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MODELLING THE IMPACT OF NETWORK SOCIAL CAPITAL ON BUSINESS AND TECHNOLOGICAL INNOVATIONS

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Modelling the Impact of Network Social Capital on Business and Technological Innovations

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Abstract
In this paper, we construct a macroeconomic growth model where social capital embedded in collaborative networks of firms (such as corporate partnerships and research consortia) increase the rate of technological and business innovations in high-tech industries. Social capital is created via network-building activities and through "learning-by-doing". We derive the optimal quantity of resources that should be channelled away from pure production into activities that build network social capital, and study both the comparative statics and transitional dynamics of the model. We also examine the implications of the model for policymakers interested in formulating innovation policies.

JEL codes: O31, O41, Z13
JEL keywords: Technological progress, business innovations, social capital, economic growth

1. Introduction

In developed countries, the "New Economy" of the 1990s and the new millennia has witnessed a distinct gravitation towards inter-organizational linkages in the form of partnerships and consortia. Many firms and industries have formed productive collaborative relationships with other firms, laboratories and universities, as well as local and national governments to leverage the benefits of cooperation. These relationships involve shared resources, group problem-solving, multiple sources of learning, collaborative development, and diffusion of innovation. The reason for this trend is that the investments required to sustain technology development and deployment have increased to such an extent that single firms are often unable to undertake the level of risk necessary for innovation.

Fountain (1998) argues that gains in economic performance and innovative capacity depend on the institutional effectiveness of these relationships as measured by the available stock of social capital. Social capital is created when a group of organizations develops the ability to work together for mutually productive gain. The relationships between the organizations may be horizontal among similar firms in associations, vertical in supply chains, and multidirectional in their linkages to sources of technical knowledge, human resources, and public agencies. Cooperation paradoxically enhances competitiveness, information sharing leads to joint gains, while the importance of reputation and trust ensure reciprocity and fair play within a given network. Social capital is located both in the sharable resources held by individual institutions in a network as well as in the overall structure of the network. Social

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capital is preserved by careful selection of network players and strict sanctioning of inappropriate network-destroying behavior.

Fountain gives two examples of high-performance network structures that have developed significant levels of intra-network trust. The first describes the ways in which firms in the biotechnology industry partner to remain at the forefront of research and development. The second examines the dynamics that undergird regional industrial systems, as exemplified by the semiconductor industry in Silicon Valley.

In this paper, we extend the Romer (1990) / Jones (1995) growth model with endogenous technological progress to incorporate network social capital.[2] Network social capital increases the gains from collaboration between firms engaged in technological innovation and raises the productivity of each R&D worker. This in turn increases the rate at which new intermediate goods are introduced and the efficiency of final goods production. We derive the optimal quantity of resources that should be channelled into social capital-building activities and examine how this quantity and the steady state growth rate of the economy depend on the spill-overs of the social capital "stock" on the creation of new social capital and the productivity of R&D. The effects of other parameters characterizing technologies and preferences in the different sectors of the model economy on the steady state solution are also considered. We quantify the under-creation of social capital arising from its public goods aspect and investigate the dynamic response of the model to various shocks. Lastly, we discuss the implications of the model for the design of innovation policies.

This paper is organized as follows. In this section, we discussed the importance of network social capital for collaborative R&D activities among high-technology firms. In Section 2, we explain how social capital may arise from "learning-by-doing" as much as it is created by deliberately channelling resources into network-building activities. The important characteristics of social capital that we wish to capture in our model are also identified in this section. Section 3 introduces the key equations in the model, while Section 4 presents the microeconomic foundations of the model. Results (steady-state solutions, comparative statics and transitional dynamics) as well as implications of the model are discussed in Section 5. Section 6 concludes.

2. Social Capital and Innovations

2.1 Social Capital and "Learning-by-Doing"

According to Maskell (2000), social capital also facilitates the `low-tech' learning and innovation that takes place when firms in traditional industries are innovative in how they handle and develop resource management, logistics, production, organization, marketing, sales, distribution, industrial relations, and other tasks and activities. He argues that much of this is due to inter-firm learning. Pure market interactions by themselves are often incapable of facilitating this due to the problem of asymmetric information. For example, potential buyers of information want to ascertain the merit of knowledge offered for sale. But when fully informed of the content of the knowledge offered, it has in effect acquired it for free.[3]

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[2] Routledge and von Amsberg (2003) model the potentially destructive impact of technology-induced economic growth on social capital. They propose a model where individuals in a community maximize lifetime gains to trade, with friendly trade being Pareto optimal but unfriendly trade the dominant strategy in one-shot game. Social capital, the social structure that supports cooperation, depends on the probability two individuals meet in a period, which in turn depends on community size. Technological innovations require a reallocation of labour - frictionless labour mobility leads to higher productivity but destroys social capital - leading to a trade-off between labor efficiency and social capital.

[3] This problem was recognized in Arrow (1970).

Maskell argues that these market failures in the exchange of knowledge between firms can only be overcome when open market relations are superseded by stable and reciprocal exchange arrangements based on trust. Trust will characterize a relation between firms when each is confident that the other's present value of all foreseeable future exchanges exceeds the possible benefits of breaking the relation. The key argument is that the time and resources needed to build a relationship varies with the stock of social capital that the firms in question might attain through membership in a community. However, according to Maskell, "(w)e still know very little about the actual process by which social capital is produced and accumulated, beyond suspecting that it might be a mainly unanticipated consequences of doing something else - just like, for instance, learning by doing." (p.114)

2.2 Characteristics of Social Capital to be Modelled

As social capital is such a multifaceted concept, it is important to focus on those aspects of it that matter for macroeconomic performance through their effects on business and technological innovations. We list the important attributes of social capital that we wish to capture in our model, and present a simple typology of the levels and forms of social capital.

