway mania, Internet mania etc), frequently leading to over-investment, resulting in a financial bubble that inevitably collapses. The *frenzy* therefore involves the untenable acceleration of the diffusion of the paradigm. The recession that usually follows marks the turning point in the technological revolution, creating the conditions for institutional restructuring and for re-routing growth onto a sustainable path. However, the frenzy phase is also one where all the possibilities unleashed by the technological revolution are explored. Through bold and experimental investment, the potential of the diffusing paradigm is completely discovered and firmly entrenched in the economy and in the minds of investors.

2.1.3 Synergy

Synergy forms the early half of the deployment period, and it can be considered the 'golden age' of the technological revolution. The basic externalities for the build-out of the revolution, especially the infrastructure, were installed during the frenzy phase, in addition to the basic investment in the industries that are the drivers of growth. The conditions are then ripe for dynamic expansion and economies of scale. The new paradigm now reigns supreme, its logic permeating every activity, from business to government to education.

2.1.4 Maturity

This represents the twilight of the golden age, the drive to maturity of the paradigm and to the gradual saturation of markets. As profits begin to suffer from the constriction of productivity increases, ways are sought to prop them up, often involving concentration through mergers and acquisitions (as well as export drives and migration of activities to less-saturated markets overseas).

2.2 Development Surges in History

Perez argues that economics growth since the 18^{th} century has passed through five distinct stages, associated with five successive technological revolutions: The ‘Industrial Revolution’, the ‘Age of Steam and Railways’, the ‘Age of Steel, Electricity and Heavy Engineering’, the

‘Age of Oil, the Automobile and Mass Production’, and the ‘Age of Information and Telecommunications’ (see Table 1).

Each of these revolutionary clusters irrupted in a specific country or even a specific region. For example, Lancashire was both the cradle and symbol of the key industries of the first industrial revolution while Silicon Valley is the counterpart for the current microelectronics revolution. Moreover, each technological revolution originates from a core country before diffusing and propagating to other countries.

Before coming together as an entity, each technological revolution undergoes a gestation period that may be very lengthy. However, it is possible in every instance to find a single defining event (the “big bang”) that marks the beginning a technological revolution. A highly visible ‘attractor’ appears (such as Robert Louis Stephenson’s contest-winning ‘Rocket’ steam locomotive, Andrew Carnegie’s efficient new Bessemer steel plant in Pittsburgh, and Intel’s first microprocessor in 1971), symbolic of the enormous potential of the revolution and a catalyst for the technological and business imagination of a cluster of pioneers.

Technological Revolution	*Popular name for the period*	*“Big-bang” initiating the revolution*	*Year*
First	The ‘Industrial Revolution’	Arkwright’s mill opens in Cromford	1771
Second	Age of Steam and Railways	Test of the ‘Rocket’ steam engine for the Liverpool-Manchester railway	1829
Third	Age of Steel, Electricity and Heavy Engineering	The Carnegie Bessemer steel plant opens in Pittsburgh, Pennsylvania	1875
Fourth	Age of Oil, the Automobile and Mass Production	First Model-T produced at the Ford plant in Detroit, Michigan	1908
Fifth	Age of Information and Telecommunications	The Intel microprocessor is announced in Santa Clara, California	1971

Table 1. Five successive technological revolutions, 1770-2000
Source: Perez (2002)

2.3 Technological Revolutions and Financial Development

2.3.1 Financial Innovations and Development Surges in History

According to Hicks (1969), as mentioned previously, 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 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 institutionalised financial capital. The more recent microelectronics, computers and software explosion was characterized by the emergence of a bountiful supply of risk and venture capital underwriting the introduction of successive new products and services. But the link between financial and technological developments goes both ways. To facilitate the purchasing of new products and services, appropriate credit instruments are often required. For example, after World War I, when the fourth technological revolution was diffusing vigorously, hire-purchase credit systems were developed to enable new home durables, such as refrigerators,

