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Abstract: We develop a two-sector model to analyze which kind of social organization generates social capital. The hypothesis is that social capital must be added as an important production factor when considering decentralization of production. Thus, market centralization processes in a capitalist society eventually may fragmentize and thus destroy social capital if the positive externality of local production and social capital is not taken into account. To our knowledge, no such attempt to model social capital has yet been undertaken and this gap or 'missing link' in economic debates has to be developed to grasp a more holistic understanding of the big differences in the wealth of nations or regions. The model shows that if the policy maker decides to centralize the economy, then the economy moves from an potentially stable equilibrium to an unstable one that may under certain condition even fluctuate forever.

JEL classification: A12, C71, D23, D60, D70, Z13.

Keywords: Social capital, market centralization, two-sector model, economic growth.

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1 Introduction

Social capital is probably the scientific concept that has gathered most attention and most followers ever within a short period of time. It provides a common language for all social sciences and has become a new buzzword (Paldam, 2000). If social capital really is a new production factor which must be added to the conventional concepts of human and physical capital, the concept will be of extreme interest to all social scientists. Social capital was first defined by the American sociologist James S. Coleman (1988) as “the ability to cooperate in groups” and thereby achieve a common goal. Such ability to cooperate assures an individual that he or she will not be taken advantage of by another individual, even if the latter might get an economic net benefit from doing it. Even if it pays economically to commit a crime, free-ride or ignore the rules in a contract, fewer will do it in the presence of trust because social norms tell them not to do so. Thus, the community members' preferences can be affected and shaped, due to social norms and social pressures (see Becker, 1996; Green and Shapiro, 1994; North 1990, for further discussions on unstable preferences). The concept, however, is a broad concept in strong need of both deductive modeling and inductive empirical surveys (Paldam, 2000). Social capital can be defined in many ways. Robert M. Solow, for example, writes

“Just what is social capital a stock of? Any stock of capital is a cumulation of past flows of investment, with past flows of depreciation netted out. What are those past investments in social capital? How could an accountant measure them and cumulate them in principle?” (Solow 2000:7)

Poulsen and Svendsen (2004), for example, assume that social capital is defined as the social norm a person adheres to. This is expressed through the person's willingness to cooperate or defect in games like the Prisoner's Dilemma game. Despite the variety of definitions that prevail in the literature there is a widely accepted consensus that, as any other form of capital, social capital yields a profit. Individuals invest in social interactions in order to earn a payoff that would otherwise not be earned.

As economists we are interested in investigating how individuals' social interactions and networking produce social capital. In what follows we explore which social structure generates social capital. Sociologists still debate today whether closed or opened network are required to generate and maintain social capital[1]. Bourdieu (1986), Coleman (1988, 1990), and Putman (1993, 2000) argue that closed networks in which all members are connected are the source of social capital because it is closure that maintains trust, norms, authority and sanctions.

Lin (1999), Burt (1992) and Rosenthal (1996) believe that extending connection between networks is a better strategy[2] than closure in order to produce social capital. Borrowing to this literature we intend to show in an economic

[1] We do not intend to give here a full survey of the literature on social capital. For a more detailed exposition the interested reader is referred to Lin (2001).

[2] In this theory the absence of links between networks is refered to as “structural holes”. A person who connects two networks is called a broker.

context that extending connections across networks without network closure cannot result in the maintenance of the stock of social capital inside a society. In fact we show via the use of two different economic models that in a society in which networks are extensive but not closed social capital cannot accumulate. This view echoed the view of Burt (2001:52):

"While brokerage across structural holes is the source of value-added, closure can be critical in realizing the value buried in the structural holes."

To show this, we develop two different models with two production sectors. In each model, sector 1 is specialized in producing a pure consumption good. Sector 2 is the informal sector, the one in which production of social capital takes place. In both models, we assume that social capital is a collective asset resulting from individuals' social interaction. Social capital therefore "represents some aggregation of valued resources...of members acting as a network or as networks". (Lin 2001:9).

In economic terms this translates into assuming the externalities enter the production of both goods. Furthermore we can restrict these externalities to be positive. This because social capital contributes positively to the production of goods in society by facilitating the flow of information between individuals. By giving social credentials to individuals inside the networks it also speeds up economic transactions. To understand this last point, assume, for the sake of simplicity, that these community members socially can punish each other at negligible costs, and that an agent receives the same return in terms of money and saved time per unit of opportunism. Assume further, that the costs to the opportunistic individual increases because the voluntary provision of collective good is hampered more and more thus reducing the individual share of the gains following collective good provision. Then an economically rational individual will, without the presence of social capital, undertake opportunistic and non-cooperative behavior at a higher level compared to the situation with the presence of social capital. This idea is derived from the work of Ostrom (1990, 35) who writes that 'Norms of behavior reflect valuations that individuals place on actions or strategies in and of themselves, not as they are connected to immediate consequences. When an individual has strongly internalized a norm related to keeping promises, for example, the individual suffers shame and guilt when a personal promise is broken. If the norm is shared with others, the individual is also subject to considerable social censure for taking an action considered to be wrong by others' (our italics).

We now give two other economic example of the role of social capital in economic transactions:

A firm for example, may lower transaction costs by having numerous informal transactions taking place that are not formally sanctioned. These observations relate to the transaction cost ideas of Coase (1937) and Williamson (1975) and may also reflect the general business climate in a country. E.g., a business manager in a high social capital country like Iceland would be less likely to cheat you than a business manager in a low social capital country like Russia (see Paldam and Svendsen, 2004; 2002; 2000).

Another example could be the relationship between tax payers and the government. If people hold a high level of social capital, they will trust each other and elected decision-makers as well. By that, the build-up and maintenance of social capital will ease policy-making and make it more effective since less monitoring is necessary when a high level of social capital is present. Basically, people trust that the government will spend tax revenues for collective good provisions (beneficial to all taxpayers) rather than stealing their money. This reciprocity idea is illustrated by a survey on shadow economy activities by Schneider and Enste (2002). Here, one could argue that less monitoring of shadow economy activity and tax evasion was needed in countries with high levels of social capital because people generally cheat less.

Overall the social capital approach can be regarded as an attempt to combine sociology (social norm) and economics (production factor). Concerning a thorough review of the interdisciplinary development and theoretical foundations of social capital within economics, political science, sociology, development theory and philosophy, see Ostrom and Ahn (2003).

Our contribution is to make a first attempt to model the informal institution of social capital for voluntary collective good provision by developing a two-sector model for economic growth. The starting point is the empirical observation from Svendsen and Svendsen (2004) claiming that social capital is actually created in small-group settings with regular face-to-face interaction, for example around small and decentralized production units such as cooperative voluntary dairy movements. Hence, we hypothesize that the missing link of social capital must be added as an important production factor when considering economic growth and the net outcome of any economic solution such as economies of scale and centralization of production. Consequently, market centralization processes in a capitalist society eventually may fragmentize and thus destroy social capital if the collective good of local production and social capital is not taken into account. To our knowledge, no such attempt to model social capital has yet been undertaken and this gap or 'missing link' in economic debates has to be developed to grasp a more holistic understanding of the big differences in the wealth of nations or regions (Svendsen and Svendsen, 2003).

