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# SOCIAL CAPITAL AND INVESTMENT IN R&D: NEW EXTERNALITIES

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**Abstract**. We introduce social capital in an endogenous growth model with physical capital, human capital, and research and development (R&D), and we compare the market with the efficient solutions. As social capital is not tradable in the market and since it favours research networks, it introduces new externalities in this framework. These externalities induce the market to invest less in social capital than would a social planner and decrease the tendency to underinvestment in R&D. We quantify the distortions in the model. In some conditions, the new distortions are strong enough to overcome the usual result of underinvestment in R&D.

**Keywords**: R&D, social capital, human capital, endogenous growth.

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## 1. Introduction

In this work we study the interaction effects between social capital and R&D. This is an important topic to approach since social capital, in the form of social networks, can help knowledge sharing between researchers who work in close proximity to each other, in an informal way, through "cheap talk" at lunch, etc. The presence of social capital can introduce distortions in market allocations due mainly to two of its features: the failure of a market for social capital and the impact it can have on R&D due to research networks. The first reason is justified, as firms do not pay for social capital when they contract workers; they pay for hours of work and, at most, for the level of qualifications. This may be because the features usually included in social capital (confidence, truth, informal networks) are more difficult to evaluate and monitor than academic degrees or years of schooling. The second reason is based on the importance of social networks between researchers in R&D productivity. An example often given is the importance of networks of researchers in Silicon Valley. Another is the proximity of research staff in universities. The notion of clusters and the creation of a knowledge based economy in the European Union, goals of the Lisbon Agenda, are also based on the idea of networks, as discussed in Melnikas (2005).

Social capital is a sociological concept that has been introduced recently in the economic growth literature. The definition of Putnam (1993) refers to this concept as "features of social organization, such as trust, norms, and networks that can improve the efficiency of society by facilitating coordinated actions". Most of the empirical literature has found a positive influence of social capital on economic growth, although it varies considerably (examples include Knack, Keefer (1997); Temple and Johnson (1998); Whiteley (2000), and Rupasingha *et al.* (2000)). The introduction of social capital in growth models is still uncommon, but a good example is Beugelsdijk and Smulders (2009), who also test the model against empirical data using the European Values Survey. Economic agents like to socialize (*bonding*), which they do by losing consumption, since participation in social networks is time-consuming and erodes time available for work. Hence, higher levels of social capital may decrease economic growth. However, participation in community networks (*bridging*) reduces the incentive for rent seeking and cheating, and so through this channel, a higher level of social capital produces positive effects on economic growth[1].

The positive connection between social capital and human capital accumulation was first described in Coleman (1988) and in Teachman *et al.* (1997) in sociological studies of high school dropouts. Grafton *et al.* (2007) test a theoretical growth model against empirical data to explain international country differences in productivity and find a positive impact of people's knowledge connections on productivity. Dinda (2008) uses an AK-type growth model to study the role of social capital in the production of human capital and in economic growth and compares theoretical results with empirical results finding a positive effect of social capital. In an endogenous growth model framework Sequeira and Ferreira-Lopes (2011) also study the interactions between human and social capital and document the decline in social capital reported by Putnam (2000). Piazza-Giorgi (2002) gives a comprehensive survey of empirical results on this topic.

Literature on the links amongst social capital, R&D, and economic growth is also very recent, scarce, and empirical. For example, Landry *et al.* (2002), De Clercq and Dakhli (2004), Lee *et al.* (2005), and Doh and Acs (2010) test empirically if there is indeed a connection and find positive effects of social capital in R&D and in innovation activities, although estimates vary widely.

No previous attempt that we know of has brought the positive connection between social capital and R&D to an endogenous growth model. Our main contribution to the literature is to evaluate for the first time the impact of externalities caused by the presence of social capital in an endogenous growth model.

[1] Durlauf and Fafchamps (2005) provide an extensive survey of this literature.

We also wish to contribute to the discussion on "Too Much of a Good Thing?" i. e., the optimality of R&D investments[2]. Thus, this paper is also inserted in the literature on the macroeconomic efficiency of R&D investments within endogenous growth models without scale effects, whose first contributions were Jones (1995) and Jones and Williams (2000). The most common finding reported in the literature tends to indicate that underinvestment in R&D occurs in the real world (Romer (1990), Grossman, Helpman (1991), and Aghion and Howitt (1998) in endogenous growth models with scale effects, and also Jones (1995) and Jones, Williams (2000) in models without scale effects, and Jones, Williams (1998) in an empirical article). The exceptions are Stokey (1995) and Benassy (1998) who, in models with scale effects, found that for more general preferences or production, overinvestment in R&D can occur. Most recently, Reis and Sequeira (2007) and Strulik (2007) showed that overinvestment in R&D is more plausible than earlier believed.

We build an increasing varieties model with different production sectors, into which we introduce social capital. We argue that in this type of model the presence of social capital decreases the scope for underinvestment. Social capital brings utility to individuals and it is also used in the accumulation of human capital and R&D, and in the production of the final good. These features of the model are inspired by the empirical results stated above.

Section two presents the model and Sections three and four present, respectively, the social planner problem and the decentralized equilibrium. Section 5 compares the shares of human capital allocation in the social planner and in the decentralized equilibrium and discusses distortions in the decentralized equilibrium. In Section 6 we implement a calibration exercise to answer the question of how much social capital influences the distortions between the efficient and the decentralized solution. Section 7 concludes.

## 2. Model

In this model we combine different types of capital: physical, human, social, and technological. Physical capital is used in the production of the final good. Human capital has different uses: it is employed in the production of differentiated goods, in schools, where it is the main input to new human capital; it is used in the accumulation of social capital, as suggested by earlier literature, and is also used in the innovation process. Social capital is used in the production of the final good, in facilitating the accumulation of embodied knowledge (human capital), in facilitating the research networks that increase R&D productivity, and in its own accumulation. Technological capital is used as an intermediated good, in the production of the final good.

A crucial feature in the model is that there is no market for social capital. Social capital is produced because it makes families happier. This follows the notion of *bonding* in Beugelsdijk and Smulders (2009). However, firms (firms in the final good and those in the R&D market) benefit from social capital, which follows the notion of *bridging* in

[2] When applied to the economics of investment in R&D this expression was first used by Jones and Williams (2000) as part of the article's title.

the same article. As firms benefit from social capital without paying for it, this carries out externalities with less social capital in the market than in the efficient solution. The distortions caused by social capital act in the opposite direction as gains from specialization and spillovers in the R&D process.