2.2.1 Key Attributes of Social Capital

Social capital is capital because it is an accumulated stock from which a stream of benefits flows. It is therefore more than simply a set of social organizations or social values. Like human capital, social capital may accumulate as a result of its use; it is therefore both an input and output of collective action. However, although every other form of capital has a potential productive impact in a Robinson Crusoe economy, social capital does not – creating and activating social capital requires at least *two* people. Social capital therefore has public good characteristics, so underproduction is likely because of incomplete internalization of the positive externalities inherent in its production.

On the other hand, like other forms of capital, social capital is not costless to produce and requires a significant amount of time and effort. Moreover, since trust is more easily destroyed than rebuilt, there is a maintenance expense to social capital, often in the form of time.

2.2.2 The Scope and Forms of Social Capital

Social capital may exist on multiple levels. At the *micro* level, social capital encapsulates features of social organizations, such as networks of individuals or households. At the *meso* level, social capital includes vertical as well as horizontal associations and behaviour within and among other entities, such as firms. At the *macro* level, social capital includes the most formalized institutional relationships and structures, such as the political regime, the rule of law, the court system, and civil and political liberties. In this paper, we are primarily interested in studying meso-level “linking” social capital.

At each level of social capital, social capital affects economic performance as a result of the interactions between two distinct types of social capital. As noted by Grootaert and van Bastalaer (2002), *structural* social capital (or *institutional* capital) facilitates information sharing and collective action and decision-making through established roles and social networks supplemented by rules, procedures and precedents. *Cognitive* social capital (or *relational* capital), on the other hand, refers to shared norms, values, trust, attitudes and beliefs, and is a more subjective and intangible concept.

3. The Key Equations

In this paper, we are interested in modelling the impact of network social capital on the innovative activities of high-technology firms and the relationship between these activities and macroeconomic growth, as discussed in Section 2.1. However, we will also draw on insights by Maskell (2000) on how social capital may be created (in his case, by firms in traditional industries) through "learning-by-doing" (see Section 2.2).

3.1 The Creation of Network Social Capital

In our model, there are many identical infinitely-lived agents. Each agent may devote time to final goods production (which enables current consumption), or to R&D activities. R&D activities include the design of new technical blueprints and the building of network social capital. The last activity produces no revenues for the R&D firms by itself but increases the effectiveness of collaborative R&D and hence the rate of technological progress in the economy.

In modelling the evolution of network social capital, we wish to incorporate the following elements: (1) the building or accumulation of social capital requires resources to be diverted from other productive uses; (2) social capital decays over time without new "investment" in social capital; (3) the existing stock of social capital has spillover effects on the building of new social capital; and (4) social capital has a positive impact of the rate of technological progress through R&D but no direct effect on final goods production. The dynamic equation for social capital from a social planner's perspective, denoted $\dot{S}$, is of the form:

$$\dot{S} = P\left(u_S L\right)^{\sigma} S^{\phi} \hat{K}^{\lambda} - \delta_S S \tag{1}$$

where u_S in the share of the economy's labor L devoted to social capital creation, $\hat{K}$ is the aggregate physical capital stock, δ_S is the rate at which social capital decays, P is a productivity constant, while σ, ϕ, and λ are positive elasticity parameters. ϕ measures the spillover effect of existing social capital on the creation of new social capital, while λ measures the strength of the Maskell (2000) "learning-by-doing effect". The more the economy has worked with physical capital, the more social capital it generates as a by-product.

From the perspective of an individual firm, the equation governing the creation of social capital is

$$\dot{S} = \tilde{P}\left(u_S L\right)^{\sigma} \hat{K}^{\lambda} - \delta_S S\,, \tag{1'}$$

where $\tilde{P} = PS^{\phi}$. That is, each firm takes the network-wide stock of social capital as exogenously given. The positive externality that this stock confers on each firm (the public goods aspect of social capital) means that social capital will be under-produced in the decentralized, competitive model.

3.2 Network Social Capital and the Evolution of Technology

The rate of technological innovation is governed by the production function

$$\begin{aligned} \dot{A} &= \tilde{B} L_A \\ \tilde{B} &= B A^{\psi} L_A^{\eta-1} S^{\beta} \end{aligned} \tag{2}$$

where $\tilde{B}$ is the productivity of each worker in the R&D sector, and $L_A = u_A L$ where u_A is the share of labor devoted to the production of new technical designs. As argued previously, the amount of network social capital is a determinant of the productivity of R&D, the strength of the relationship being measured by the parameter β. The rest of equation (2) follows the Jones

(1995) specification for a R&D growth model. $L_A^{\eta-1}$ measures the "stepping on toes" effect whereby an increase in the number of researchers increases the likelihood of replication and thereby lowers the productivity of each R&D worker. A^{ψ} measures the strength of the "standing on the shoulders of giants" effect whereby a large existing stock of technology increases the rate of innovation.