The model answers the big question whether social capital is a new production factor along the traditional ones of human and physical capital. Presumably, a group or society with members that trust each other may be capable of accomplishing more economic growth than a similar society without trust. To model this we proceed as follows.

In the first model, we assume that society is composed of a continuum of individuals that operate through extensive, open and well connected networks. In the extreme, we can think as a network as a single household. Some households are connected to other via public communications means or institutions controlled by the central planner. We refer to the first economy as the centralized economy. We see that in such an economy interactions between household in the informal sector can be totally anonymous (or at least does not involve personal ties). Thus, we assume that social capital is only used as an input in the consumption good sector.

In the second model we assume that society is composed of a continuum of individuals that interact within closed and interconnected group. Society is organized in small networks. each network is connected to an other through personal ties between at least two members of each network. We see that in this setting interaction between network is no longer anonymous. Due to potential social sanctioning in a small group with regular face-to-face interaction, individuals are more likely to trust that other individuals will act cooperatively. In terms of modelling assumption this translates into assuming that social capital is now used as an input in its own production. We refer to this economy as the decentralized economy.

In both the centralized and decentralized economy we assume that social capital is the product of interaction between individuals. To simplify matters we assume that the number of interactions between individuals is equal to the total number of individuals in this economy. Since population is not growing by assumption, we can normalize the total number of contacts to unity. In the centralized economy we assume that social capital is solely the product of the number of interactions between individuals. In the decentralized economy social capital is produced using a fraction of the current stock of social capital and the number of interactions between individuals.

2 The common framework of both models

The economy is populated by a continuum of identical consumers indexed by h, where $h \in [0, 1]$. All consumers are infinitely lived and rational. Each consumer h is initially endowed with an equal fraction of the aggregate capital stock $k_0^h = \overline{k}$, and a single unit of labor. These productive resources are allocated optimally between the two productive sectors of the economy. The representative consumer maximizes his (discounted) intertemporal welfare. At any point of time (which is discrete), welfare is measured by a utility function of current consumption per capita $u(c_t)$. We assume the following restriction on the utility function:

Assumption 1 :

$$u(c) = \frac{c^\alpha}{\alpha}.$$

At time $t = 0$, the representative agent maximizes

$$U_0 = \sum_{t=0}^{\infty} \beta^t \frac{c_t^\alpha}{\alpha}, \tag{1}$$

where β is the discount rate, $0 < \beta < 1$. Any consumer $h \in [0, 1]$ is initially endowed with an equal fraction of the aggregate capital stock $k_0^h = \overline{k}$. . The production side is composed of two continua of firms indexed by i, where $i = 1, 2$. Within each sector firms are identical. We assume that, the production technology of both representative firms also depends on the aggregate stock of social capital in any given period. We denote this variable by X, where $X = \int_0^1 k(h)dh$. Social Capital is assumed to depreciate in each time period. Denoting by δ the depreciation rate, this amounts to

Assumption 2 : $0 < \delta < 1$ for all $t \geq 0$.

The number of total interactions l_t is a factor in fixed supply. It is equal to the number of agents in this economy. It will for simplicity be normalized to unity. We assume that some of the interactions between the agents of the model only happens at the production level (some agents come together to produce a good). Some interactions between agents happens outside the production process (agents meet informally and creates ties). The total number of interactions happens in the two sectors of the economy. We assume that sector 1 is the output sector. Sector 2 is the informal sector in which social capital is produced. The number of interactions happening at the production level will be labelled by l_t^1. The number of interactions happening at the informal level will be labelled by l_t^2. If y_t denotes the current production of the social capital good sector, then the the stock of social capital for next period, k_{t+1} is equal to

$$k_{t+1} = y_t + (1 - \delta)k_t. \tag{2}$$

3 The centralized Economy

3.1 The Model

We omit the time subscripts whenever they are not necessary. We assume that production of output in sector 1 uses all the social capital available in the economy. The production technology used in sector 2 is linear[3]. Social capital also generate positive externalities that affect the production of both sectors.

$$\begin{aligned} c &= F^1(k, l^1, X), \\ y &= \mathcal{A}l^2 X. \end{aligned}$$

In sector 1, we suppose that along a path with external effects, the marginal productivities of both inputs are positive. The production of output is assumed to exhibit diminishing marginal productivities in private inputs for a given level of the aggregate capital stock X. We restrict the spillovers to be labor augmenting[4] In other words, we assume the following:

[3]This assumption guarantees that private returns are constant in the investment good sector. The same result would be obtained had we assumed that the investment good sector were to use a factor in fixed supply and labor as inputs.

[4]This form of labor augmenting technological progress has been extensively used by the learning by doing literature see Arrow (1962), Uzawa (1961), Sheshinski (1967), Harrod (1973), Romer (1986) and Lucas (1988).

Assumption 3: For $i = 1, 2$, $F^1 : \Re^3_+ \to \Re_+$, are continuous functions. For a given $X \in \Re_+$:

(i) $F^1(.,.,.)$ is C^3 on $\Re_{++} \times \Re_{++} \times \Re_+$;
(ii) $F^1(.,.,X)$ is homogenous of degree one and increasing over $\Re_{++} \times \Re_{++}$;
(iii) $F^1_{11}(.,l^i,X) < 0$, for all $k^i \in \Re_{++}$ and $\lim_{k^i \to 0} F^i_1(k^i,l^i,X) = \infty$;
(iv) $F^1_{22}(k^i,.,X) < 0$, for all $l^i \in (0,1]$ and $\lim_{l^i \to 0} F^i_2(k^i,l^i,X) = \infty$.
(v) External effects in sector 1 are Harrod-Neutral. $F^1(k,l^1,X) = \mathcal{F}^1(k,l^1X)$, where $\mathcal{F}^1(.,.)$ is homogenous of degree 1 in k and l^1X.
(vi) $F^1(0,l^1,X) = F^1(k^1,0,X) = 0$

Assumption 4:$\mathcal{A} > \delta$.

For this class of economies, the Production Possibility Frontier (P.P.F.) is given by the following maximization problem:

$$
\begin{aligned}
T(k_t, y_t, X_t) &= \max_{l^1_t} \mathcal{F}^1(k_t, l^1_t X_t) \\
&\quad \text{subject to} \\
y_t &= \mathcal{A} l^2_t X_t, \\
1 &= l^1_t + l^2_t, \\
k_t &\geq 0,\ l^i_t \geq 0,\ \{X_t\}^{\infty}_{t=0} \text{ given.}
\end{aligned} \tag{3}
$$

Under Assumption 3, and given that $k_t \in \Re^*_+, l^i_t \in [0,1]$, Problem (3) is a standard concave maximization problem, for $\{X_t\}^{\infty}_{t=0}$ given. Assumption 3 ensures interiority of solutions to (3). Under Assumption $T3b$, we can apply the implicit function theorem to solve for the demand of labor in the investment good sector. For all given $X \geq 0$, we find that

$$
l^2 = \frac{y}{\mathcal{A}X}. \tag{4}
$$

We can use (4) to write the value function of Problem (3) as

$$
T(k,y,X) = \mathcal{F}^1\left(k, \frac{\mathcal{A}X - y}{\mathcal{A}}\right). \tag{5}
$$

For interior solutions to (3) for all given $X_t \geq 0$ the feasible set $D(X_t)$ can then be restricted to

$$
\{(k_t, k_{t+1}) \in \Re^+ \times \Re : (1-\delta)k_t \leq k_{t+1} \leq \mathcal{A}X_t + (1-\delta)k_t\}.
$$

Using the standard definition of the indirect utility function given by $V(k_t, k_{t+1}, X_t)$, we can reformulate the representative agent's problem as

$$\max_{\{k_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \frac{\left[\mathcal{F}^1 k_t, \mathcal{A}X_t - y_t/\mathcal{A})\right]^{\alpha}}{\alpha}$$

subject to:

$$\begin{aligned} k_o &= \bar{k}, \\ (k_t, k_{t+1}) &\in D(X_t). \end{aligned} \tag{6}$$

$\{X_t\}_{t=0}^{\infty}$ given.