### 2.1. Production factors and final goods

#### 2.1.1. Capital accumulation

The accumulation of physical capital ($K_p$) arises through production that is not consumed, and is subject to depreciation:

$$\dot{K}_P = Y - C - \delta_P K_P, \tag{1}$$

where $Y$ denotes production of final goods, $C$ is consumption, and $\delta_P$ represents depreciation.

As in the literature stream that began with Arnold (1998), in this model human capital is the "ultimate" source of growth. We follow Sequeira and Ferreira-Lopes (2011) in considering that human capital $K_H$ is produced using human capital allocated to schooling as well as the total amount of social capital, $K_S$; according to:

$$\dot{K}_H = \xi H_H + \gamma K_S - \delta_H K_H, \tag{2}$$

where $H_H$ are school hours, $\xi > 0$ is a parameter that measures productivity inside schools, $\gamma \geq 0$ measures the sensitivity of human capital accumulation to the stock of social capital, and $\delta_H \geq 0$ is the depreciation of human capital. This expression captures the idea of Coleman (1988) and Teachman *et al.* (1997) according to which social capital is important to the production of human capital. It also ensures that human and social capital are substitutes in the production of human capital.

Individual human capital can be divided into skills in final good production ($H_Y$), school attendance ($H_H$), networking for social capital accumulation ($H_S$), and conducting R&D ($H_R$), in a division similar to that of Lucas (1988), used to differentiate between human capital allocated to the final good and to schooling, and also used in Dinda (2008). Assuming that the different human capital activities are not cumulative, we have:

$$K_H = H_Y + H_H + H_S + H_R. \tag{3}$$

We based the choice of the functional form for the dynamic evolution of the stock of social capital on the literature that suggests a strong link between human capital and social capital. Also, some empirical literature on social capital has already reported an economic payoff from it (e.g., Knack, Keefer (1997) and Temple, Johnson (1998)). Hence, social capital accumulation requires that human capital be allocated to its production, but at each point in time it will also depend on the current stock of social capital, i.e.,:

$$\dot{K}_S = \omega H_S + \Omega K_S, \tag{4}$$

where $\omega$ measures the productivity of human capital in the production of social capital and $\Omega \lesseqgtr 0$ measures the dynamic effect of social capital on its own production. If $\Omega > 0$, existing social networks are strong enough to keep growing without additional human capital. Some types of social capital (such as cultural norms or values) are given by the family, which mean that people do not have to make efforts to acquire them. An alternative way of thinking about a positive $\Omega$ is that people with stronger social networks find it easier to continue improving networks than people with weaker. If $\Omega < 0$; on the other hand, there is a net depreciation effect[3].

### 2.1.2. R&D technology

Technological capital, or new varieties of it, $K_R$, is produced in an R&D sector with human capital employed in R&D labs ($H_R$), by the stock of disembodied knowledge ($K_R$), and is also influenced by the stock of social capital:

$$\dot{K}_R = \varepsilon H_R^{\upsilon} K_R^{\phi} K_S^{\chi}, \tag{5}$$

where $\varepsilon > 0$ measures the productivity in the production of technological capital, $\upsilon$ measures duplication effects, $0 < \phi < 1$ measures the degree of spillover externalities on R&D across time, as in Jones (1995), and $0 < \chi < 1$ measures the positive effect of social networks in R&D productivity[4]. The parameter $\chi$ measures an externality from social capital to R&D, representing the ideas and results found in the empirical work of Landry *et al.* (2002), De Clercq and Dakhli (2004), Lee *et al.* (2005), and Doh and Acs (2010). Since agents, when deciding how much to invest in social capital, do not take into account the effect this has on the R&D firms, they invest less in social capital than what would be socially optimal. This externality acts in the same direction as the duplication effects (the parameter $\upsilon$ in the equation) and in the opposite direction of spillovers (parameter $\phi$ in the equation), since it acts in favour of overinvestment in R&D.

### 2.1.3. Final good production

The final good is a differentiated one, produced with a Cobb-Douglas technology[5]:

$$Y = D^{\beta} K_S^{\sigma} H_Y^{1-\beta-\sigma} K_R^{\eta}, \ \beta \text{ and } \sigma < 1, \ \eta > 0. \tag{6}$$

$D$ is an index of intermediate capital goods and is produced using the following Dixit-Stiglitz CES technology:

$$D = K_R \left[ \frac{1}{K_R} \int_0^{K_R} x_i^{\alpha} di \right]^{\frac{1}{\alpha}}. \tag{7}$$

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3 We choose to model social capital based on the still scarce literature about it, i.e., we do not consider higher bounds for the stock of social capital. This is the same assumption we make for human capital, following the recent literature on human capital. There is no reason to consider that human capital grows without bounds, at a constant long-run rate, and to consider the opposite for social capital. This functional form is also used in Sequeira and Ferreira-Lopes (2011).

4 Theoretically, one could generally assume that $\chi$ might have negative values and values greater than unity. However, for simplification we assume that it varies between 0 (no effect of researchers' networks) and 1 (proportional effect of researchers' networks). In fact, in the calibration exercise we reasonably assume that the effect of researchers' networks is less than the effect of past technological knowledge ($\chi < \phi$). If $\chi = 0$, we would obtain the formulation for R&D technology used in Jones (1995).

5 Using $\sigma > 1$ instead does not change our main results.

The elasticity of substitution between varieties is measured by $0 < \alpha < 1$. $x_i$ is the intermediate capital good $i$ and is produced in a differentiated goods sector using physical capital:

$$x_i = K_{P_{x_i}}{}^{6}.$$

This means that (6) can be re-written as:

$$Y = K_R^{\eta} K_P^{\beta} K_S^{\sigma} H_Y^{1-\beta-\sigma}. \tag{8}$$

In what follows we will see that σ measures an externality from the households' to the firms' choice of social capital. Although households choose social capital comparing its marginal utility with its opportunity cost in terms of human capital, firms do not choose social capital. Instead, they face social capital as a "gift" embodied in workers. This leads to another externality, which implies less social capital in the decentralized equilibrium than in the optimum and also tends to increase the scope for overinvestment in R&D.

### 2.2. Consumers

We assume that households benefit directly from socializing. This follows the concept of *bonding* (as, for example, in Beugelsdijk, Smulders 2009). A similar utility function, with a positive effect of social capital on utility, can also be found in Roseta-Palma *et al.* (2010):

$$U\left(C_t, K_{S_t}\right) = \frac{\tau}{\tau-1} \int_0^{\infty} \left(C_t K_{St}^{\psi}\right)^{\frac{\tau-1}{\tau}} e^{-\rho t} dt, \tag{9}$$

where Ψ represents the preference for social capital and ρ is the utility discount rate[7].