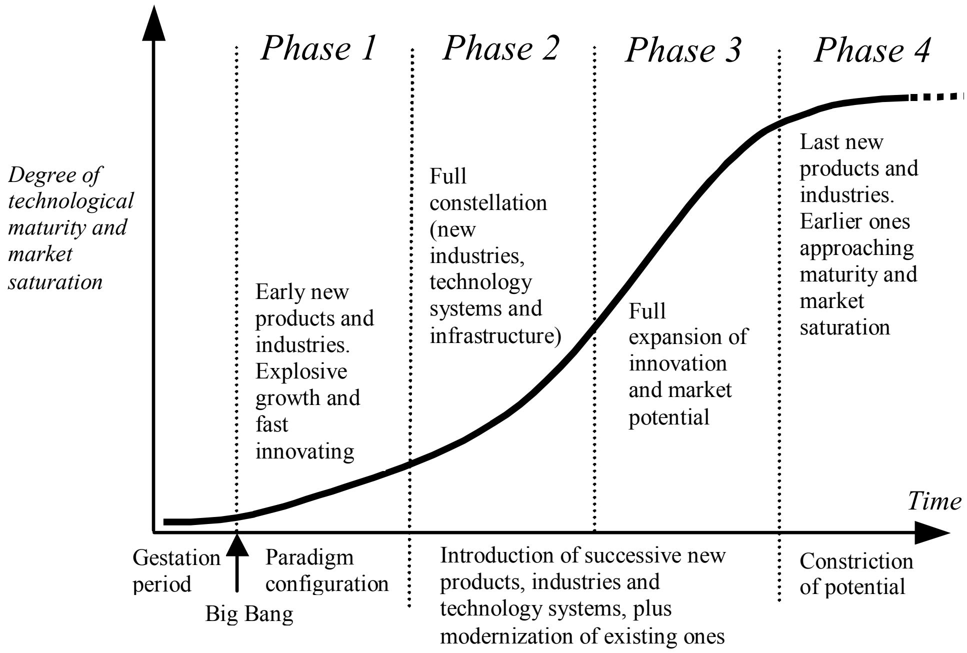

Fig 1. The life cycle of a technological revolution
Source: Perez (2002)

vacuum cleaners and automobiles to be paid for from monthly salaries. The development and diffusion of each technological revolution therefore tends to stimulate innovations in finance and then benefit from the impulse they generate.

2.3.2 Financial Capital and the Development of New Paradigms

As the old paradigm matures and fizzles out, financial capital seeking high returns no longer found from further investment in economic activities associated with the old paradigm become available for new entrepreneurs to bring their ideas into commercial reality. The exhaustion of a paradigm thus brings with it both the need for radical entrepreneurship as well as the idle capital to take the risks associated with trial and error.

Within this climate, various strands of innovation come together: those from large firms attempting to overcome technical obstacles, those from entrepreneurs with novel ideas and others associated with under-utilized or marginalized innovations introduced previously. Eventually, the required breakthroughs are achieved and recognized, and brought together with other new or redefined technologies to spearhead the next technological revolution. New financial instruments are developed at this time to accommodate the peculiarities of the new products and their diffusion.

2.3.3 Financial Capital and the ‘Irruption’ and ‘Frenzy’ Phases

Immediately following the big bang that heralds a technological revolution, financial capital rushes towards the new revolutionary entrepreneurs who outperform the profit-making potential of the established production sectors. Appropriate new instruments are developed where necessary. There is a prevailing innovative attitude in the creation of risk capital instruments on the part of financial capital.

In the ‘frenzy’ phase of each technological revolution, asset inflation often results from the desire of financiers, who having become used to the enormous returns experienced in the ‘irruption’ phase, to make money from money. Consequently, an entire range of purely financial, speculative instruments are created or reinvented and applied to make more wealth out of existing wealth, some of which are legally questionable. In addition, leveraged buy-outs of existing companies become more commonplace, together with speculation in real estate, gold or other precious metals, futures markets, art, hedge funds and other instruments of financial manipulation that serve the purpose of using money that cannot find profitable use in productive activities.

2.3.4 Adoption of New Technologies by the Financial World

As noted in Section 2.3.1, each technological revolution acts as a catalyst for financial innovation and development. Balling (2003) notes that technology has important implications for the earnings, costs, risks and competitiveness of financial institutions, and affects the way securities transactions are carried out, the transparency of the markets, settlement activities and the structure of the exchange industry. Llewellyn (2003) argues that new technology (in information processing, trading and delivery) affects management methods, production processes, entry of competitors, and distribution channels in the banking sector.[3]

On the other hand, by being one of the most voracious clients for its products and services, the financial sector propels each technological revolution in an indirect but significant way. Perez (2002) argues that among the technological, infrastructural and organizational innovations of each paradigm are those that accelerate the transport and transmission of goods and information. These in turn serve as a source of innovation in money, banking and the financial sector itself. For example, banks were early customers of the national railways and telegraphy in the beginning of the second technological surge, as well as the international railways, steamships, telephone, typewriter and calculator from the start of the third revolution. The pace of adoption of information and telecommunications technologies by the banking and financial systems has been equally impressive since the mid-1970s.

3. The Model

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 The Key Equations

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 shown in Table 2. We denote the stock of financial products (that is, old financial innovations) as τ.

In the Perez typology of financial innovations, type A and B innovations are those related to the basic role of finance as an intermediary in relation to production investment, either to initiate activities (A), or for growth, expansion and extension (B). Type C innovations improve the performance of the financial world itself as a service production activity. Type D innovations reduce the apparent risk of investment activities for clients and facilitate the

[3] A European Central Bank (1999) report states: ‘The developments in information collection, storage, processing, transmission and distribution technologies … have an impact on practically all aspects of banking and can be regarded as one of the main driving forces for change in the banking sector …’.

profit-taking of the original investors, in the case of venture capital, and of subsequent investors. Type E innovations point to the role of financial services as vehicles for mobilizing existing assets or facilitating the change of ownership of these assets. Finally, type F innovations are the manipulative activities practiced by financial agents that are socially undesirable even if they are sometimes legitimate.

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 2. Types of financial innovations.
Source: Perez (2002)

3.1.1 Financial Innovation

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

$$\dot{\tau} = F\left(u_{\tau}L\right)^{\lambda} \tau^{\phi} A^{\varepsilon} \tag{1}$$

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". Finally, $\varepsilon \in (0,1)$ measures the impact of technological innovations on the rate of financial innovation. (Recall the discussion in section 2.3.4.)