An *equilibrium path* $\{k_t\}$, is an interior solution to Problem (6) if it solves a fixed point problem[5] $\{k_t\{X_t\}\} = \{X_t\}$ together with the necessary and sufficient conditions given in the next Lemma:

Lemma 1 *Let $\{k_t\}_{t=0}^{\infty}$ be feasible path from k_0. Then it solves the maximization Problem (6) if the following conditions are satisfied.*

Euler equation:

$$-\gamma_t^{1-\alpha} V_2(1, \gamma_t, 1) + \beta V_1(1, \gamma_{t+1}, 1) = 0, \tag{7}$$

Transversality condition:

$$\lim_{t \to \infty} \beta^t k_t^{\alpha-1} V_1(1, \gamma_{t+1}, 1) = 0. \tag{8}$$

Summability condition:

$$\sum_{t=0}^{t=\infty} \beta^t V(1, \gamma_t, 1) < \infty. \tag{9}$$

Proof. See Boldrin, Nishimura, Shigoka and Yano (2003), Drugeon, Poulsen and Venditti (2003). ■

3.2 Existence, uniqueness and stability of the growth ray

We have define the growth factor of capital as

$$\frac{k_{t+1}}{k_t} = \gamma_t. \tag{10}$$

In this framework since $\overline{\gamma} = \mathcal{A} + 1 - \delta$ and $\underline{\gamma} = 1 - \delta$. The Transversality Condition (8) will be satisfied if the following assumption holds:

Assumption 5: $\beta \overline{\gamma}^{\alpha} < 1$.

[5] We do not consider the question of existence to the fixed point problem for which the sequence of externalities $\{X_t\}$ satisfies $\{k_t\{X_t\}\} = \{X_t\}$ for all $t \geq 0$. A detailed treatment of this issue is beyond the scope of this paper. We refer the reader to Romer (1983) and Mitra (1998). They both address the existence issue of the fixed point problem $\{k_t\{X_t\}\} = \{X_t\}$ for all $t \geq 0$ in a slightly different framework.

Lemma 2 *Assume that Assumptions 1-5 are satisfied. Then there exists an interior equilibrium balanced growth factor* γ*.*

Proof. See the Appendix. ■

Lemma 3 *Suppose that Assumptions 1-5 are satisfied. Then there exists a unique interior growth ray that satisfies the conditions of Lemma* 1*.*

Proof. See the Appendix. ■

Following Boldrin and Rusticchini (1998) we give next a more precise definition of what is meant by indeterminacy.

Definition 4 *A growth ray* $k_t = \gamma^t k_0$ *is locally indeterminate if for every* $\epsilon > 0$*, there exists another equilibrium sequence* $\{k_t'\}$ *with* $\acute{\gamma_t} = \acute{k}_{t+1}/\acute{k_t}$ *such that* $|k_1 - k_1'| < \epsilon$ *with* $k_0 = k_0'$*.*

For a system of dimension two, indeterminacy occurs when the two roots of the characteristic polynomial are inside the unit circle. We see, from (15), that in our model the dynamic system is of dimension 1. Therefore, if the root associated with (15) is within $(-1, 1)$, then the growth ray will be locally indeterminate. In this model stability means indeterminacy.

Proposition 5 *Suppose that Assumptions 1-5 are satisfied. Suppose also that* V_{21} *is strictly monotonic increasing for all* $\gamma_t \in (0, \overline{\gamma})$*, then the balanced growth path is locally unstable (i.e. locally determinate).*

Proof. See the Appendix. ■

Corollary 6 *If* $\{c_t\}_{t=0}^{\infty} > 0$ *for all* $t \geqslant 0$*, then the stock of social capital in the decentralized economy will fall forever.*

Proof. See the Appendix. ■

Proposition 5 and Corollary 6 imply that unless an economy starts initially in the interior equilibrium, it will never converge to it. Suppose that the economy is initially in the equilibrium and that $\gamma > 1$. In this case the stock of social capital grows at a constant rate $\mathcal{G} = \gamma - 1 > 0$. Suppose now that an exogenous shock hits the economy, then the economy will converge either to the equilibrium where $\underline{\mathcal{G}} = \underline{\gamma} - 1 = -\delta$ or towards $\overline{\mathcal{G}} = \mathcal{A} - \delta$. In the first equilibrium, as time goes by the stock of social capital will disappear. In the second equilibrium, the stock of social capital would grow at a positive rate but all productive resources would be allocated to the production of social capital at the expense of consumption.

We now need to consider what happens in this framework if V_{21} is not strictly monotonic increasing. this is the purpose of the next subsection.

3.3 Chaos

In this paper we will use the notion of chaos in the sense of Geometric Sensitivity and Ergodic Oscillations. The notion of geometric sensitivity can be defined as follows:

Definition 7 *(Nishimura and Yano (2000)). The dynamical system (I, θ), exhibits Geometric Sensitivity (GS) if there exists a constant $h > 1$ such that for any $\tau \geq 0$ there exists $\varepsilon > 0$ such that for all x and $x' \in I$ with $|x_t - x'_t| < \varepsilon$ and for all $t \in \{0, 1, ..., \tau\}$*

$$\left|\theta^t(x) - \theta^t(x')\right| \geq h^t \left|x - x'\right|.$$

As I is bounded, the geometric magnification of the effects of a small perturbation cannot last indefinitely. Furthermore, the dynamical system (I, θ) has no locally stable cyclical path.

There is also the notion of *ergodic chaos.* Ergodic chaos is a stronger property than topological chaos in the sense that it is "observable chaos".

Let Υ be a σ-algebra on I. [6] Define a probability measure $\mu : \Upsilon \to \Re^+$ such that (i) $\mu(\varnothing) = 0$ and (ii) $\mu(\cup_{n=0}^{\infty} Y_n) = \Sigma_{n=0}^{\infty} \mu(Y_n)$, (iii) $\mu(I) = 1$, where $\{Y_t\}_{n=0}^{\infty}$ is a countable collection of disjoint sets in Υ. We can now define the concepts of ergodic chaos in the following way:

Definition 8 *The dynamical system (I, θ) exhibits ergodic chaos if there exists a probability measure μ on I which is absolutely continuous, invariant and ergodic.*

Lasota and Yorke (1973) establish that if θ is a *piecewise* C^2 and *expansive* mapping then there exists an absolutely continuous invariant measure

Definition 9 *A mapping θ defined on $[a, b]$ is piecewise C^2 and expansive if:*

1. *There exists a finite set $x_0 = a < x_1 < x_2 < ... < x_n = b$,*
2. *For all $j = 0, 1, ..., n$, θ is C^2 on (x_j, x_{j+1}) and can be extended as a C^2 function to $[x_j, x_{j+1}]$,*
3. *$\left|\theta'(x)\right| \geq h > 1$ for all $x \in (x_j, x_{j+1})$.*

Li and Yorke (1978) show that if θ is also a unimodal map then this measure is ergodic.