## 3. Optimal growth

In this section we derive the conditions associated with the maximization of (9) subject to the production function (6) as well as the transition equations for the different types of capital (1), (2), (4), and (5)[8].

The problem gives rise to the following Hamiltonian function:

$$\mathcal{H} = \frac{\tau}{\tau-1}\left(CK_S^{\psi}\right)^{\frac{\tau-1}{\tau}} + \lambda_P\left(K_R^{\eta} K_P^{\beta} K_S^{\sigma} H_Y^{1-\beta-\sigma} - C - \delta_P K_P\right) +$$
$$\lambda_H \; (\xi H_H + \gamma K_S - \delta_H K_H) + \lambda_S(\omega H_S + \Omega K_S) + \lambda_R(\varepsilon H_R^{\upsilon} K_R^{\phi} K_S^{\chi}), \tag{10}$$

where the $\lambda_j$ are the co-state variables for each stock $K_j$; with $j = P, H, S, R$. Considering choice variables $C$, $H_Y$, $H_S$, and $H_R$ (and substituting $H_H$ for $K_H - H_Y - H_S - H_R$ using (3)), the first-order conditions yield:

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[6] We modeled taste for variety in this specific manner in order to isolate the gains of specialization (η) from the mark-up (1/ α) and from the share of physical capital in the final good production (β). This specification follows Alvarez-Pelaez and Groth (2005) and allows us to separate important externalities in comparison to what happens in the standard specification.

[7] The t subscripts are dropped hereinafter for ease of notation.

[8] In this section we are dealing with aggregated variables.

$$\frac{\partial U}{\partial C}=\lambda_P, \tag{11}$$

$$\lambda_H=\frac{\lambda_P(1-\beta-\sigma)Y}{\xi H_Y}, \tag{12}$$

$$\lambda_H=\frac{\lambda_S\omega}{\xi}, \tag{13}$$

$$\lambda_R=\frac{\xi\lambda_H}{\varepsilon\nu H_R^{\upsilon-1}K_R^{\phi}K_S^{\chi}}, \tag{14}$$

as well as:

$$\frac{\dot{\lambda}_P}{\lambda_P}=\rho+\delta_P-\frac{\beta Y}{K_P}, \tag{15}$$

$$\frac{\dot{\lambda}_H}{\lambda_H}=\rho+\delta_H-\xi, \tag{16}$$

$$\dot{\lambda}_S=\rho\lambda_S-\left(\frac{\partial U}{\partial K_S}+\frac{\lambda_P\sigma Y}{K_S}+\lambda_H\gamma+\lambda_S\Omega+\lambda_R\varepsilon\chi H_R^{\upsilon}K_R^{\phi}K_S^{\chi-1}\right), \tag{17}$$

$$\dot{\lambda}_R=\rho\lambda_R-\left(\eta\frac{Y}{K_R}\right)\lambda_P-\lambda_R\varepsilon\phi H_R^{\upsilon}K_R^{\phi-1}K_S^{\chi}, \tag{18}$$

with $\frac{\partial U}{\partial C}=C^{-\frac{1}{\tau}}K_S^{\psi\left(1-\frac{1}{\tau}\right)}$, $\frac{\partial U}{\partial K_S}=\psi C^{\left(1-\frac{1}{\tau}\right)}K_S^{\psi\left(1-\frac{1}{\tau}\right)-1}$ representing the marginal utilities of consumption and social capital, respectively.

### 3.1. Optimal growth rates

By definition growth rates will be constant in the steady state, so equation (1) tells us that $K_p$, $Y$, and $C$ all grow at the same rate. Furthermore, $K_S$ and $K_H$ components will also be growing at that same rate, respecting equations (2) to (4)[9].

Denote the growth rate of technological capital as $g_{K_R}$ and the growth rate of human capital as $g_{K_H}$: From equation (5) we can see that these two growth rates must respect this relationship: $g_{K_H}=\frac{(1-\phi)}{\chi+\upsilon}g_{K_R}$. In the steady state, we can obtain the human capital growth rate as follows. From (12) we find $g_{\lambda_H}=g_{\lambda_P}+g_Y-g_{K_H}$ and using equation (16) we can then replace the previous two equations in $-\frac{1}{\tau}g_Y+\psi\left(1-\frac{1}{\tau}\right)g_{K_H}=\frac{\dot{\lambda}_P}{\lambda_P}$, which we calculated from (11). Then, using equations (5) and (8) we obtain:

$$g_{K_H}^{*}=\frac{\xi-\delta_H-\rho}{\left(\frac{\eta\left(\frac{\chi+\upsilon}{1-\phi}\right)}{1-\beta}+\psi\right)\left(\frac{1}{\tau}-1\right)+\frac{1}{\tau}}. \tag{19}$$

[9] In this work we did not analyse the transitional dynamics of the model. We analyse the unique inner steady-state solution of the model.

Using the fact that $g_{K_H} = \frac{(1-\phi)}{\chi+\upsilon} g_{K_R}$, we solve for the growth rate of technological capital:

$$g_{K_R}^{*} = \frac{\frac{\chi+\upsilon}{(1-\phi)}\left(\xi-\delta_H-\rho\right)}{\left(\frac{\eta\left(\frac{\upsilon+}{1-\phi}\right)}{1-\beta}+\psi\right)\left(\frac{1}{\tau}-1\right)+\frac{1}{\tau}}. \tag{20}$$

From (8) and $g_{K_H} = \frac{(1-\phi)}{\chi+\upsilon} g_{K_R}$ we find $g_Y = g_{K_H}\left(\frac{\eta\left(\frac{\chi+\upsilon}{1-\phi}\right)}{1-\beta}+1\right)$. By substituting (19) in the previous equality we find:

$$g_Y^{*} = \frac{\left(\xi-\delta_H-\rho\right)\left(\frac{\eta\left(\frac{\chi+\upsilon}{1-\phi}\right)}{1-\beta}+1\right)}{\left(\frac{\eta\left(\frac{\chi+\upsilon}{1-\phi}\right)}{1-\beta}+\psi\right)\left(\frac{1}{\tau}-1\right)+\frac{1}{\tau}}. \tag{21}$$

While the impact of the social capital share ($\sigma$) is positive in growth rates, the impact of preference for social capital ($\psi$) is negative, as it has a trade-off with consumption. This has a parallel with the effects of *bonding* and *bridging* in growth rates in the article from Beugelsdijk and Smulders (2009). Optimal growth rates depend on parameters of the model as usual in non-scale models of endogenous growth.