3.1.2 Financial Intermediation

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.

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

$$\xi = \frac{\tau}{A^{\omega}L^{\kappa}} \qquad (2)$$

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. Our model allows for κ to be infinitely small but not zero.

In a similar vein, holding the stock of financial products constant, the efficiency of intermediation decreases as the level of technology rises. This specification attempts to capture the fact, with technological progress, economic agents' demands on the financial system increases. For example, as individuals become accustomed to the speed and convenience of exchanging information over the Internet, they no longer find the hassle of conventional branch banking acceptable. Internet banking, electronic payment systems that facilitate e-commerce, and internet-based stock trading are examples of innovations devised to satisfy their growing demands. These innovations do not automatically increase ξ since the amount of money individuals invest in the stock market or the volume of funds raised by firms through the stock market may not have changed.

3.1.3 Capital Accumulation and Production

The capital accumulation process therefore takes the form:

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

where K denotes the stock of capital, C is the level of aggregate consumption, and δ is the rate at which capital depreciates.

The aggregate production function for the final good, Y, is of the Cobb-Douglas form:

$$Y = K^{\alpha}(Au_Y L)^{1-\alpha} \qquad (4)$$

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) even as the stock of financial products, τ, continues to grow. 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.

3.2 Microeconomics of the Model

3.2.1 The Financial Sector

Tufano (1989)'s empirical finding on the pricing behaviour 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 arise. 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

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

where $\tilde{F} \equiv F\tau^\phi A^\psi$. In the decentralized model, financial innovators do not internalize the spillover effects from the existing stock of financial products and from technological progress. They treat $\tilde{F}$ as exogenously given.

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

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

where P_τ is the price of each financial innovation and w_τ is prevailing wage for labor hired by financial innovators. While financial innovators benefit from the technological innovations that raise the level of technology *A*, they do not have to pay for these benefits. The first order condition implies that

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

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

Downstream in the financial sector, financial intermediaries purchase innovations from financial innovators and use them in transforming savings into productive investment as well as the funding of real R&D activities. As the focus of our model is on financial intermediaries, 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 m 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:

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

3.2.2 The Real R&D Sector

We next examine the production of new designs in the real R&D sector. The rate of real innovation is given by

$$\dot{A} = \tilde{B}\left(u_A L\right)^\eta \tau^\beta , \tag{9}$$

$$\tilde{B} \equiv BA^\psi ,$$

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, R&D firms also do not take into account spillovers from existing designs, so they regard $\tilde{B}$ as exogenously given. Moreover, as argued previously, a more sophisticated financial sector (with a larger stock of financial products, 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 in bringing these technological innovations to the market.

Each R&D firm derive 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.

3.2.3 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:

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

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

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

where w_Y is the prevailing wage in the final goods sector and $p(x(i))$ 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

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

3.2.4 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. 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:

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

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

and

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

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

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

we can rewrite the aggregate final goods production function as

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

3.2.5 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 all firms. Their optimisation problem is:

$$\max \int_0^{\infty} \frac{C^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt ,$$

subject to

$$\dot{V} = r_V K + w_Y u_Y L + w_\tau u_\tau L + w_A u_A L + A\overline{\pi}_x + \pi_\tau + \pi_A - P_A \dot{A} - C,$$

$$\dot{K} = \xi \dot{V} ,$$

$$1 = u_Y + u_\tau + u_A , \tag{23}$$

where $\dot{V}$ represents the flow of households' stock of assets (that is, savings), $\overline{\pi}_x$, 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 three labor markets, i.e. $w_Y = w_\tau = w_A$. These conditions together with the equation (8) yield the following budget constraint:

$$\dot{K} = \xi \left(r_K K + \overline{w} u_Y L + \overline{w} u_A L + R_t \tau + A\overline{\pi}_x + \pi_A - P_A \dot{A} - C \right). \tag{24}$$

3.3 Solving the Model

We now derive the solution to 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 innovation activities.

3.3.1 The Planner's Problem

The representative agent in this economy seeks to

$$\max \int_0^{\infty} \frac{C^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt ,$$

subject to

$$\dot{K} = \xi\left[K^{\alpha}\left(Au_Y L\right)^{1-\alpha} - C\right] - \delta K,$$
$$\dot{\tau} = F\left(u_\tau L\right)^{\lambda}\tau^{\phi}A^{\varepsilon},$$
$$\dot{A} = B\left(u_A L\right)^{\eta}\tau^{\beta}A^{\psi},$$
$$1 = u_Y + u_t + u_A. \tag{25}$$

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

$$\begin{aligned} \mathrm{H} \equiv\ & \frac{C^{1-\theta}-1}{1-\theta}e^{-\rho t} + \nu\left\{x\left[K^{\alpha}\left(Au_Y L\right)^{1-\alpha} - C\right] - \delta K\right\} \\ & + \mu F\left(u_\tau L\right)^{\lambda}\tau^{\phi}A^{\varepsilon} + \upsilon B\left(u_A L\right)^{\eta}\tau^{\beta}A^{\psi}, \end{aligned} \tag{26}$$