4. Microeconomics of the Model

We describe the microeconomic foundations of the model in this section. The economy consists of R&D firms, final goods firms, intermediate goods producers, and households. As in the Romer (1990) and Jones (1995) models of R&D and growth, technological progress is characterized by an expanding variety of intermediate goods that are combined in the final goods sector to produce the consumption good. Intermediate goods producers each produce a unique intermediate good after having purchased the design for that good from an R&D firm. They then remain as monopolists in the production of that good indefinitely. Households are ultimate owners of all firms and decide on the optimal allocation of their labor time to the final goods sector and the R&D sector. Within the final goods sector, labor is allocated between production and activities that build network social capital.

4.1 The Real R&D Sector

The rate of technological innovation is governed by the production function in (2). Each R&D firm derives revenue $P_A \dot{A}$ from the sale of new designs to intermediate goods producers where P_A is the price of each design, and incurs labor cost $w_A u_A L$ where w_A is the prevailing wage in the R&D sector. Its profits are therefore

$$\pi_A = P_A \dot{A} - w_A u_A L \,. \tag{3}$$

The final goods firm maximizes profit subject to the constraints given in equations (1') and (2). Labor is compensated according to its marginal productivity in R&D:

$$w_A = P_A / \tilde{B} \,. \tag{4}$$

4.2 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:

$$Y = \left(u_Y L\right)^{1-\alpha} \int_0^A x(i)^{\alpha}\, di \,. \tag{5}$$

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

$$\max_{u_Y, x(i)} \pi_Y = \left(u_Y L\right)^{1-\alpha} \int_0^A x(i)^{\alpha}\, di - w_Y u_Y L - \int_0^A p\left(x(i)\right) x(i) di \,, \tag{6}$$

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 goods is normalized to unity. The first-order conditions dictate that

$$w_Y = (1-\alpha)\frac{Y}{u_Y L} \qquad (7),$$

and

$$p(x(i)) = \alpha \left(u_Y L\right)^{1-\alpha} x(i)^{\alpha-1} \quad \forall i \,. \tag{8}$$

4.3 Intermediate Goods Producers

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

$$\max_{x} \ \pi_x = p(x)x - r_K x \ . \tag{9}$$

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 rising to the following solutions:

$$\overline{p}(i) = \overline{p} = \frac{r_K}{\alpha} \quad \forall i \ , \tag{10}$$

$$\overline{x}(i) = \overline{x} = \left[\frac{\alpha \left(u_Y L \right)^{1-\alpha}}{\overline{p}} \right]^{\frac{1}{1-\alpha}} \quad \forall i \ , \tag{11}$$

and

$$\pi_{x(i)} = \overline{\pi}_x = (1-\alpha)\overline{px} = \alpha(1-\alpha)\frac{Y}{A} \quad \forall i \ . \tag{12}$$

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

$$K = \int_0^A x di = A\overline{x} \ , \tag{13}$$

we can rewrite the aggregate final goods production function as

$$Y = K^{\alpha} \left(A u_Y L \right)^{1-\alpha} \ . \tag{14}$$

4.4 Households

Finally, the 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, intermediate goods producers, and R&D firms. The optimization problem is thus:

$$\max_{c, u_Y, u_S} \ \int_0^{\infty} \frac{C^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt \ , \tag{15}$$

subject to

$$\dot{K} = rK + w_Y u_Y L + w_A u_A L + A\overline{\pi}_x - P_A \dot{A} - C$$
$$1 = u_Y + u_A + u_S \ ,$$

where C is aggregate consumption. In equilibrium, wages are equal across all sector, that is, $w_Y = w_A = w$.

5. Equilibrium, Solutions and Results

5.1 Solving the Model

For ease of exposition, we show the solution to the social planner's version of the model, and then describe subsequently (in Section 5.5) how it differs from the decentralized, competitive solution. The model is solved by the standard optimal control method. The Hamiltonian for the social planner model is given by:

$$\begin{aligned}\mathrm{H} = \frac{C^{1-\theta}-1}{1-\theta}e^{-\rho t} + \upsilon\left[K^{\alpha}\left(u_Y AL\right)^{1-\alpha} - C - \delta_K K\right] \\ +\mu B\left(u_A L\right)^{\eta} S^{\beta} A^{\psi} + \pi\left[P\left(u_S L\right)^{\sigma} S^{\phi}\hat{K}^{\lambda} - \delta_S S\right]\end{aligned}, \tag{16}$$

where c, u_Y and u_A are control variables; K, A and S are state variables, and υ, μ and π are the corresponding co-state variables.

The first-order conditions are obtained from $\partial\mathrm{H}/\partial C = 0$, $\partial\mathrm{H}/\partial u_Y = 0$, $\partial\mathrm{H}/\partial u_A = 0$, $\partial\mathrm{H}/\partial K = -\dot{\upsilon}$, $\partial\mathrm{H}/\partial A = -\dot{\mu}$ and $\partial\mathrm{H}/\partial S = -\dot{\pi}$ respectively:

$$\frac{\dot{c}}{c} = -\frac{1}{\theta}\left(\rho + \frac{\dot{\upsilon}}{\upsilon}\right), \tag{17}$$

$$\frac{\upsilon}{\pi} = \frac{\sigma}{1-\alpha}\cdot\frac{P(u_S L)^{\sigma} S^{\phi}\hat{K}^{\lambda}}{K^{\alpha}\left(u_Y AL\right)^{1-\alpha}}\cdot\frac{u_Y}{u_S}, \tag{18}$$