## 4. Decentralized equilibrium

In the decentralized equilibrium both consumers and firms make choices that maximize, respectively, their own felicity or profits[10]. Consumers maximize their intertemporal utility function (9) subject to the budget constraint:

$$\dot{a} = \left(r-\delta_P\right)a + W_H\left(K_H - H_H - H_S - H_R\right) - C, \tag{22}$$

where $a$ represents the family physical assets, $r$ is the gross return on physical capital, and $W_H$ is the market wage. The market price for the consumption good is normalized to 1. Since it is making an intertemporal choice, the family also takes into account equations (2) and (4), which represent human and social capital accumulation, respectively[11].

The markets for purchased production factors are assumed to be competitive. However, we assume that the firm cannot buy social capital, as there is, in effect, no market for

[10] In this section we are working with individual variables.

[11] FOC and growth rates for the decentralized equilibrium are available upon request. They are derived in the same way than the ones for the social planner problem.

it. Social capital is treated here as exogenous, although it affects the firm's production. Hence, consumer decisions will carry social capital externalities.

From this problem we know that returns on production are as follows:

$$W_H = \frac{(1-\beta-\sigma)Y}{H_Y}, \tag{23}$$

$$p_D = \frac{\beta Y}{D}, \tag{24}$$

where $p_D$ represents the price for the index of intermediate capital goods.

Each firm in the intermediate goods sector owns an infinitely-lived patent for selling its variety $x_i$. Producers of differentiated goods act under monopolistic competition in which they sell their own variety of the intermediate capital good $x_i$ and maximize operating profits, $\pi_i$:

$$\pi_i = (p_i - r)x_i, \tag{25}$$

where $p_i$ denotes the price of intermediate good $i$ and $r$ is the gross unit cost of $x_i$. The demand for each intermediate good results from the maximization of profits in the final goods sector. Profit maximization in this sector implies that each firm charges a price of:

$$p_i = p = r/a. \tag{26}$$

With identical technologies and symmetric demand, the quantity supplied is the same for all goods, $x_i = x$. Hence, equation (7) can be written as:

$$D = K_R x. \tag{27}$$

From $p_D D = pxK_R$, together with (24) and (26), we obtain:

$$xK_R = K_P = \frac{\alpha\beta Y}{r}. \tag{28}$$

After insertion of equations (26) and (28) into (25), profits can be rewritten as:

$$\pi = (1-\alpha)\beta Y / K_R. \tag{29}$$

Let υ denote the value of an innovation, defined by:

$$\nu_t = \int_t^{\infty} e^{-[R(\tau)-R(t)]}\pi(\tau)d\tau, \text{ where } R(\tau) = \int_0^t r(\tau)d\tau. \tag{30}$$

Taking into account the cost of an innovation as determined by equation (5), free-entry in R&D implies that,

$$\omega H_R = \nu\varepsilon H_R^{\upsilon} K_R^{\phi} K_S^{\chi} \text{ if } \dot{K}_R > 0 \ (H_R > 0), \tag{31}$$

$$\omega H_R > \nu\varepsilon H_R^{\upsilon} K_R^{\phi} K_S^{\chi} \text{ if } \dot{K}_R = 0 \ (H_R = 0). \tag{32}$$

Finally, the no-arbitrage condition requires that investing in patents has the same return as investing in bonds:

$$\frac{\dot{\nu}}{\nu} = (r - \delta_P) - \pi / \nu. \tag{33}$$

## 5. Optimality of human capital allocations

Using the FOC obtained from the social planner solution (11) to (18) and the equations that describe the evolution of the four capital stocks (1), (2), (4), and (5), it is possible to obtain the shares of human capital allocated to the different sectors in the economy (final good, human capital, social capital, and R&D). The shares of human capital allocated to the different sectors are:

$$u_Y^* = \frac{H_Y}{K_H} = \frac{\left[\xi - \delta_H - \frac{\omega\gamma}{\xi} - \Omega\right]\left(\frac{K_S}{K_H}\right)^* - \frac{\omega\chi}{\nu} u_R^*}{\frac{\omega}{(1-\beta-\sigma)}\left[\psi \frac{C}{Y} + \sigma\right]}, \tag{34}$$

$$u_S^* = \frac{H_S}{K_H} = \left(\frac{g_{K_S}^* - \Omega}{\omega}\right)\left(\frac{K_S}{K_H}\right)^*, \tag{35}$$

$$u_H^* = \frac{H_H}{K_H} = \frac{1}{\xi}\left(g_{K_H}^* + \delta_H\right) - \frac{\gamma}{\xi}\left(\frac{K_S}{K_H}\right)^*, \tag{36}$$

$$u_R^* = \frac{H_R}{K_H} = \frac{\frac{\eta\nu}{(1-\beta-\sigma)} g_{K_R}^*}{\xi - \delta_H + g_{K_R}^*\left[(\nu - 1 + \chi)\left(\frac{1-\phi}{\chi+\nu}\right)\right]} u_Y^*, \tag{37}$$

$$u_Y^* = \frac{H_Y}{K_H} = \frac{\left[\xi - \delta_H - \frac{\omega\gamma}{\xi} - \Omega\right]\left(\frac{K_S}{K_H}\right)^* - \frac{\omega\chi}{\nu} u_R^*}{\frac{\omega}{(1-\beta-\sigma)}\left[\psi \frac{C}{Y} + \sigma\right]} =$$

$$\frac{\left[\xi - \delta_H - \frac{\omega\gamma}{\xi} - \Omega\right]\left(\frac{K_S}{K_H}\right)^*}{\frac{\omega}{(1-\beta-\sigma)}\left[\psi \frac{C}{Y} + \sigma\right] + \frac{\frac{\omega\chi}{\nu}\frac{\eta\nu}{(1-\beta-\sigma)} g_{K_R}^*}{\xi - \delta_H + g_{K_R}^*\left[(\nu - 1 + \chi)\left(\frac{1-\phi}{\chi+\nu}\right)\right]}}.$$