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 their associated costate variables. The first order conditions yield the following equations:

$$\frac{\dot{c}}{c} = -\frac{1}{\theta}\left(\rho + \frac{\dot{\nu}}{\nu} + \frac{\dot{\xi}}{\xi}\right), \tag{27}$$

$$\frac{\nu}{\upsilon} = \frac{\eta}{1-\alpha}\cdot\frac{B\left(u_A L\right)^{\eta}\tau^{\beta}A^{\psi}}{\xi K^{\alpha}\left(Au_Y L\right)^{1-\alpha}}\cdot\frac{u_Y}{u_A}, \tag{28}$$

$$\frac{\mu}{\upsilon} = \frac{\eta}{\lambda}\cdot\frac{B\left(u_A L\right)^{\eta}\tau^{\beta}A^{\psi}}{F\left(u_\tau L\right)^{\lambda}\tau^{\phi}A^{\varepsilon}}\cdot\frac{u_\tau}{u_A}, \tag{29}$$

$$\frac{\dot{\nu}}{\nu} = \xi\alpha\hat{k}^{\alpha-1}u_Y^{1-\alpha} - \delta, \tag{30}$$

$$\begin{aligned} \frac{\dot{\mu}}{\mu} =\ & \frac{\lambda}{1-\alpha}\cdot\frac{F\left(u_\tau L\right)^{\lambda}\tau^{\phi-1}A^{\varepsilon}}{\hat{k}^{\alpha-1}u_Y^{1-\alpha}}\cdot\frac{u_Y}{u_\tau}\left(k^{\alpha-1}u_Y^{1-\alpha} - \frac{\hat{c}}{\hat{k}}\right) \\ & + F\left(u_\tau L\right)^{\lambda}\tau^{\phi-1}A^{\varepsilon}\left(\phi + \frac{\lambda\beta}{\eta}\frac{u_A}{u_t}\right), \end{aligned} \tag{31}$$

$$\frac{\dot{\upsilon}}{\upsilon} = B\left(u_A L\right)^{\eta}\tau^{\beta}A^{\psi-1}\left[\frac{\eta(1-\alpha-\omega)}{1-\alpha}\frac{u_Y}{u_A} + \frac{\eta\varepsilon}{\lambda}\frac{u_t}{u_A} + \psi\right], \tag{32}$$

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

$$\lim_{t\to\infty} \nu(t)K(t) = 0,$$
$$\lim_{t\to\infty} \mu(t)\tau(t) = 0,$$
$$\lim_{t\to\infty} \upsilon(t)A(t) = 0.$$

3.3.2 Implications of the Model

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_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 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 $\kappa n + \omega\gamma_A^*$.

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

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

$$\frac{\dot{\gamma}_\tau}{\gamma_\tau} = \lambda\left(\frac{\dot{u}_\tau}{u_\tau} + n\right) - \left(1-\phi\right)\gamma_\tau + \varepsilon\gamma_A. \tag{33}$$

Since γ_τ and u_τ are both constant in the steady state,

$$\gamma_\tau = \frac{\lambda n + \varepsilon\gamma_A}{1-\phi}. \tag{34}$$

As $\xi \equiv \tau/(A^\omega L^\kappa)$,

$$\frac{\dot{\xi}}{\xi} = \frac{\dot{\tau}}{\tau} - \omega\frac{\dot{A}}{A} - \kappa n. \tag{35}$$

Substituting in γ_τ from the previous line, the constancy of ξ in the steady state means that

$$\frac{\lambda n + \varepsilon\gamma_A}{1-\phi} = \omega\gamma_A + \kappa n. \tag{36}$$

Therefore, $\kappa = \lambda/(1-\phi)$ and $\omega = \varepsilon/(1-\phi)$.

■

Proposition 2 *The steady state growth rate of the economy,* γ_A^* *must be equal to* $\left[\eta(1-\phi)+\beta\lambda\right]n/\left[(1-\psi)(1-\phi)-\beta\varepsilon\right]$.

Proof. Let $\gamma_A \equiv \dot{A}/A = B\left(u_A L\right)^\eta \tau^\beta A^{\psi-1}$. Differentiating the logarithm of γ_τ with respect to time yields

$$\frac{\dot{\gamma}_A}{\gamma_A} = \eta\left(\frac{\dot{u}_A}{u_A} + n\right) + \beta\gamma_\tau + (1-\psi)\gamma_A. \tag{37}$$

Since γ_A and u_A are both constant in the steady state,

$$\gamma_A = \frac{\eta n + \beta\gamma_\tau}{1-\psi}. \tag{38}$$

From Proposition 1, we found that $\gamma_\tau = \left(\lambda n + \varepsilon\gamma_A\right)/(1-\phi)$. Solving for γ_A and γ_τ simultaneously yields

$$\gamma_A^* = \frac{\left[\eta(1-\phi)+\beta\lambda\right]n}{(1-\psi)(1-\phi)-\beta\varepsilon}. \tag{39}$$

■

The growth rate of the economy is a monotonically increasing function of the parameters λ, ϕ, η, β, ε and ψ which govern the production of financial innovations $\dot{\tau}$ and technological innovations $\dot{A}$.