$$\frac{\mu}{\pi} = \frac{\sigma}{\eta}\cdot\frac{P(u_S L)^{1-\sigma} S^{\phi}}{B\left(u_A L\right)^{\eta} S^{\beta} A^{\psi}}\cdot\frac{u_A}{u_S}, \tag{19}$$

$$-\frac{\dot{\upsilon}}{\upsilon} = \alpha\hat{k}^{\alpha-1}u_Y^{1-\alpha} - \delta_K, \tag{20}$$

$$-\frac{\dot{\mu}}{\mu} = \gamma_A\left(\eta\frac{u_Y}{u_A} + \psi\right), \tag{21}$$

$$-\frac{\dot{\pi}}{\pi} = \left(\frac{\sigma\beta}{\eta}\frac{u_A}{u_S} + \phi\right)\left(\gamma_S + \delta_S\right) - \delta_S, \tag{22}$$

where $\gamma_A \equiv B\left(u_A L\right)^{\eta} S^{\beta} A^{\psi-1}$ and $\gamma_S \equiv P\left(u_S L\right)^{\sigma} S^{\phi-1}\hat{K}^{\lambda} - \delta_S$.

The transversality conditions are:

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

From $\gamma_A \equiv B\left(u_A L\right)^{\eta} s^{\beta} A^{\psi-1}$, we have

$$\frac{\dot{\gamma}_A}{\gamma_A} = \eta\left(\frac{\dot{u}_A}{u_A} + n\right) + \beta\gamma_S - (1-\psi)\gamma_A. \tag{23}$$

In the steady state, $\dot{\gamma}_A = \dot{u}_A = 0$. Hence, $\gamma_A = \left(\eta n + \beta\gamma_S\right)/(1-\psi)$.

From $\dot{\gamma}_S \equiv P\left(u_S L\right)^{\sigma} S^{\phi-1}\hat{K}^{\lambda} - \delta_S$, taking logs and time derivatives yields

$$\sigma\left(\frac{\dot{u}_S}{u_S} + n\right) - (1-\phi)\gamma_S + \lambda\left(\gamma_A + n\right) = 0, \tag{24}$$

as $\dot{\gamma}_S = 0$ in the steady state. Moreover, since $\dot{u}_S = 0$ in the steady state,

$$\gamma_S = \frac{\left(\sigma+\lambda\right)n+\lambda\gamma_A}{1-\phi}.$$

Solving for γ_A and γ_S simultaneously then yields the steady-state growth rates

$$\gamma_A^* = \frac{\eta(1-\phi)+\beta(\sigma+\lambda)}{(1-\psi)(1-\gamma)-\beta\lambda}n, \tag{25}$$

$$\gamma_S^* = \frac{(\sigma+\lambda)n+\lambda\gamma_A^*}{1-\phi}. \tag{26}$$

5.2 Steady State Solutions

The model economy is in its steady state or balanced growth path when all variables are growing at constant rates. Defining $\hat{k} \equiv K/AL$, $\hat{c} \equiv C/AL$, and $\hat{y} \equiv Y/AL$ as variables that are constant in the steady state, the steady state conditions $\dot{\hat{k}}/\hat{k} = 0$, $\dot{\hat{c}}/\hat{c} = 0$, $\dot{u}_Y/u_Y = 0$, and $\dot{u}_A/u_A = 0$ may be simplified to the following:

$$\hat{k}^{\alpha-1}u_Y^{1-\alpha} - \frac{\hat{c}}{\hat{k}} = n+\gamma_A^*+\delta_K, \tag{27}$$

$$\alpha\hat{k}^{\alpha-1}u_Y^{1-\alpha} = \rho+\theta\gamma_A^*+\delta_K, \tag{28}$$

$$-\frac{\dot{\pi}}{\pi} = -\frac{\dot{\upsilon}}{\upsilon}+(\sigma+\lambda-1)n+\phi\gamma_S^*+(\lambda-1)\gamma_A^*, \tag{29}$$

$$-\frac{\dot{\pi}}{\pi} = -\frac{\dot{\mu}}{\mu}+(\sigma+\lambda-1)n+\left(\phi-\beta\right)\gamma_S^*+(\lambda-\psi)\gamma_A^*. \tag{30}$$

Combining these four equations and simplifying then yields the following solutions:

$$u_S^* = \frac{1}{1+(1+\Gamma)\Phi}, \tag{31}$$

$$u_A^* = \frac{\Phi}{1+(1+\Gamma)\Phi}, \tag{32}$$

$$u_Y^* = \frac{\Gamma\Phi}{1+(1+\Gamma)\Phi}, \tag{33}$$

$$\Gamma \equiv \frac{\rho+(\eta-1)n+\beta\gamma_S^*+(\theta-1)\gamma_A^*}{\eta\gamma_A^*},$$

$$\Phi \equiv \frac{\eta\left[\rho+(1-\phi)\delta_S+(\sigma+\lambda-1)n+(\theta+\lambda-1)\gamma_A^*\right]}{\sigma\beta\left(\gamma_S^*+\delta_S\right)}.$$

$$\hat{k}^* = \left(\frac{\alpha}{\rho+\theta\gamma_A^*+\delta_K}\right)^{\frac{1}{1-\alpha}}u_Y^*, \tag{34}$$

$$\hat{c}^* = \frac{\rho+\theta\gamma_A^*+\delta_K-\alpha\left(n+\gamma_A^*+\delta_K\right)}{\alpha}\hat{k}^*, \tag{35}$$

$$\hat{y}^* = \hat{k}^{*\alpha}u_Y^{*1-\alpha}. \tag{36}$$

5.3 Comparative Statics

We now examine the impact of changes in various parameters of the model on the steady state allocation of labor to the production of final goods, the creation of innovations, and the accumulation of social capital. The top panels in Figure 1 show that a larger risk aversion parameter, θ, and a larger discount rate, ρ, are associated with a greater allocation of labor to the final goods sector, and correspondingly smaller allocations to the other sectors. This is because final goods production brings instant gratification through current consumption, while social capital accumulation and R&D activities only increase future consumption.