Using the restriction that $u_Y^* + u_S^* + u_H^* + u_R^* = 1$; we obtain the social to human capital ratio:

$$\left(\frac{K_S}{K_H}\right)^* = \frac{1 - \frac{1}{\xi}\left(g_{K_H}^{DE} + \delta_H\right)}{\phi^* + \frac{g_{K_S}^{DE} - \Omega}{\omega} - \frac{\gamma}{\xi}}, \tag{38}$$

where

$$\phi^* = \frac{\dfrac{\left[\xi - \delta_H - \dfrac{\omega\gamma}{\xi} - \Omega\right]}{\left[\dfrac{\omega}{(1-\beta-\sigma)}\left[\psi\dfrac{C}{Y}+\sigma\right]\right]}}{1 + \dfrac{\dfrac{\omega\chi}{\nu}}{\dfrac{\omega}{(1-\beta-\sigma)}\left[\psi\dfrac{C}{Y}+\sigma\right]}\dfrac{\dfrac{\eta\nu}{(1-\beta-\sigma)}}{\xi-\delta_H+g^*_{K_R}\left[(v-1+\chi)\left(\dfrac{1-\phi}{\chi+\nu}\right)\right]}g^*_{K_R}}\left(1+\frac{\dfrac{\eta\nu}{(1-\beta-\sigma)}}{\xi-\delta_H+g^*_{K_R}\left[(v-1+\chi)\left(\dfrac{1-\phi}{\chi+\nu}\right)\right]}g^*_{K_R}\right). \quad (39)$$

Using the FOC obtained for the decentralized equilibrium solution, the equations that describe the evolution of the four capital stocks (1), (2), (4), and (5), and also equations (23), (29), (31) and (33), it is possible to obtain the shares of human capital allocated to the different sectors in the economy: final good, human capital, social capital, and R&D. The shares of human capital allocated to the different sectors in the decentralized equilibrium are:

$$u_Y^{DE} = \frac{H_Y}{K_H} = \frac{\xi - \delta_H - \dfrac{\omega\gamma}{\xi} - \Omega}{\dfrac{\omega}{(1-\beta-\sigma)}\left[\psi\dfrac{C}{Y}\right]}\left(\frac{K_S}{K_H}\right)^{DE}, \quad (40)$$

$$u_S^{DE} = \frac{H_S}{K_H} = \left(\frac{g_{K_S}^{DE} - \Omega}{\omega}\right)\left(\frac{K_S}{K_H}\right)^{DE}, \quad (41)$$

$$u_H^{DE} = \frac{H_H}{K_H} = \frac{1}{\xi}\left(g_{K_H}^{DE} + \delta_H\right) - \frac{\gamma}{\xi}\left(\frac{K_S}{K_H}\right)^{DE}, \quad (42)$$

$$u_R^{DE} = \frac{H_R}{K_H} = \frac{\dfrac{\beta(1-\alpha)}{(1-\beta-\sigma)}g_{K_R}^{DE}}{\xi - \delta_H + g_{K_R}^{DE}\left[\left(\dfrac{1-\phi}{\chi+\nu}\right)(\chi+v-1)+\phi\right]}u_Y^{DE}. \quad (43)$$

Using the restriction that $u_Y^{DE} + u_S^{DE} + u_H^{DE} + u_R^{DE} = 1$; we obtain the social to human capital ratio:

$$\left(\frac{K_S}{K_H}\right)^{DE} = \frac{1 - \dfrac{1}{\xi}\left(g_{K_H}^{DE} + \delta_H\right)}{\phi^{DE} + \dfrac{g_{K_S}^{DE} - \Omega}{\omega} - \dfrac{\gamma}{\xi}}, \quad (44)$$

where

$$\phi^{DE} = \frac{\left[\xi - \delta_H - \dfrac{\omega\gamma}{\xi} - \Omega\right]}{\left[\dfrac{\omega}{(1-\beta-\sigma)}\left[\psi\dfrac{C}{Y}\right]\right]}\left(1 + \frac{\dfrac{\beta(1-\alpha)}{(1-\beta-\sigma)}}{\xi - \delta_H + g^*_{K_R}\left[(v-1+\chi)\left(\dfrac{1-\phi}{\chi+\nu}\right)+\phi\right]}g^*_{K_R}\right). \quad (45)$$

As growth rates and the consumption to output ratio are equal in the social planner and decentralized equilibrium solutions, the differences from the two solutions are spillovers in R&D, duplication effect in R&D, the specialization gains, and the externalities from social capital. As in Alvarez-Palaez and Groth (2005), the social gains from specialization ($\eta$) compare with the private gain from an innovation $\beta(1-\alpha)$[12]. From the comparison of (34)–(37) to (40)–(43) taking into account the comparison between (45) and (39), it is possible to advance the following proposition.

**Proposition 1.** *The Decentralized Equilibrium yields a sub-optimal or over-optimal social capital to human capital ratio and R&D effort, depending on the opposite effects of the following externalities:*

*(i) the social capital externalities* ($\sigma$ *and* $\chi$)*, which increase the social to human capital ratio in the social planner solution, increase the human capital allocated to social capital production, and decrease human capital allocated to "schools", final good, and R&D sectors;*

*(ii) the spillover externality* ($\phi$)*, which decreases human capital allocated to R&D in the market, increases the social to human capital ratio, and then increases allocations to the final good and to social capital production, but decreases the allocation to the education sector in the market;*

*(iii) the duplication externality* ($\upsilon$)*, which decreases human capital allocated to R&D in the planner's solution, increases the social to human capital ratio, and then increases allocations to the final good and to the social capital production, but decreases allocation to the education sector in the planner's solution;*

*(iv) the difference between the social gain from specialization and the private gain from specialization* ($\eta \neq (\beta 1-\alpha)$)*, which decreases social to human capital ratio in the social planner's solution, decreases human capital allocated to the final good and to the social capital production, and increases allocation to all the other sectors in the economy.*

*Thus, relatively high social capital shares in the final good production and R&D technology may contribute to decrease the underinvestment in R&D. Spillovers and social gains from specialization act in favour of underinvestment and duplication, and social capital externalities act in favour of overinvestment.*

As is usual in studies seeking to evaluate distortions between the social planner and decentralized equilibrium solutions, this evaluation is a quantitative issue. Thus, we now implement a calibration exercise to evaluate the distortions.