3.3.3 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 $\dot{u}_t/u_\tau = 0$) that enable us to solve analytically for the five key variables of the model. Expressed sequentially, the solution is:

$$u_Y^* = \frac{\Phi(\Psi_2+\Delta)-\Delta(\Gamma_2+\Phi)}{(\Gamma_1+\Phi)(\Psi_2+\Delta)+(\Gamma_2+\Phi)(\Psi_1-\Delta)}, \tag{40}$$

$$u_\tau^* = \frac{(\Psi_1-\Delta)u_Y^*+\Delta}{\Psi_2+\Delta}, \tag{41}$$

$$\xi^* = \left(\frac{Fu_\tau^{*\lambda}}{\kappa n}\right)^{\frac{1}{1-\phi}}, \tag{42}$$

$$\hat{k}^* = \left(\frac{\alpha\xi^*}{\theta\gamma_A^*+\rho+\delta}\right)^{\frac{1}{1-\alpha}} u_Y^*, \tag{43}$$

$$\hat{c}^* = \frac{\theta\gamma_A^*+\rho+\delta-\alpha(\gamma_A^*+n+\delta)}{\alpha}\cdot\frac{\hat{k}^*}{\xi^*}, \tag{44}$$

where

$$\Gamma_1 \equiv \eta(1-\alpha-\omega)\gamma_A^*,$$
$$\Gamma_1 \equiv \eta\varepsilon\gamma_A^*,$$
$$\Phi \equiv (1-\alpha)\left[(\theta-\psi)\gamma_A^*+\rho-n\right].$$

3.4 Comparative Statics

3.4.1 Calibration

As can be seen in equations (40)-(44), the solution to the model's key variables are complicated functions of the parameters characterizing the various sectors of the model economy. As such, we cannot perform comparative statics analytically. Instead, we first calibrate the model and compute the comparative statics numerically. The results of this exercise are shown in graphical form. Table 3 shows the chosen baseline values for the parameters of the model.

α	β	η	ε	κ	λ	ω	ϕ	ψ	δ	ρ	θ	n	B	F
0.33	0.2	0.67	0.1	0.83	0.67	0.125	0.2	0.2	0.05	0.02	1.5	0.02	1	0.037

Table 3. Baseline values for the model's parameters

3.4.2 The Impact of Parameter Values on the Steady State Allocation of Labor

From Fig.2, we see that an increase in the rate of time preference, ρ, and the desire for consumption smoothing, θ, increases the steady state allocation of labor (and the embodied human capital) to final goods production, u_Y^*, and reduces the allocation of labor to R&D and financial innovation, u_A^* and u_τ^* respectively. The intuition is straightforward: as households become more impatient, they care more for current consumption than future consumption. More labor is channelled to the final goods sector to produce the consumption good, and correspondingly less labor is devoted to real R&D and financial innovation activities.

In addition, an increase in the intertemporal spillover effect of current financial innovation on future financial innovation, as captured by ϕ, increases the steady state allocation of labor to financial innovative activities, u_τ^*, and decreases the allocation of labor to final goods production and R&D. In a similar vein, an increase in the intertemporal spillover effect of current real R&D on future R&D increases u_A^* but reduces u_Y^* and u_τ^*.