Definition 10 *Assume there exits a constant $c \in [a, b]$, $a < c < b$. Then a mapping θ, defined on $[a, b]$ is unimodal if*

1. *θ is continuous on $[a, b]$,*

[6] A $\sigma-$algebra is a collection of subsets Υ of I such that (i) I is inside Υ, (ii) the complement of any set Y included in Υ is also in Υ, (iii) the union of any countable collection of subsets in Υ is inside Υ.

2. θ is strictly increasing on (a, c) and strictly deceasing on (c, b).

Nishimura and Yano (2000) establish that a map that is expansive is also chaotic in the sense of GS. We state the Lasota and Yorke (1973) and Li and Yorke (1978) results as well as the result on GS in the next theorem.

Theorem 11 *(Lasota and Yorke (1973), Li and Yorke (1978), Nishimura and Yano (2000)):*
Let (I, θ) be a dynamical system. If $\theta : I \to I$ is expansive and unimodal then θ is chaotic in the sense of ergodic oscillations and GS.

Let us investigate the occurrence of chaos.

Proposition 12 *Suppose that Assumptions 1-3 are satisfied. If V_{21} is not strictly monotonic increasing for all $\gamma_t \in (0, \overline{\gamma})$, then if the growth ray exhibits chaos in the sense of Geometric Sensitivity and ergodicity.*

Proposition 12 implies that unless the economy initially starts in an equilibrium where the stock of social capital is originally growing at a constant rate, then the growth factor of social capital will fluctuate forever. Because it of geometric sensitivity, unless the policy maker knows exactly the initial growth factor of the social capital stock, it cannot predict the long run evolution of the system. Hence any policy designed to increase the growth factor of social capital would have unpredictable consequences in the long run.

4 The Decentralized Economy

4.1 The Model

As above we assume that sector 1 is the output sector. It uses some social capital and the number of interactions between agents. Social capital and output are produced using both social capital and the number of interactions between agents as inputs. In the centralized economy, we assumed that social capital is solely the product of the number of interactions between individuals because interactions between individuals are anonymous. Therefore, individuals do generally not experience repeated face-to-face interaction with the same individuals. This situation changes in the decentralized economy as individuals tend to interact in non-anonymous way in small group settings. Here, members get to know each personally due to repeated social encounter and therefore social capital is arguably produced using a fraction of the current stock of social capital and the number of interactions between individuals. In other words, social capital does not enter the production of social capital in the centralized economy because the social sanction mechanism is weaker and it is easier to free-ride on collective good provisions. As in the centralized economy, social capital also generate positive externalities that affect the production of both sectors. We again restrict the spillovers to be labor augmenting:

Assumption 3b: $F^i : \Re^3_+ \rightarrow \Re_+$, $i = 1, 2$ is continuous. For a given $X \in \Re_+$, it satisfies:

(i) $F^i(.,.,.)$ is of class C^2 on $\Re_{++} \times \Re_{++} \times \Re_+$;

(ii) $F^i(.,.,X)$ is homogenous of degree one and increasing over $\Re_{++} \times \Re_{++}$;
(iii) $F^i_{11}(.,l^i,X) < 0$, for all $k^i \in \Re_{++}$ and $\lim_{k^i \to 0} F^i_1(k^i,l^i,X) = \infty$;

(iv) $F^i_{22}(k^i,.,X) < 0$, for all $l^i \in]0,1]$ and $\lim_{l^i \to 0} F^i_2(k^i,l^i,X) = +\infty$.

(v) $F^i(k^i,l^i,X) = \mathcal{F}^i(k^i,l^iX)$, $i = 1, 2$, where $\mathcal{F}^i(.,.)$ is homogenous of degree 1 in k^i and l^iX.

We define the social production possibility frontier, $T(k,y,X)$. It is the value function of the maximization problem in which the representative firm chooses its output level given the existing stock of social capital, full employment of inputs, and the aggregate social capital stock X. In other words,

$$\begin{aligned} T(k,y,X) = \max_{\{k^1,l^1\}} & \mathcal{F}^1(k^1,l^1X) \\ & \text{subject to} \\ & y = \mathcal{F}^2(k^2,l^2X), \\ & k = k^1 + k^2, \\ & 1 = l^1 + l^2, \\ & k^i \geq 0,\ l^i \geq 0,\ i = 1,2. \end{aligned} \tag{11}$$

For all given $X \geq 0$

Assumption 6 : $T(k,y,X)$ is of class C^2 on $\Re_{++} \times \Re_{++} \times \Re_+$.

Using a standard argument it can be shown that for any given $X \geq 0$, $T(k,y,X)$ is concave. The set of feasible interior solutions to (11) is is non-empty and convex and defined as

$$D\left(X_t\right) = \{(k_t,k_{t+1}) \in \Re_+ \times \Re_+ : (1-\delta)k_t \leq k_{t+1} \leq \mathcal{F}^2(k_t,X_t)\}.$$

Benhabib and Nishimura (1985) show that the sign of T_{21} is positive (negative) if the investment good sector is more (less) capital intensive than the consumption good sector. The consumption good sector is said to be more social capital intensive if the net social capital stock, k^1/l^1, in the output sector is higher than the net social capital stock in the investment good sectork^2/l^2. Drugeon and Venditti (1998) establish that $k^i(k_t,y_t,X_t)$ and $l^i(k_t,y_t,X_t)$, $i = 1,2$, are homogenous of degree 1 and 0, respectively if external effects in both sectors are Harrod-Neutral. Hence $T(k_t,y_t,X_t)$ is homogenous of degree 1. Drugeon, Poulsen and Venditti (2003) and Poulsen (2003)establish:

Lemma 13 *Let Assumptions 1-3b and 4-6 be satisfied. Then $T(k_t, y_t, X_t)$ is homogenous of degree 1. Furthermore,*

$$T_{21} = \frac{\mathcal{F}_{12}^1 \mathcal{F}_{12}^2 q \mathcal{F}^2 l^1}{\Delta k^2 k^1} \left(\frac{k^1}{l^1} - \frac{k^2}{l^2} \right), \tag{12}$$

$$T_{22} = T_{21} \frac{l^2}{\mathcal{F}^2} \left(\frac{k^1}{l^1} - \frac{k^2}{l^2} \right) < 0, \tag{13}$$

$$T_{23} = -T_{21} \frac{k^1}{l^1 X} + \frac{2l^2}{\mathcal{F}_1^2} \left(\mathcal{F}_{12}^1 + q\mathcal{F}_{12}^2 \right), \tag{14}$$

where

$$\Delta = -\frac{\mathcal{F}_{12}^1 (\mathcal{F}^1)^2 (\mathcal{F}_1^2)^2}{(\mathcal{F}_1^1)^2 k^1 l^1 X} - \frac{\mathcal{F}_{12}^1 (\mathcal{F}^2)^2 \mathcal{F}_1^1}{\mathcal{F}_1^2 k^2 l^2 X} < 0.$$