## 6. Results and calibration

### 6.1. Calibration procedure

It is not easy to take a model with social capital to data, as research dealing with social capital is still scarce. Some parameters in our model are quite standard in the literature: the intertemporal substitution parameter ($\tau = 0.5$), the intertemporal discount factor ($\rho = 0.02$), the share of physical capital in income ($\beta = 0.36$), the markup ($1/\alpha = 1.33$),

[12] This proof is available upon request.

and the productivity of R&D ($\varepsilon = 0.1$), and we therefore do not discuss them[13]. For others, there is a range of plausible values: the depreciation rates ($\delta_K$, $\delta_H$), the productivity of human capital accumulation ($\xi$), the contribution of social capital to economic growth ($\sigma$), spillovers ($\phi$), and duplication effects ($\upsilon$). For these values we discuss our options. For other parameters there is greater uncertainty. For $\gamma$ and $\omega$, we conclude that changes in them are not crucial for the distortion evaluation. We therefore fix their values at 0.01. For the preference for social capital ($\psi$) we test different values and conclude that values greater than 0 and less than 1 (i.e., consumers prefer consumption to social capital, which seems reasonable) do not change conclusions on distortions. Thus, we choose an intermediate value of $\psi = 0.5$. For the spillover and duplication effects we choose $\phi = 0.4$ and $\upsilon = 0.5$ as reasonable values suggested in the literature[14]. For the externality of social capital in the R&D technology we choose one half of the spillover value, reasonably assuming that the effect of research networks on R&D is much lower than the "standing on shoulders" effect.

For the depreciation of physical capital, we set the realistic and commonly used value $\delta_K = 0.05$. In earlier research that considers human and physical capital accumulation simultaneously, a zero depreciation is considered. For the human capital depreciation, Heckman (1976) reports that it lies between 0.7% and 4.7%. We consider either $\delta_H = 0$, as in most earlier models with human capital accumulation or an intermediate value between 0.007 and 0.047, $\delta_H = 0.02$. However, this value does not influence our main results. For the parameter $\Omega$, which can measure a positive effect of social capital in its accumulation or a depreciation of social capital, we use alternatively –0.01 and 0.01. For each of these exercises, we set the steady-state economic growth rate to 1.85%, which gives us a value for $\xi$. This procedure yields values in the range used in the human capital literature (e.g., Funke, Strulik 2000). For the impact of social capital on economic growth, we use a lower bound estimate for $\sigma$ of 0.08, as in Knack and Keefer (1997), where in a 10% increase in trust implies a 0.8% increase in the economic growth rate. We also use a high bound for $\sigma = 1 - \beta - \sigma = 0.32$, suggested by the evidence in Whiteley (2000), which points to an effect of social capital as great as the effect of human capital. Whiteley's findings also approximate the evidence in World Bank (2006), reporting a share of 0.78 to intangible capital, which includes both human and social capital. For the consumption-output ratio ($C/Y$) we found a reasonable value around 0.8.

Table 1 below summarizes the calibration values, in which we use two sets. The first, which we call "benchmark", shows the distortion caused by social capital in the absence of any other distortion (in this calibration there are no spillovers, duplication effects, or specialization gains). In the second (designated "Reasonable"), we set spillovers to 0.4 (see Reis, Sequeira 2007), duplication to 0.5 (see Pessoa 2005), specialization gains to 0.196 (see Jones and Williams 2000), and the social capital share to a value between 0.08 and 0.32 (see above).

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[13] For the markup value we use a median value from Norrbin (1993).

[14] See Reis and Sequeira (2007) for a discussion about the value of $\phi$ in models with human capital accumulation and Pessoa (2005) for estimations of $\phi$ and $\upsilon$.

**Table 1.** Calibration values

| Basic Parameters | | Parameters for Externalities | | |
|---|---|---|---|---|
| Parameter | Benchmark/Reasonable | Parameter | Benchmark | Reasonable |
| $\tau$ | 0.5 | $\chi$ | varies | 0.2 |
| $\beta$ | 0.36 | $\sigma$ | varies | 0.08 or 0.32 |
| $\rho$ | 0.02 | $\phi$ | 0 | 0.4 |
| $\alpha$ | 0.75 | $\upsilon$ | 1 | 0.5 |
| $\delta_H$ | 0/0.02 | $\eta$ | $\beta(1-\alpha)$ | 0.196 |
| $\delta_K$ | 0.05 | Calibrated Variables | | |
| $\gamma$, $\omega$ | 0.01 | $\xi$ | depends on $g_Y$; | [0.05; 0.1] |
| $\Omega$ | –0.01/0.01 | $g_Y$ | 0.0185 | |

## 6.2. Distortions from social capital

We now present the differences between the decentralized equilibrium and the optimal solution when there are distortions from only social capital. Thus, we apply benchmark calibration values. Figure 1 shows the different values of the $K_S/K_H$ ratio through different values for the share of social capital in production. Figure 2 shows the change of the allocation of human capital to the social capital sector. Figure 3 shows the change in the allocation of human capital to the R&D sector through different values of the same share. We also present three figures showing the change in the ratio $K_S/K_H$, the share $u_S$, and the share $u_R$ through different values for the externality of social capital in the R&D technology.

From Figures 1 to 3 we can note that increasing the value of the share of social capital in the final good production increases the distortions in the decentralized economy, increasing the differences between the socially desired ratio of social to human capital and the ratio obtained by the decentralized action of different agents (Figure 1).

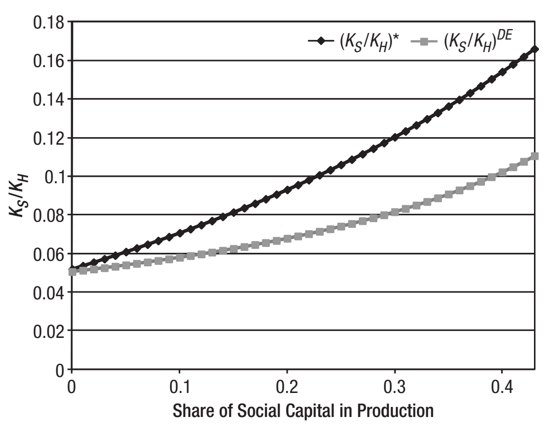


**Fig. 1.** Comparison between $(K_S/K_H)^{DE}$ and $(K_S/K_H)^*$ for different values of the share of social capital in production