The middle left panel in Figure 1 shows that the social capital elasticity parameter in the $\dot{A}$ equation has a negative relationship with the allocation of labor to final goods production, u_Y, a positive relationship with the allocation of labor to social capital accumulation, u_S, and hump-shaped relationship with the fraction of the labor force allocated to innovative activities, u_A. The middle right panel in Figure 1 shows that the intertemporal spillover parameter in the $\dot{A}$ equation has a negative relationship with u_Y, a hump-shaped relationship with u_S, and a positive relationship with u_A.

The bottom panels in Figure 1 show that a larger social capital spillover parameter (φ) or a larger physical capital "learning-by-doing" effect (λ) in the social capital accumulation equation results in a greater steady state allocation of labor to both innovation creation and social capital accumulation, at the expense of labor allocated to final goods production.

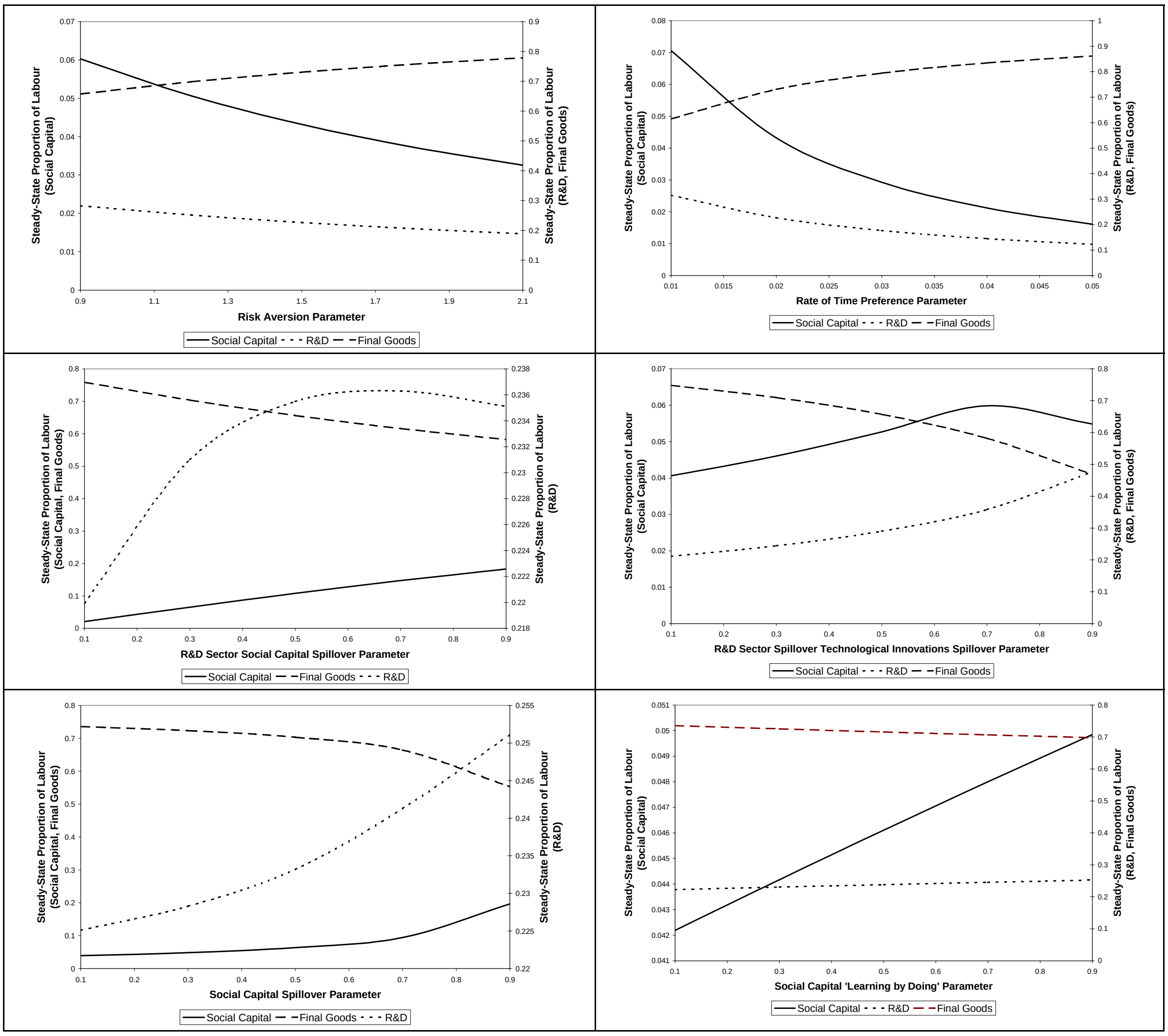

Fig. 1: The Impact of Parameter Values on Steady-State Resource Allocation

5.4 Transitional Dynamics

To study the dynamic properties of the model away from its steady state, we need to reduce its dimensionality by assuming a constant physical capital investment rate, s_K, as well as constant (and exogenously given) labor allocation shares, u_A, u_Y and u_S. The dynamics of the model may then be summed by the following equations describing the $\dot{\hat{k}} = 0$, $\dot{\gamma}_A = 0$ and $\dot{\gamma}_S = 0$ schedules respectively:

$$\hat{k} = \left(\frac{s_K}{n + \delta_K + \gamma_A} \right)^{\frac{1}{1-\alpha}} u_Y \,, \tag{37}$$

$$\gamma_A = \frac{\eta n + \beta \gamma_S}{1-\psi} \,, \tag{38}$$

$$\gamma_A = \frac{(1-\phi)\gamma_S - (\sigma + \lambda) n}{\lambda} \,. \tag{39}$$

These schedules are illustrated in the phase diagram in Figure 2.

Figure 2 also shows the impact of an increase in β, the elasticity parameter measuring the spillover effect of social capital on the rate of innovation, $\dot{A}$. The increase in β causes the steady state growth rates of technology and social capital, γ_A^* and γ_S^*, to increase permanently. In addition, steady state capital per effective unit of labor, $\hat{k}^* \equiv K / AL$, decreases since technology grows faster than the capital stock in the transition to the new steady state.

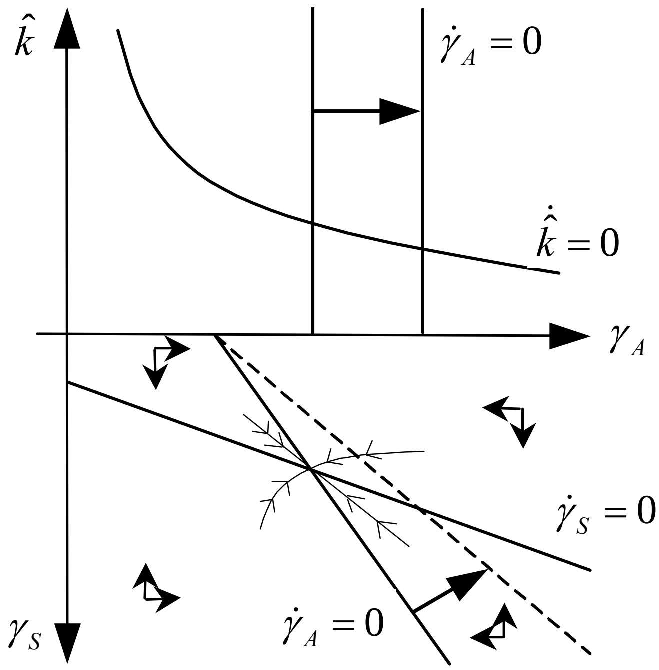

Figure 2: The Phase Diagram of the Model Showing the Impact of an Increase in β.

5.5 Divergence between the Social Planner and Competitive Solutions

We can quantify the divergence between the social planner's solution and the decentralized, competitive solution and examine how the divergence varies with the different parameters in the model. Recall that there are multiple sources of divergence in the model: (1) the spillover associated with the public goods aspect of social capital, captured by the parameter ϕ; (2) the "learning-by-doing" effect in social capital creation; (3) the "standing on the shoulders of giants" effect in R&D, captured by the parameter ψ; (4) the "stepping on toes" effect in R&D, captured by η; and (5) the monopolistic power of intermediate goods producers, which varies with α.

Algebraically, the decentralized, competitive solution for the share of labor time allocated to social capital creation, u_S, differs from the social planner's (shown in Section 5.2) in the following way:

$$u_S^{*DC} = \frac{1}{1+(1+\Gamma^{DC})\Phi^{DC}}, \tag{40}$$

$$\Gamma^{DC} \equiv \frac{\rho+(\eta-1)n+\beta\gamma_S^* + (\theta-1+\psi)\gamma_A^*}{\gamma_A^*},$$

$$\Phi^{DC} \equiv \frac{\rho+\delta_S+(\sigma+\lambda-1)n+(\theta+\lambda-1)\gamma_A^*}{\sigma\beta\left(\gamma_S^*+\delta_S\right)}.$$

To calibrate the model, we chose the following baseline values for the various parameters:

B	η	λ	ϕ	ψ	ρ	σ	θ	n	δ_S
0.2	2/3	0.2	0.5	0.5	0.02	2/3	1.5	0.01	0.05

The rate of time preference was set to 0.02, the risk-aversion parameter in the utility function chosen as 1.5, the rate of growth of the labor force as 0.01, and the depreciation rate of social capital at 0.05.