Proof. See Drugeon and Venditti (1998) and Drugeon, Poulsen and Venditti (2003), Poulsen (2001). ■

Corollary 14 *Suppose the consumption good sector is capital intensive. Then, $T_{23} > 0$.*

5 Existence, Uniqueness and Indeterminacy

The *growth factor* of social capital can be defined as $k_{t+1}/k_t = \gamma_t$. The maximum feasible growth factor is $\overline{\gamma}$ and $\underline{\gamma}$ is the minimum feasible growth factor. Under Harrod-Neutrality, $\overline{\gamma} = \mathcal{F}^2(1,1)$ and $\underline{\gamma} = 1 - \delta$. For the model to display endogenous growth we need $\overline{\gamma} > 1$. To ensure existence of an interior growth ray with endogenous growth we also need $\mathcal{F}^2(1,1) > \delta$. In this case the model does not have a steady state. A growth ray is defined as follows:

Definition 15 *An equilibrium path $\{k_t\}$ is a growth ray if there exists a growth factor $\gamma \in [0, \overline{\gamma}]$ such that for all $t \geq 0$, $k_t = \gamma^t k_0$, where $k_0 \neq 0$.*

An equilibrium path is a solution to Problem 11 if it the following necessary and sufficient conditions:

$$\gamma_t^{1-\alpha} V_2(1, \gamma_t, 1) + \beta V_1(1, \gamma_{t+1}, 1) = 0, \tag{15}$$

$$\lim_{t\to\infty} \beta^t k_t V_1(1, \gamma_t, 1) = 0, \tag{16}$$

$$\sum_{t=0}^{t=\infty} \beta^t V(1, \gamma_t, 1) < \infty. \tag{17}$$

The transversality condition (16) is satisfied along a growth ray if the following assumption holds:

Assumption 4b: $\beta[\mathcal{F}^2(1,1) + 1 - \delta]^\alpha < 1$.

Proposition 16 *Let Assumptions 1-4b and 5-7 be satisfied. Then there exists an interior growth ray,* $\widetilde{\gamma} \in (1, \overline{\gamma})$ *if* $\mathcal{F}^2(1,1) > \delta$ *and*

$$\beta[\mathcal{F}_1^2(k^2(1,\widetilde{\gamma},1), l^2(1,\widetilde{\gamma},1)) > 1.$$

Proof. See Goenka and Poulsen (2004). ■

In what follows we show that local indeterminacy arises no matter which sector is more social capital intensive. Drugeon, Poulsen and Venditti (2003) show that the allocation of productive resources between the two sectors affects the uniqueness property of the growth ray. Furthermore, a necessary condition for the occurrence of multiple growth ray is that the investment good sector is capital intensive at the private level at the growth ray. The multiplicity results are not affected by the time structure of the model. We therefore refer the reader to this paper for a more detailed exposition.

Proposition 17 *Let Assumptions 1-5 be satisfied. Then,*
(i) A necessary condition for the growth ray to be locally indeterminate is

$$\left.\frac{V_{23}}{V_{12}}\right|_{(1,\widetilde{\gamma}+1-\delta,1)} < 0. \tag{18}$$

(ii) A necessary and sufficient condition for the growth ray to be locally indeterminate is

$$\left|\frac{1}{\beta\widetilde{\gamma}^{\alpha}} + \frac{V_{23}}{\beta\widetilde{\gamma}^{\alpha}V_{12}}\right|_{(1,\widetilde{\gamma}+1-\delta,1)} < 1.$$

Proof. See Goenka and Poulsen (2004). ■

Proposition 17 and the uniqueness result of Drugeon, Poulsen and Venditti (2003) imply that when the consumption good sector is more social capital intensive, then the stock of social capital will grow at a constant rate $\mathcal{G}$. It may stay there forever if $V_{21}(1,\gamma,1) < 0$ i.e. if social capital does not depreciate too slowly and if the marginal utility of consumption is relatively inelastic[7]. In this case they would also exists an infinity of social capital sequences all growing asymptotically at the same rate.

If the investment good sector is more social capital intensive then the Drugeon, Poulsen and Venditti (2003) have established the following result

[7] Goenka and Poulsen (2004) shows that $V_{21} < 0$ if $T\left[T_{12} - (1-\delta)T_{22}\right] + (\alpha - 1)T_2\left[T_1 - (1-\delta)T_2\right] < 0$. Under the results of Lemma this requires both that

$$\delta > 1 + \frac{T_{12}}{T_{22}}$$

and

$$\frac{T\left[T_{12} - (1-\delta)T_{22}\right]}{T_2\left[T_1 - (1-\delta)T_2\right]} > 1 - \alpha.$$

Proposition 18 *Let assumptions1-4b and 5-7 be satisfied.*
(i) A sufficient condition for the occurrence of at least three growth rays is that

$$\frac{\mathcal{F}^1_{11}\mathcal{F}^1_{12}\mathcal{F}^1}{q\Delta k^1}\left(\frac{k^2}{l^2}-\frac{k^1}{l^1}\right)\Big|_{(1,\widetilde{\gamma}-1+\delta,1)} > \frac{1-\alpha}{\beta\widetilde{\gamma}^{\alpha}}.$$

(ii) A necessary condition for the occurrence of at least three growth rays is that the investment good sector is more capital intensive.

Proof. See Drugeon, Poulsen and Venditti (2003). ■

This would imply that there exists at least one equilibrium with a low growth rate, one equilibrium with a medium growth rate and one equilibrium with a high growth rate for social capital. If the medium equilibrium is stable then it follows that the low one and the high one are unstable. The economy 's stock of social capital would be growing at a positive growth rate. We can now establish the following result.

Corollary 19 *Suppose there exists three equilibria. Then a necessary condition for the stock of social capital will growth forever at the constant rate $\widetilde{\gamma}-1$ is*

$$\widetilde{\gamma} > \left(\frac{1-\alpha}{\beta}\right)^{1/\alpha} > 1$$

Proof. See the Appendix. ■

6 Conclusion

We developed a two-sector social capital model to answer the question whether social capital is a new production factor along the traditional ones of human and physical capital. The hypothesis was that social capital must be added as an important production factor when considering economic growth and the net outcome of any economic solution such as economies of scale and centralization of production.

To model this, we suggested two models, namely a centralized and a decentralized economy. Also, we assumed that social capital is the product of repeated social interaction between individuals. Thus, in the centralized economy, we assumed that social capital is for, a given level of the aggregate social capital stock, solely the product of the number of interactions between individuals because interactions between individuals are anonymous. Therefore, individuals do generally not experience repeated face-to-face interaction with the same individuals. This social pattern situation changes in the decentralized economy as individuals tend to interact in non-anonymous way in small group settings. Here, members get to know each personally due to repeated social encounter and therefore social capital is arguably produced using a fraction of the current stock of social capital and the number of interactions between individuals. In other words, social capital does not enter the production of social capital in the centralized economy because the social sanction mechanism is weaker and it is easier to free-ride on collective good provisions.