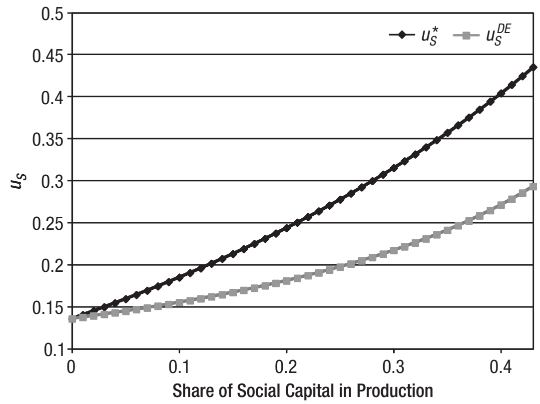


**Fig. 2.** Comparison between $u_S^{DE}$ and $u_S^*$ for different values of the share of social capital in production

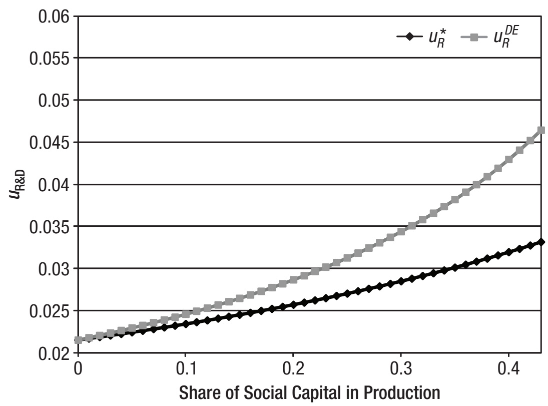


**Fig. 3.** Comparison between $u_R^{DE}$ and $u_R^*$ for different values of the share of social capital in production

This distortion clearly causes underallocation of human capital to the social capital sector (Figure 2) and overinvestment in R&D, as can be seen from Figure 3. While the ratio $K_S/K_H$ by nearly four times until $\sigma = 0.43$ in the optimal solution, it rises by only half that in the decentralized economy. The difference between the efficient allocation to the R&D sector and the market allocation can rise up to 1.3%, while the difference between efficient allocation to social capital and the market allocation can go up to 14%.

From Figures 4 to 6 we can see that increasing the effect of social capital on R&D technology also increases distortions, but less so than the rise in distortions caused by the final good social capital share. In this case a change from $\chi = 0$ to $\chi = 1$ implies distortion in $K_S/K_H$ of 0.004, a distortion in $u_S$ of about 1%, and finally a distortion in $u_R$ of near 0.05%. We also have a tendency for underinvestment in social capital and overinvestment to R&D.

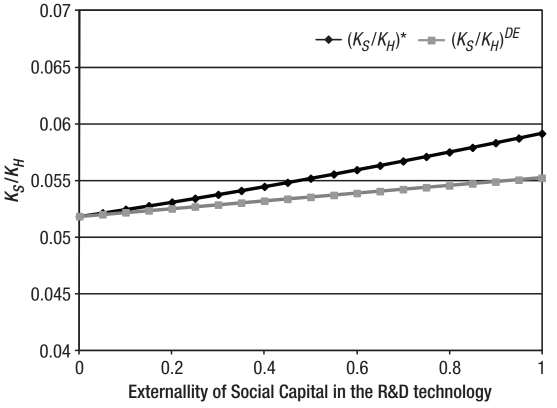


**Fig. 4.** Comparison between $(K_S/K_H)^{DE}$ and $(K_S/K_H)^*$ for different values of the share of social capital in R&D

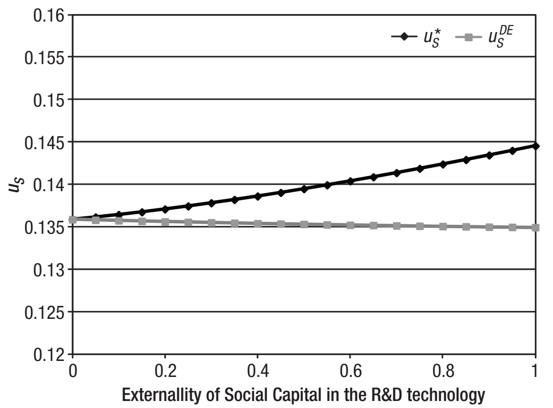


**Fig. 5.** Comparison between $u_S^{DE}$ and $u_S^*$ for different values of the share of social capital in R&D

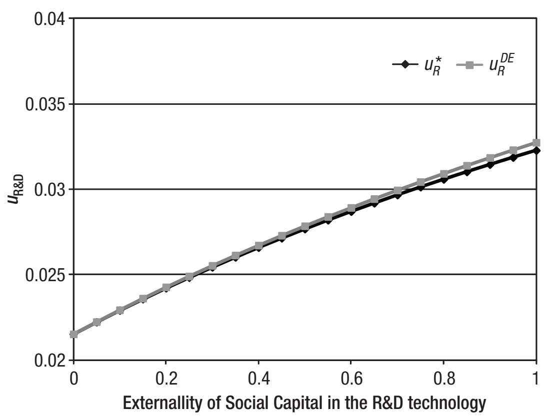


**Fig. 6.** Comparison between $u_R^{DE}$ and $u_R^*$ for different values of the share of social capital in R&D

### 6.3. Taking all distortions together

In this section we present results from quantitative exercises in which we apply the calibration values depicted as "Reasonable" in Table 1. Tables 2 to 4 compare the social planner allocations to the decentralized equilibrium ones. We show three different exercises: the first eliminates the distortions due to social capital and sets other distortions at reasonable levels, given by parameter values discussed above; the second considers a lower limit for the social capital share in production and a reasonable value for the externality of social capital in the R&D technology, and keeps values for other parameters at the level used in the first exercise; the third exercise is equal to the second, except for the share of social capital in production, which increases to 0.32. The only difference in Table 3 (from Table 2) is that it uses a depreciation for human capital of $\delta_H = 0.02$. The only difference in Table 4 (also from Table 2) is to consider a depreciation of social capital ($\Omega = -0.01$). In all these exercises $g_{KH}$ oscillates from 1.36% to 1.47% and $g_{KR}$ from 1.23% to 1.59%.

Without the distortions introduced in this article ($\sigma = 0$, $\chi = 0$), we note that the tendency for underinvestment in R&D is high, as predicted in earlier literature (e.g., Jones, Williams 2000). Human capital allocation in the decentralized economy is almost at the optimal level and there are over-allocations to the final good production and to the social capital sector. It is worth noting that due to the distortions from social gains from specialization, spillovers, and duplication, there is a relatively higher ratio of social capital to human capital in the market economy when compared to the social planner choice.

When we consider positive values for $\sigma$ and $\chi$ we note that the social to human capital ratio is now higher in the efficient solution than in the market economy, which is due to the distortions introduced in this article. The absence of a market for social capital is responsible for having relatively lower social capital in the market than in the case in which social welfare would be taken into account. This is reflected in the allocation of human capital to social capital production, which should also be higher than it is in the market economy. As a result, allocation of human capital to the human capital accumulation sector is above the optimal level and the level of underinvestment in R&D is reduced.