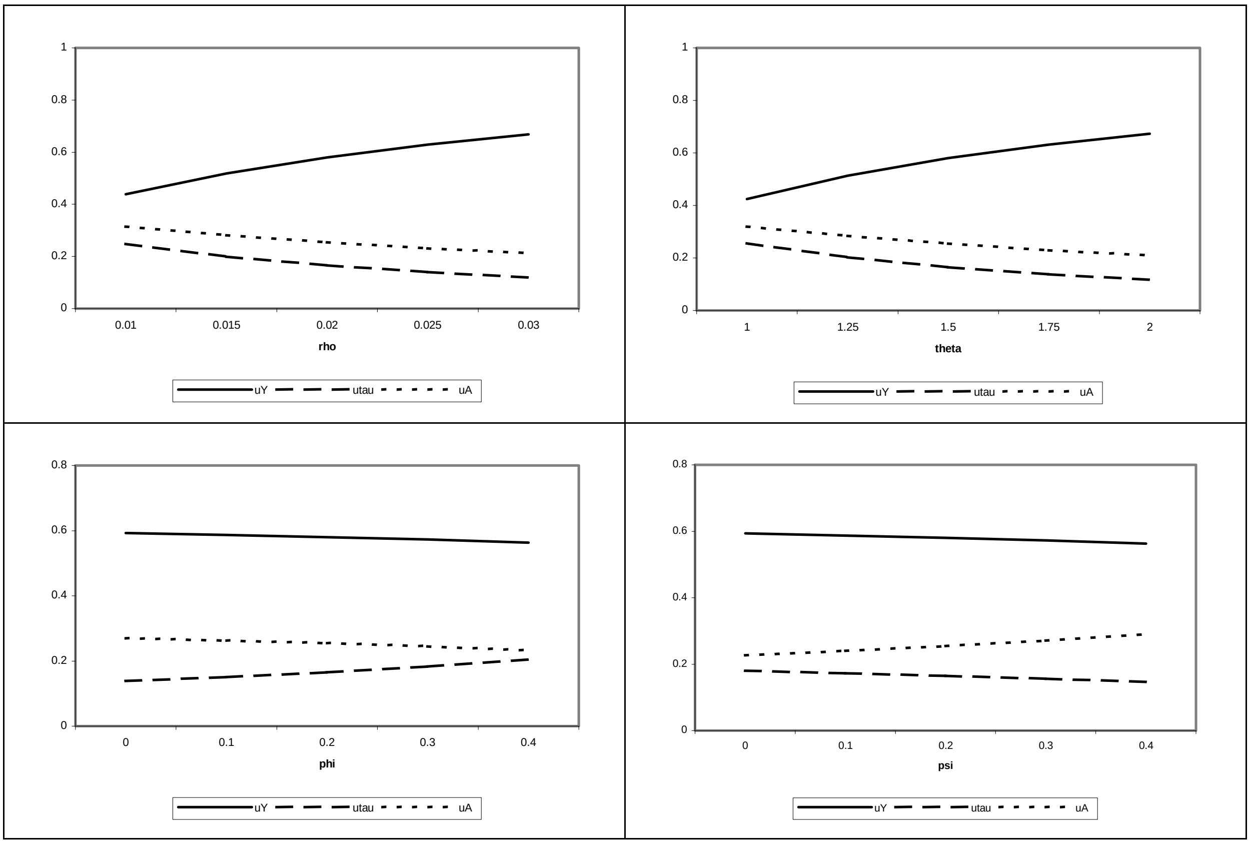

Fig.2 The Impact of ρ, θ, ϕ and ψ on the allocation of labor

4. Modelling the Development Surge

4.1 The Changing Nature of Financial Innovations through Phases of the Technological Revolution

Although innovations of all types may occur in all phases of the technological revolution, the frequency of each type may change significantly. The 'irruption' phase, occurring just after the 'big bang', presents the maximum intensity and variety of innovations. It will provide a crop of type A innovations (see Table 1), involving venture capital. Concurrently, new ways of financing development of the periphery (type B innovations) are likely to accompany the last period of diffusion of the old industries. Moreover, type C innovations will also abound as the financial world incorporates technological advances in communications, security and printing etc as well as organizational changes that allow higher productivity and wider coverage for their services. Finally, in the irruption phase the bulk of the industries of the old paradigm are mature and offer few good investment opportunities, so that idle money accumulates and fosters innovations of types D, E and F. (See Table 4.)

In the 'frenzy' phase, the limit to the absorptive capacity of the still incipient technologies and methods of production generates a profitability gap. The resulting urge to mimic the high profitability levels of the new industries attracts more and more investors into the bubble economy, moving the pendulum towards type D, E and F innovations. After the bursting of the bubble, between 'frenzy' and the golden age of early Deployment, that is, in the 'synergy' phase, type A, B and C innovations will tend to dominate in the form of adaptive innovations to accompany the full deployment of the paradigm. By 'maturity', in contrast, decreasing opportunities are being pursued by more and more idle money generated from the 'cash cows' of the established industries. Creativity in finance thus moves towards type E innovations for concentration of ownership and power. Other innovations in this phase attempt to search for dubious means of propping up profits. They are likely to be of type F, often characterized by efforts to increase opacity to stockholders or to fiscal authorities.

Phase	*Prevalent types of innovation*						*Prevalent characteristics of finance during the phase*
	A	B	C	D	E	F	
Irruption	■	■	■	■	■	■	Maximum intensity of real financial innovation
Frenzy				■	■	■	Escape control, attract funds, speculate, inflate assets
Synergy	■	■	■				Adaptive innovations to accompany growth
Maturity		■			■	■	Accompany outspreading, escape, control and manipulate

Table 4. The shifting behavior of financial capital through phases of the technological revolution

Source: Perez (2002)

4.2 Analyzing the Impact of Specific Types of Financial Innovations

4.2.1 Type A Innovations: Increase in β

Recall from Table 2 that Type A financial innovations are financial instruments that aid innovative real activities, such as bank loans, venture capital, and joint stock. The predominance of these innovations during the 'irruption' and 'synergy' phases of the technological cycle may be modelled as an increase in β, the parameter characterizing the extent of spillovers from financial development on the rate of technological innovation.

From Fig. 3a and Fig. 3b, we can see that an increase in β increases the steady state growth rate of the economy, and causes labor (and the embodied human capital) to be reallocated from the final goods and real R&D sector into the financial innovation sector.