The comparison between the decentralized economy and the centralized economy indicates that as one moves from a decentralized to a centralized economy social capital is lost. This is because as the economy moves from a decentralized to a centralized economy social capital is no longer used in the production of social capital. This affects the stability and uniqueness property of the equilibrium. We showed that, the necessary conditions for the decentralized economy to converge in the long run to a positive growth rate of the social capital stock are satisfied both when either of the two productive sector is social capital intensive provided that utility is not too concave. In the centralized economy, the stock of social capital either never grows or is aperiodic and exhibits strong dependency on initial conditions. In other words policies aiming at enhancing the rate of growth of social capital in a centralized economy are not feasible.

In the decentralized economy, if the social capital good sector is more social capital intensive then there may also exists several equilibria. An important implication of this is that the policy maker should be very careful in designing policies to enhance the growth rate of the social capital in a decentralized society. When there exist several equilibria policy fine tuning is essential in determining which equilibrium the economy converges to.

The model showed that if the policy maker decides to centralize the economy, then the economy moves from an potentially stable equilibrium to an unstable one that may under certain condition even fluctuates forever.

One important implication of these results is that market centralization processes in a capitalist society eventually may fragmentize and thus destroy social capital if the positive externality of local production and social capital is not taken into account. Therefore, both private and public decision-makers and all students of the social sciences should take this potential market failure of centralizing ‘too much’ at the expense of social capital. Rather decision-making and future research should be guided towards the search of new optimal outcomes when adjusting centralization processes for potential social capital losses or gains.

7 Appendix

Proof of Lemma 2

Looking at (7) we see that along the growth ray the Euler equation simplifies to

$$-\frac{T_1(1,\gamma,1)}{T_2(1,\gamma,1)} = \frac{\gamma^{1-\alpha}}{\beta}.$$

Using the definition of $T(k, y, X)$ given in (3) we derive

$$\begin{aligned} T_1 &= \mathcal{F}_1^1, \\ T_2 &= -\frac{\mathcal{F}_2^1}{\mathcal{A}}. \end{aligned}$$

So the Euler equation reduces to

$$\left[\mathcal{A}\mathcal{F}_1^1/\mathcal{F}_2^1 + 1 - \delta\right] = \frac{\gamma^{1-\alpha}}{\beta}$$

Let us define the following two functions:

$$\varsigma(\gamma) = \frac{\gamma^{1-\alpha}}{\beta}, \tag{19}$$

$$\xi(\gamma) = \mathcal{A}\mathcal{F}_1^1\left(1, \frac{\overline{\gamma} - \gamma}{\mathcal{A}}\right)\left[\mathcal{F}_2^1\left(1, \frac{\overline{\gamma} - \gamma}{\mathcal{A}}\right)\right]^{-1} + 1 - \delta. \tag{20}$$

Under Assumption 3, $\mathcal{F}^1(k, l^1X)$ is homogenous of degree one. The Euler theorem on homogenous functions tells us that

$$\mathcal{F}^1(k, l^1X) = \mathcal{F}_1^1(k, l^1X)k + \mathcal{F}_2^1(k, l^1X)l^1X. \tag{21}$$

We can rewrite (21) as

$$\frac{\mathcal{F}^1(k, l^1X)}{\mathcal{F}_2^1(k, l^1X)} = \frac{\mathcal{F}_1^1(k, l^1X)k}{\mathcal{F}_2^1(k, l^1X)} + l^1X. \tag{22}$$

From the Euler theorem on homogenous functions, we know that $\mathcal{F}_1^1$ and $\mathcal{F}_2^1$ are homogenous of degree 0. So, along an equilibrium path (22) can be rewritten as

$$\mathcal{A}\frac{\mathcal{F}^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})}{\mathcal{F}_2^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})} = \mathcal{A}\frac{\mathcal{F}_1^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})}{\mathcal{F}_2^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})} + \bar{\gamma} - \gamma_t. \tag{23}$$

At $\gamma = \overline{\gamma}$ taking the limit of (23) on both sides we obtain

$$\lim_{\gamma \to \overline{\gamma}} \frac{\mathcal{A}\mathcal{F}^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})}{\mathcal{F}_2^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})} = \lim_{\gamma \to \overline{\gamma}} \mathcal{A}\frac{\mathcal{F}_1^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})}{\mathcal{F}_2^1(1, \frac{\bar{\gamma}-\gamma_t}{\mathcal{A}})}. \tag{24}$$

However under Assumption 3 (ii) and (vi)

$$\lim_{\gamma \to \overline{\gamma}} \mathcal{A}\mathcal{F}^1(1, \frac{\bar{\gamma} - \gamma_t}{\mathcal{A}})\left[\mathcal{F}_2^1(1, \frac{\bar{\gamma} - \gamma_t}{\mathcal{A}})\right]^{-1} = 0^+. \tag{25}$$

This is equivalent to

$$\lim_{\gamma \to \overline{\gamma}} \xi(\gamma) < \overline{\gamma}. \tag{26}$$

We can rewrite Assumption 4 as

$$\frac{\overline{\gamma}^{1-\alpha}}{\beta} > \overline{\gamma}.$$

Or using the definition of $\zeta(\gamma)$ given in (19) as

$$\lim_{\gamma \to \overline{\gamma}} \zeta(\gamma) > \overline{\gamma}. \tag{27}$$

So (26) and (27) imply that, as $\gamma_t \to \overline{\gamma}$, we have $\lim_{\gamma \to \overline{\gamma}} \zeta(\gamma) - \lim_{\gamma \to \overline{\gamma}} \xi(\gamma) > 0$. A sufficient condition for the existence of $\gamma \in [1, \overline{\gamma}]$ is then

$$\zeta(\underline{\gamma}) - \xi(\underline{\gamma}) < 0.$$

This is equivalent to $0 < \beta \left[\mathcal{F}_1^1(1, \frac{\mathcal{A}-\delta}{\mathcal{A}}) \left[\mathcal{F}_2^1(1, \frac{\mathcal{A}-\delta}{\mathcal{A}}) \right]^{-1} + 1 - \delta \right]$.

Proof of Lemma 3
If we differentiate (19) with respect to γ, we find that

$$\acute{\zeta}(\gamma) = \frac{(1-\alpha)\gamma^{-\alpha}}{\beta} > 0.$$

The condition of Proposition 2 guarantees that we have

$$\begin{array}{rcl} \zeta(0) & < & \xi(0) \\ \lim_{\gamma \to \overline{\gamma}} \zeta(\gamma) & > & \lim_{\gamma \to \overline{\gamma}} \xi(\gamma). \end{array}$$

So, the uniqueness of the balanced growth path depends on whether or not $\xi(\gamma)$ is strictly decreasing. Recall from (20) that

$$\xi(\gamma) = \mathcal{A}\mathcal{F}_1^1 \left(1, \frac{\overline{\gamma} - \gamma}{\mathcal{A}}\right) \left[\mathcal{F}_2^1 \left(1, \frac{\overline{\gamma} - \gamma}{\mathcal{A}}\right) \right]^{-1} + 1 - \delta.$$

If we differentiate this function with respect to γ we find that

$$\acute{\xi}(\gamma) = \frac{-\mathcal{F}_{12}^1 \mathcal{F}_2^1 + \mathcal{F}_{22}^1 \mathcal{F}_1^1}{(\mathcal{F}_2^1)^2} < 0.$$

Hence, we see that the sufficient condition for a unique balanced growth path is satisfied. The uniqueness result follows.