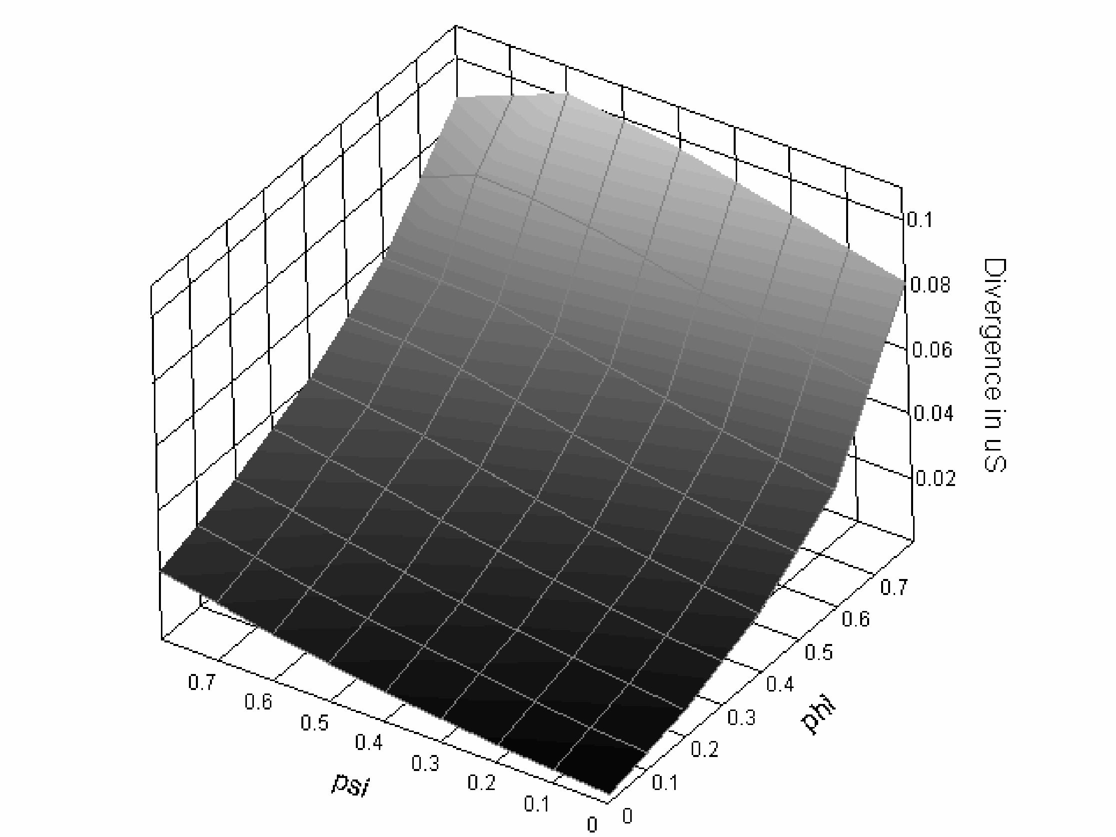

Figure 3(a): The Impact of ψ and ϕ on the Under-Allocation of u_A.

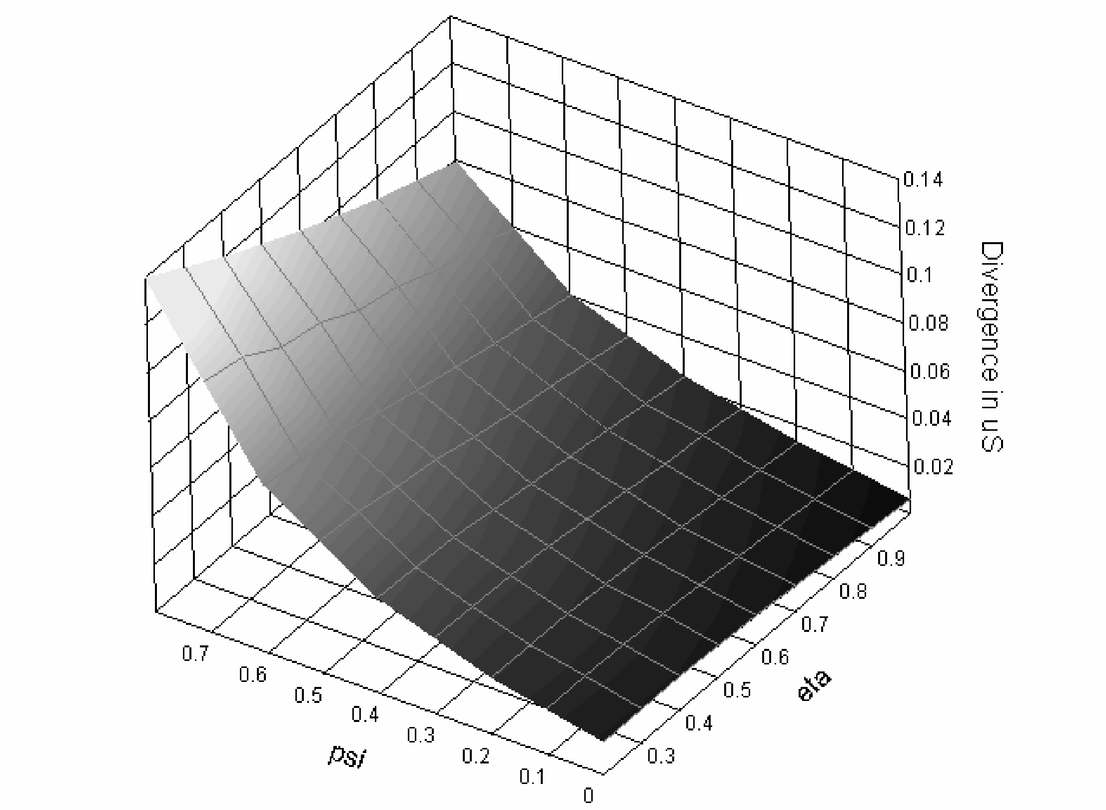

Figure 3(b): The Impact of ψ and η on the Under-Allocation of u_A.