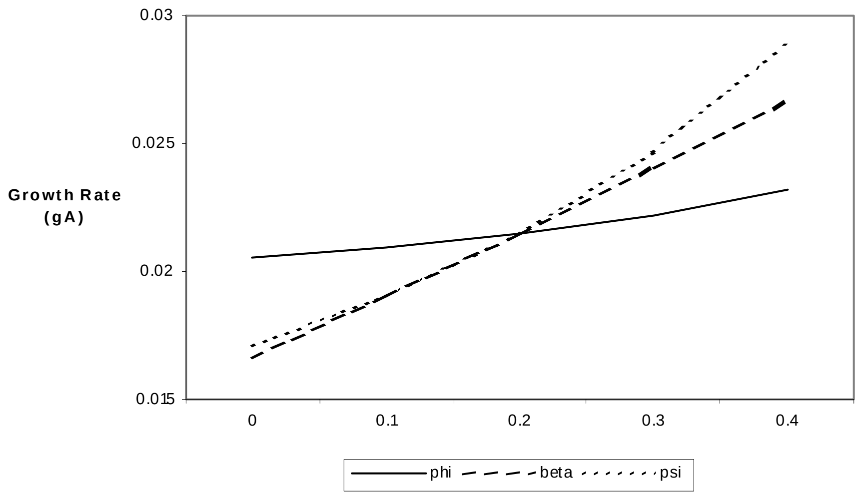

Fig. 3a: The impact of an increase in β, ϕ, and ψ on the economy's growth rate

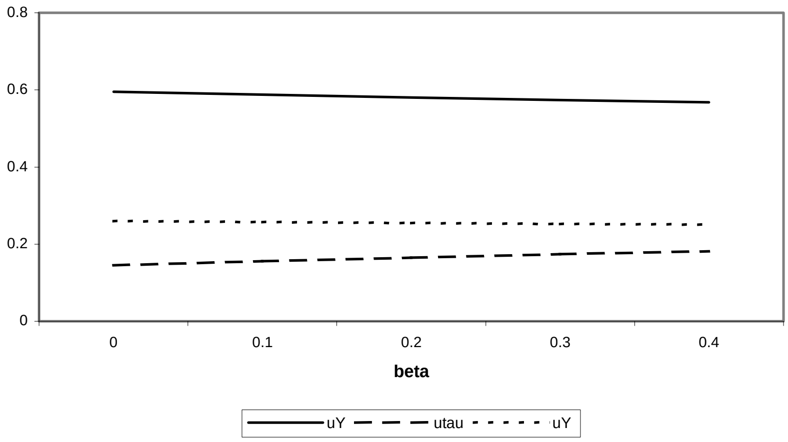

Fig 3b. The impact of an increase in β on the allocation of labour

4.2.2 Type C Innovations: Increase in ε

Type C innovations are those that concern the modernization of the financial services themselves. Historical examples include the invention of the telegraph transfer of funds, personal checking account, ATM, and electronic banking. We model this type of innovation as an increase in ε, the parameter measuring the elasticity of spillovers from real R&D into financial innovation.

From Fig. 4a and Fig. 4b, we see that an increase in ε increases the steady state growth rate of the economy, and causes labor to be reallocated from the real R&D sector into the final goods and financial innovation sectors.