Proof of Lemma 5
Using the definition of $V(k_t, k_{t+1}, X_t)$ we can derive

$$V_2 = -\frac{(\mathcal{F}^1)^{\alpha-1} \mathcal{F}_2^1}{\mathcal{A}}. \tag{28}$$

Using (28), we can derive V_{21} as

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1+(1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}^2}-\frac{(\mathcal{F}^1)^{\alpha-1}\left[\mathcal{A}\mathcal{F}_{12}^1+(1-\delta)\mathcal{F}_{22}^1\right]}{\mathcal{A}^2} \tag{29}$$

and V_{23} as

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}(\mathcal{F}_2^1)^2}{\mathcal{A}}-\frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{F}_{22}^1}{\mathcal{A}}>0. \tag{30}$$

Using (30) and (35) we can compute $V_{23}(1,\gamma_t,1)$ as

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}(\mathcal{F}_2^1)^2}{\mathcal{A}}+\frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{F}_{12}^1}{\bar{\gamma}-\gamma_t}. \tag{31}$$

Differentiating the Euler equation, we get

$$\frac{d\gamma_{t+1}}{d\gamma_t}=\frac{V_{12}(1,\gamma,1)+V_{23}(1,\gamma,1)}{\beta\gamma^\alpha V_{12}(1,\gamma,1)}. \tag{32}$$

Adding (31) to (37) along an equilibrium path we can compute $V_{23}(1,\gamma,1)+V_{21}(1,\gamma,1)$ as

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1+\mathcal{F}_2^1\left(1-\delta+\mathcal{A}\right)\right]}{\mathcal{A}^2}+\frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{F}_{12}^1\gamma_t}{\mathcal{A}(\bar{\gamma}-\gamma_t)}>0. \tag{33}$$

It follows that we have the sign of $d\gamma_{t+1}/d\gamma_t$. depends on the sign of $V_{21}(1,\gamma,1)$. The necessary and sufficient condition for the growth ray to be locally stable is

$$\left|\frac{1}{\beta\gamma^\alpha}+\frac{V_{23}}{\beta\gamma^\alpha V_{12}}\right|<1. \tag{34}$$

Using the Euler theorem on homogenous function, we have

$$-\mathcal{F}_{12}^1\left(\frac{\mathcal{A}k}{\mathcal{A}X-y}\right)=\mathcal{F}_{22}^1. \tag{35}$$

Substituting this into (29) we can rewrite it as

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1+(1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}^2}-\frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{A}\mathcal{F}_{12}^1\left[\mathcal{A}X_t-k_{t+1}\right]}{\mathcal{A}^2\left(\mathcal{A}X_t-y_t\right)}. \tag{36}$$

Along an equilibrium path (36) can be reduced to

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1+(1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}^2}-\frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{F}_{12}^1(\mathcal{A}-\tilde{\gamma})}{\mathcal{A}\left(\bar{\gamma}-\tilde{\gamma}\right)}, \tag{37}$$

where

$$\mathcal{F}^1=\mathcal{F}^1(1,\frac{\bar{\gamma}-\gamma_t}{\mathcal{A}}).$$

(37) implies that, for $\gamma \in [\mathcal{A}, \bar{\gamma})$, we have $V_{21}(1, \gamma, 1) > 0$. So, for all $\gamma_t \in [\mathcal{A}, \overline{\gamma})$, (37) and (37) imply that

$$\left| \frac{1}{\beta\gamma^{\alpha}} + \frac{V_{23}}{\beta\gamma^{\alpha}V_{12}} \right| > 1. \tag{38}$$

Suppose now that $V_{21}(1, \gamma_t, 1) > 0$ for all $\gamma_t \in [0, \mathcal{A})$ i.e. suppose that

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1 + (1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}^2} > \frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{F}_{12}^1(\mathcal{A}-\gamma_t)}{\mathcal{A}\left(\bar{\gamma}-\gamma_t\right)}$$

for all $\gamma_t \in [0, \mathcal{A})$ and that $\gamma \in [0, \mathcal{A})$. Since by assumption $V_{21}(1, \gamma, 1) > 0$ it follows that the growth ray is determinate (i.e. unstable).

Proof of Lemma 6

Rewrite the Euler equation as

$$g(\gamma_t) + f(\gamma_{t+1}) = 0$$

where $g(\gamma_t) = \gamma_t^{1-\alpha}V_2(1, \gamma_t, 1)$ and $f(\gamma_t) = V_1(1, \gamma_{t+1}, 1)$.

If $V_{21}(1, \gamma_t, 1) > 0$ it follows that we can transform the Euler into the first order difference equation

$$\gamma_{t+1} = \theta(\gamma_t).$$

where $\theta = f^{-1}(g(\gamma_t))$.

We can compute

$$\theta^{'}(\gamma_{t+1}) = \frac{d\gamma_{t+1}}{d\gamma_t}.$$

Recall from 32 that

$$\frac{d\gamma_{t+1}}{d\gamma_t} = \frac{V_{12}(1, \gamma_t, 1) + V_{23}(1, \gamma_t, 1)}{\beta\gamma_t^{\alpha}V_{12}(1, \gamma_t, 1)}. \tag{39}$$

We have seen above that the sign of $\theta^{'}(\gamma_t)$ depends on the sign of $V_{12}(1, \gamma_t, 1)$. If $V_{12}(1, \gamma_t, 1) > 0$ for all $\gamma_t \in [0, \mathcal{A})$ then it follows that $\theta^{'}(\gamma_t) > 0$ for all $\gamma_t \in [1-\delta, \overline{\gamma}]$. Furthermore, using the definition of $V(k_t, k_{t+1}, X_t)$ we can compute

$$V_1 = \frac{(\mathcal{F}^1)^{\alpha-1}\left[\mathcal{A}\mathcal{F}_1^1 + (1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}}.$$

So, looking at the expression of $V_2(k_t, k_{t+1}, X_t)$ obtained in (**??**) we see that

$$V_2 = -\frac{V_1}{\mathcal{A}\mathcal{F}_1^1/\mathcal{F}_2^1 + 1 - \delta}.$$

We can rewrite the Euler equation (**??**) as

$$-\gamma_t^{1-\alpha}\frac{v(\gamma_t)}{\mathcal{A}\mathcal{F}_1^1/\mathcal{F}_2^1 + 1 - \delta} + \beta v(\theta(\gamma_t)) = 0, \tag{40}$$

where $v(\gamma_t) = V_1(1, \gamma_t, 1)$. As $\gamma_t \to \bar{\gamma}$, we can rewrite (40) as

$$\lim_{\gamma_t \to \bar{\gamma}} \frac{\gamma_t^{1-\alpha}}{\beta\left[\mathcal{A}\mathcal{F}_1^1/\mathcal{F}_2^1 + 1 - \delta\right]} = \lim_{\gamma_t \to \bar{\gamma}} \frac{v(\theta(\gamma_t))}{v(\gamma_t)}. \tag{41}$$

However, we know from the existence result that

$$\lim_{\gamma_t \to \bar{\gamma}} \frac{\gamma_t^{1-\alpha}}{\beta\left[\mathcal{A}\mathcal{F}_1^1/\mathcal{F}_2^1 + 1 - \delta\right]} = \lim_{\gamma_t \to \bar{\gamma}} \frac{\zeta(\gamma)}{\xi(\gamma)} > 1.$$

As $\gamma_t \to \bar{\gamma}$, we can use (37) to compute

$$\lim_{\gamma_t \to \bar{\gamma}} V_{21}(1, \gamma_t, 1) > 0. \tag{42}$$

So, (41) and (42) implies that, as $\gamma_t \to \bar{\gamma}$, we have

$$\lim_{\gamma_t \to \bar{\gamma}} \theta(\gamma_t) > \gamma_t. \tag{43}$$

But feasibility requires

$$\lim_{\gamma_t \to \bar{\gamma}} \theta(\gamma_t) < \overline{\gamma}.$$

It follows that

$$\theta(\overline{\gamma}) \leq \overline{\gamma}.$$

However from the result of Lemma **3** we know that there exists a unique unstable interior growth ray.