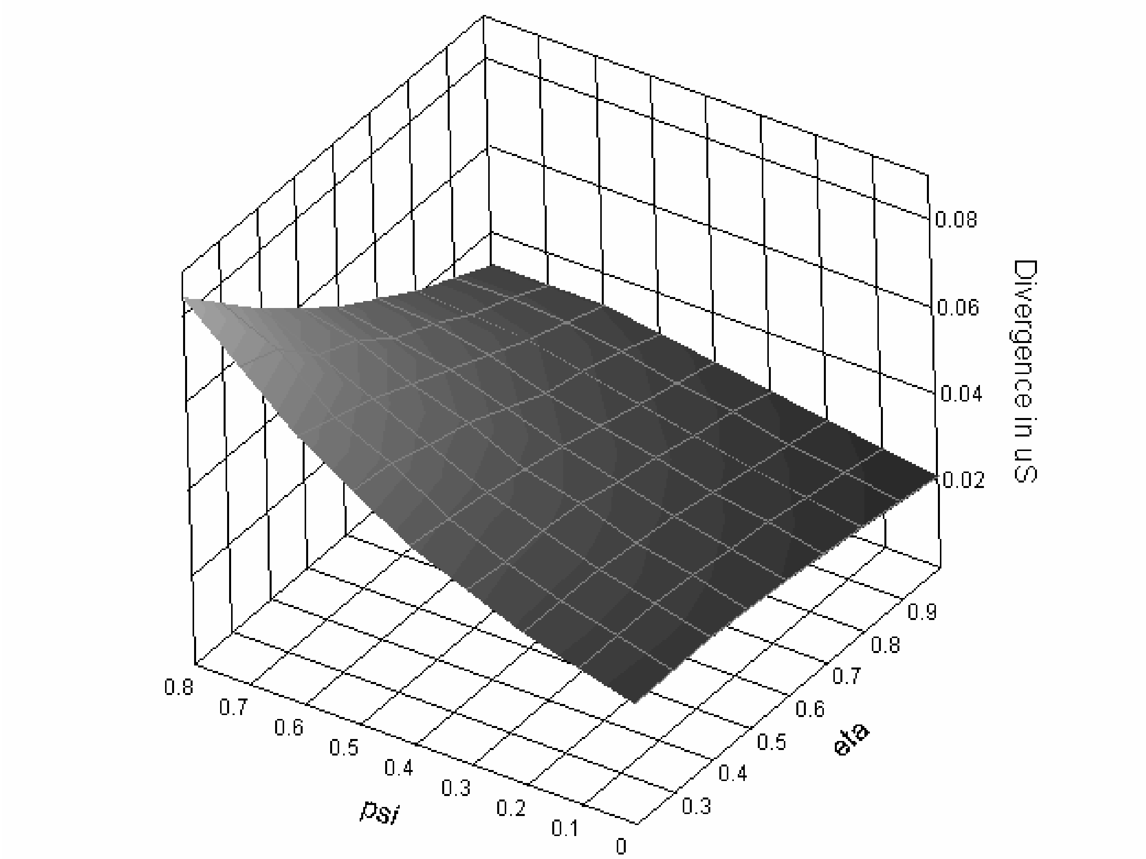

Figure 3(c): The Impact of η and ϕ on the Under-Allocation of u_A.

Figures 3(a), 3(b), and 3(c) indicate that the under-allocation of labor time to social capital creation in the competitive solution compared to the planner's solution is: increasing in ψ except when ϕ is close to 1, is always increasing in ϕ, but decreasing in η except when ψ or ϕ are close to 0 (when the relationship becomes mildly hump-shaped). Note that Figure 3(a) is plotted with η = 2/3 and ϕ = 0.5, Figure 3(b) is plotted with ψ = 0.5 and η = 2/3, while Figure 3(c) is plotted with ϕ = 0.5 and ψ = 0.5. One can demonstrate that the divergence between the competitive and planner's solutions can be narrowed by an appropriate tax and subsidy scheme.

5.6 Implications for the Design of Innovation Policies

In recognition of the importance of social capital within innovation networks, government policies should focus on inducing firms to collaborate more intensively with other firms, research labs, universities and government agencies in order to increase the number, size and efficacy of networks. Foe example, there could conceivably be tax incentives for private expenditures on network-building activities.

Because of the public goods aspect of social capital creation, governments should lay the physical infrastructure that encourage networking such as building research and development hubs, industrial parks and clusters for high technology firms. The expenditures for such construction obviously need to be financed by taxes on other economic activities. Many governments in the more successful developing countries have firmly committed themselves towards the building of physical infrastructure that aid network social capital creation. Technology and science parks abound in China, Korea, Taiwan, Japan, Hong Kong, Singapore and Malaysia.[4]

For further discussion on this important issue, see Branscomb and Keller (1998).

6. Conclusion

In this paper, we formulated a macroeconomic growth model where social capital embedded in collaborative networks of firms (such as corporate partnerships and research consortia) increase the rate of technological and business innovations in high-tech industries. The model is a significant extension of the well-known Romer (1990) / Jones (1995) model of R&D and growth. We specify a dynamic equation governing the evolution of social capital and incorporate network social capital in the equation describing the evolution of technology. We derived the optimal quantity of resources that should be channelled away from pure production into activities that build network social capital, and solved for the steady state growth rate of the model economy. We then examined the comparative statics and transitional dynamics of the model, and discussed implications of the model for policymakers interested in formulating innovation policies.

[4] For a listing, see *http://www.unesco.org/pao/s-parks/asia/asia.htm*.

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