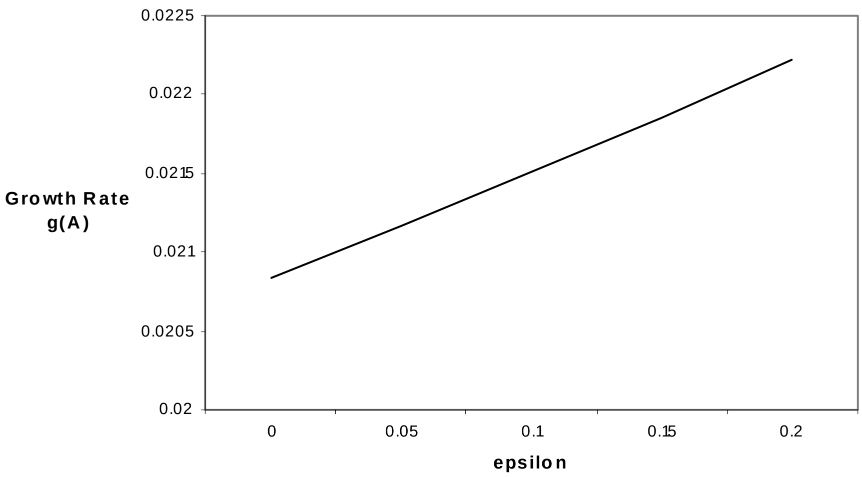

Fig. 4a: The impact of an increase in ε on the economy's growth rate

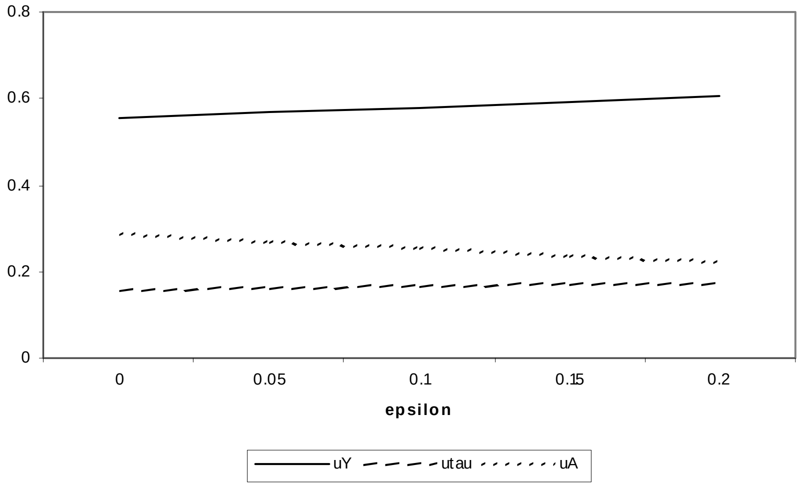

Fig 4b. The impact of an increase in ε on the allocation of labour

4.2.3 Types B, D and E Innovations: Increase in

Type B financial innovations refer to financial instruments that assist corporate growth or expansion, such as bonds. Type D innovations facilitate profit-taking and help to spread investment and risks, such as mutual funds, CDs, bonds, IPOs, junk bonds, derivatives, and hedge funds. Type E innovations are instruments or activities to refinance obligations or mobilize assets, such as Brady Bonds, swaps, acquisitions, mergers, takeovers, and futures. Types B, D and E innovations are particularly effective in improving the efficiency of financial intermediation. In the simplest and most straightforward instance, we may model the prevalence of these types of innovations over the other types as an increase in the productivity parameter in the dynamic equation for financial innovation, F. That is, for the same amount of human resources channelled into the financial innovation sector, more financial innovations are created per unit time, leading to a greater increase in τ, and consequently, ξ. While the steady state growth rate of the economy and the distribution of labor across sectors remain unchanged, equations (42) - (44) indicate that the efficiency of financial intermediation, per-capita consumption, c^*, and capital per worker, k^*, will be permanently increased. In particular,

$$k^* = A\hat{k}^* = A_0 e^{\gamma_A^*} \left(\frac{\alpha \xi^*}{\theta \gamma_A^* + \rho + \delta} \right)^{\frac{1}{1-\alpha}} u_Y^*, \tag{45}$$

$$c^* = A\hat{c}^* = A_0 e^{\gamma_A^*} \frac{\theta \gamma_A^* + \rho + \delta - \alpha \left(\gamma_A^* + n + \delta \right)}{\alpha} \cdot \frac{\hat{k}^*}{\xi^*}. \tag{46}$$

where A_0 is the initial level of technology in the economy.

4.2.4 Type F Innovations

Type F innovations do not result in additional real production or the creation of new wealth. Instead, such rent-seeking activities merely serve to redistribute existing income. Worse yet, they may erode public confidence in the financial system and reduce the efficacy of financial intermediation. That is, they have the opposite effect as innovations of types B, D and E.

5. Conclusion

In this paper, we constructed a macroeconomic growth model that embodies the thesis in Perez (2002) that financial and technological innovations have been inseparable and mutually reinforcing in each of the technological revolutions that have occurred since the beginning of the eighteenth century, beginning with the Industrial Revolution that occurred in Britain. In our model, financial innovations lead to improvements in the efficiency of financial intermediation. This enhanced mobilization of financial capital also spurs the invention and diffusion of new technologies. Conversely, the technological revolution acts as a catalyst for financial innovation and development. A recent example is the invention of computer networking technologies that enable Internet banking. We explained the key equations in the model and laid out its microeconomic foundations, including the optimization problems facing financial innovators, financial intermediaries, real R&D firms and households. We then examined the comparative statics that arise from the steady state solution to the model. In addition, we used the model to analyze the macroeconomic impact of specific types of financial innovations that predominate in each phase of the technological cycle. Future research possibilities including running dynamic simulations of the model where the varying propensities for each type of financial innovation over the technological cycle are treated as a continuous series of shocks to parameters that characterize the model's real and financial sectors.

References

Balling, M., Lierman, F. and A. Mullineux (eds) (2003): *Technology and Finance: Challenges for Financial Markets, Business Strategies and Policy Markets*. Routledge, New York.

Budworth, D. (1996): *Finance and Innovation*. Thomson, London.

European Central Bank (1999): *Technology and European Banking*. ECB, Brussels.

Gomulka, S. (1990): *The Theory of Technological Change and Economic Growth*. Routledge, London.

Herrera, H., and E. Schroth (2001): "Implications of Non-Patentable Financial Innovations," New York University Stern School of Business Working Paper BCES-01-03.

Jones, C.I. (1995): "Research and Development Based Models of Economic Growth," *Journal of Political Economy*, 103, 759-784.

Jones, C.I. (2002): *Introduction to Economic Growth, 2nd Edition*. W.W. Norton, New York.

King, R. and R. Levine (1993): "Finance, Entrepreneurship, and Growth: Theory and Evidence", *Journal of Monetary Economics*, 32, 513-542.

Llewellyn, D.T. (2003): "Technology and the New Economics of Banking: A UK Perspective" in Balling et al. (eds) *Technology and Finance: Challenges for Financial Markets, Business Strategies and Policy Markets*. Routledge, New York.

Mensch, G. (1974): "Institutional Barriers to Science and Technology Interaction" in H.F. Davidson *et al*. (eds) *Technology Transfer*. Nordhoff, Leiden.

Perez, C. (2002): *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Edward Elgar, Cheltenham, UK.

Ramsey, F. (1928): "A Mathematical Theory of Saving," *Economic Journal*, 38, 543-559.
Cass, D. (1965): "Optimum Growth in an Aggregative Model of Capital Accumulation," *Review of Economic Studies*, 32, 233-240.

Romer, P. M. (1990): "Endogenous Technological Change," *Journal of Political Economy*, 98, S71-S102.

Santarelli, E. (1995): *Finance and Technological Change: Theory and Evidence*. Macmillan, London.

Solow, R. M. (1956): "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, 70, 1, 65-94.

Tufano (1989): "Financial Innovation and First-Mover Advantages," *Journal of Financial Economics*, 25, 213-240.

Tufano (2002): "Financial Innovation", forthcoming in *The Handbook of the Economics of Finance*. North-Holland, Amsterdam.