Hence

$$\theta(\overline{\gamma}) = \overline{\gamma}.$$

As γ_t tends to $1-\delta$, we can rewrite (40) as

$$\lim_{\gamma_t \to \bar{1-\delta}} \frac{1}{\beta\left[\mathcal{A}\mathcal{F}_1^1/\mathcal{F}_2^1 + 1 - \delta\right]} = \lim_{\gamma_t \to \bar{1-\delta}} \frac{v(\theta(\gamma_t))}{v(\gamma_t)}.$$

The sufficient condition for existence given in Proposition 2 then implies that $\gamma_t = 1-\delta$, we have

$$\lim_{\gamma_t \to \bar{1-\delta}} v(\theta(1-\delta)) < \lim_{\gamma_t \to \bar{1-\delta}} v(1-\delta). \tag{44}$$

This implies that

$$\lim_{\gamma_t \to \bar{1-\delta}} \theta(1-\delta) < \lim_{\gamma_t \to \bar{1-\delta}} 1-\delta.$$

Furthermore, feasibility implies

$$\theta(1-\delta) \geqslant 1-\delta.$$

The uniqueness and stability results of Proposition 3 and imply that

$$\theta(1-\delta) = 1-\delta.$$

It follows that $\bar{\gamma}$ and $\underline{\gamma}$ are the only two stable equilibria. Hence if $\{c_t\}_{t=0}^{\infty} > 0$ for all $t \geqslant 0$, then the stock of social capital in the decentralized economy will never grow.

Proof of Proposition 12
Recall from Proposition that V_{21} can be derived as

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1+(1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}^2} - \frac{(\mathcal{F}^1)^{\alpha-1}\left[\mathcal{A}\mathcal{F}_{12}^1+(1-\delta)\mathcal{F}_{22}^1\right]}{\mathcal{A}^2} \tag{45}$$

We know from Proposition **??** that

$$\theta^{'}(\gamma_t) > 0 \text{ if } V_{12}(1,\gamma_t,1) > 0 \text{ for all } \gamma_t \in [1-\delta,\mathcal{A}) \tag{46}$$

Suppose now that $V_{21}(1,\gamma_t,1) < 0$ for some $\gamma_t \in [1-\delta,\mathcal{A})$ i.e. suppose that

$$\frac{(1-\alpha)(\mathcal{F}^1)^{\alpha-2}\mathcal{F}_2^1\left[\mathcal{A}\mathcal{F}_1^1+(1-\delta)\mathcal{F}_2^1\right]}{\mathcal{A}^2} < \frac{(\mathcal{F}^1)^{\alpha-1}\mathcal{F}_{12}^1(\mathcal{A}-\gamma_t)}{\mathcal{A}\left(\bar{\gamma}-\gamma_t\right)}$$

for some $\gamma_t \in [0,\mathcal{A})$.

It follows that there exists at least one $\gamma_t \in [0,\mathcal{A})$ such that $V_{21}(1,\gamma_t,1) = 0$. Assume for simplicity that there exists only one such point. If we rewrite the Euler equation as

$$g(\gamma_t) + f(\gamma_{t+1}) = 0$$

where $g(\gamma_t) = \gamma_t^{1-\alpha}V_2(1,\gamma_t,1)$ and $f(\gamma_t) = V_1(1,\gamma_{t+1},1)$ we see that the first order difference equation $\gamma_{t+1} = \theta(\gamma_t)$ is no longer defined[8] for at least $\gamma_t \in [0,\mathcal{A})$. However $g^{'}(\gamma_t) = (1-\alpha)\gamma_t^{-\alpha}V_2(1,\gamma_t,1) + \gamma_t^{1-\alpha}V_{22}(1,\gamma_t,1) < 0$. It follows that we can define the following first order difference equation

$$\gamma_t = \tau(\gamma_{t+1}).$$

where $\tau = g^{-1}(f(\gamma_{t+1}))$.
We can compute

$$\tau^{'}(\gamma_{t+1}) = \frac{\beta\gamma_t^{\alpha}V_{21}(1,\gamma_{t+1},1)}{V_{21}(1,\gamma_t,1)+V_{23}(1,\gamma_t,1)}.$$

Given that there exists a unique $\gamma \in [0,\mathcal{A})$. such that $V_{21}(1,\gamma,1) = 0$ and that

$$\begin{aligned} V_{21}(1,\gamma_t,1) &< 0 \text{ for all } \gamma_t \in [0,\gamma), \\ V_{21}(1,\gamma_t,1) &> 0 \text{ for all } \gamma_t \in (\gamma,\overline{\gamma}), \end{aligned}$$

[8]For a more detailled exposition see Goenka and Poulsen (2004 b).

then if $\theta(1-\delta) = \theta(\overline{\gamma}) = 0$, $\theta(\gamma_t)$ is unimodal. If

$$\beta > \frac{\gamma_t^{\alpha} V_{21}(1, \gamma_{t+1}, 1)}{V_{21}(1, \gamma_t, 1) + V_{23}(1, \gamma_t, 1)}$$

for all $\gamma_t \in (\underline{\gamma}, \overline{\gamma})$ then $\theta(\gamma_t)$ is expansive.

Proof of Corollary 19.

From Proposition we have three equilibria if

$$\frac{\mathcal{F}_{11}^1 \mathcal{F}_{12}^1 \mathcal{F}^1}{q\Delta k^1} \left(\frac{k^2}{l^2} - \frac{k^1}{l^1} \right) \Bigg|_{(1, \widetilde{\gamma}-1+\delta, 1)} > \frac{1-\alpha}{\beta \widetilde{\gamma}^{\alpha}}. \tag{47}$$

If we define the following two functions

$$\begin{aligned} \eta(\widetilde{\gamma}) &= \frac{\gamma^{1-\alpha}}{\beta}, \\ \kappa(\widetilde{\gamma}) &= \mathcal{F}_1^2 + 1 - \delta \big|_{(1, \widetilde{\gamma}-1+\delta, 1)}, \end{aligned}$$

then we see that 47 is equivalent to

$$\acute{\kappa}(\widetilde{\gamma}) > \acute{\eta}(\widetilde{\gamma}).$$

It follows that a necessary condition for $\widetilde{\gamma}$ to be stable is

$$\widetilde{\gamma} > \left(\frac{1-\alpha}{\beta} \right)^{1/\alpha}.$$

For endogenous growth we need $\widetilde{\gamma} > 1$.

8 References

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