In the third exercise, the distortion in the social capital sector is so high that the social planner would allocate to that sector nearly twice the human capital allocated by the market economy (from 6.63% to 11.48% in Table 2; from 4.86% to 8.35% in Table 3, and from 16.98% to 24.92% in Table 4). Thus, in these scenarios the social planner would reallocate human capital from final good production and schools to social capital accumulation sectors and to R&D. This means that some policies can be designed to enhance the production of social capital.

Considering a positive depreciation for human capital, as we do in Table 3, introduces almost no differences in distortions from the social planner allocations. However, such a high depreciation in human capital predicts a share of human capital allocated to the human capital accumulation sector that is at the highest limit of the reasonable interval for that variable. Nevertheless, when we introduce a depreciation in social capital accumulation, as in Table 4, we note some important differences. The share of human capital allocated to the social capital production sector is greater than in previous ex-

**Table 2.** Results from reasonable calibrations ($\delta_H = 0$, $\Omega = 0.01$)

| $\sigma$ | $\sigma = 0$ | | | $\sigma = 0.08$ | | | $\sigma = 0.32$ | | |
|---|---|---|---|---|---|---|---|---|---|
| $\chi$ | $\chi = 0$ | | | $\chi = 0.2$ | | | $\chi = 0.2$ | | |
| | SP | DE | SP/DE | SP | DE | SP/DE | SP | DE | SP/DE |
| $K_S/K_H$ | 0.090 | 0.090 | 0.99 | 0.132 | 0.110 | 1.21 | 0.316 | 0.183 | 1.73 |
| $u_Y$ | 70.41% | 70.78% | 0.99 | 70.73% | 71.76% | 0.99 | 64.99% | 68.35% | 0.95 |
| $u_S$ | 4.38% | 4.30% | 0.99 | 4.81% | 3.98% | 1.21 | 11.48% | 6.63% | 1.73 |
| $u_H$ | 22.83% | 22.82% | 1.00 | 20.88% | 21.26% | 0.98 | 17.76% | 20.02% | 0.89 |
| $u_R$ | 2.49% | 2.10% | 1.18 | 3.59% | 3.00% | 1.20 | 5.77% | 4.99% | 1.16 |

**Table 3.** Results from reasonable calibrations ($\delta_H = 0.02$, $\Omega = 0.01$)

| $\sigma$ | $\sigma = 0$ | | | $\sigma = 0.08$ | | | $\sigma = 0.32$ | | |
|---|---|---|---|---|---|---|---|---|---|
| $\chi$ | $\chi = 0$ | | | $\chi = 0.2$ | | | $\chi = 0.2$ | | |
| | SP | DE | SP/DE | SP | DE | SP/DE | SP | DE | SP/DE |
| $K_S/K_H$ | 0.067 | 0.067 | 0.99 | 0.097 | 0.081 | 1.21 | 0.230 | 0.134 | 1.72 |
| $u_Y$ | 52.97% | 52.97% | 0.99 | 52.44% | 53.27% | 0.98 | 47.73% | 50.54% | 0.94 |
| $u_S$ | 3.17% | 3.19% | 0.99 | 3.53% | 2.93% | 1.21 | 8.35% | 4.86% | 1.72 |
| $u_H$ | 42.26% | 42.26% | 1.00 | 41.37% | 41.58% | 0.99 | 39.69% | 40.90% | 0.97 |
| $u_R$ | 1.86% | 1.57% | 1.18 | 2.66% | 2.22% | 1.20 | 4.24% | 3.69% | 1.15 |

**Table 4.** Results from reasonable calibrations ($\delta_H = 0.02$, $\Omega = -0.01$)

| $\sigma$ | $\sigma = 0$ | | | $\sigma = 0.08$ | | | $\sigma = 0.32$ | | |
|---|---|---|---|---|---|---|---|---|---|
| $\chi$ | $\chi = 0$ | | | $\chi = 0.2$ | | | $\chi = 0.2$ | | |
| | SP | DE | SP/DE | SP | DE | SP/DE | SP | DE | SP/DE |
| $K_S/K_H$ | 0.041 | 0.041 | 0.99 | 0.056 | 0.048 | 1.17 | 0.105 | 0.072 | 1.47 |
| $u_Y$ | 45.60% | 45.80% | 0.99 | 42.74% | 44.84% | 0.95 | 31.06% | 38.51% | 0.82 |
| $u_S$ | 10.21% | 10.25% | 0.99 | 13.20% | 11.30% | 1.17 | 24.92% | 16.98% | 1.47 |
| $u_H$ | 42.58% | 42.58% | 1.00 | 41.89% | 41.99% | 1.00 | 41.26% | 41.69% | 0.99 |
| $u_R$ | 1.61% | 1.36% | 1.18 | 2.17% | 1.87% | 1.16 | 2.76% | 2.81% | 0.98 |

ercises because human capital allocated to that sector must compensate the depreciation effect, while in previous exercises this did not occur because social capital could grow by itself (exogenously). The most important implication is that underinvestment in R&D is much reduced (from $u_R^* / u_R = 1.16$ to $u_R^* / u_R = 0.98$), opening the possibility to overinvestment in R&D.

This means that the threshold level for the share of social capital in production ($\sigma$) above which there is overinvestment in R&D is below 0.32, which is in the range of plausible values according to World Bank (2006). The higher the depreciation for social capital, the lower the threshold value for its share in production above which overinvestment in R&D occurs. In fact, in the case of the third exercise in Table 2, we can see that considering a 1% depreciation for social capital, we can obtain overinvestment to R&D while maintaining lower and perhaps more reasonable values for the allocations through sectors in the economy, with the highest allocation to the final good production.

## 7. Conclusion

The interaction between social capital and R&D has been pointed out as an element of research networks. We build the production side of the model taking into account the interactions between the different types of capital that have been discussed in earlier (mainly) empirical literature. In particular, we note the importance of the use of human capital in social capital accumulation and the importance of this last factor in the production of the final good, and also in the discovery of new ideas, i.e., in the R&D sector.

In the model we also consider the most important distortions present in previous models: the social benefit from specialization, spillovers, and duplication in R&D. We implement a calibration exercise in order to evaluate the strength of the new distortions from social capital. First we show that new distortions lead to underinvestment in social capital, when we examine the social to human capital ratio and when we compare allocations of human capital to the social capital accumulation sector. Second, we also show that the presence of these distortions decreases the tendency to underinvestment in R&D. However, quantitatively these distortions are not strong enough to cause overinvestment in R&D when social capital has a positive effect on its own accumulation. The opposite result is obtained when social capital depreciates. In fact, in this case, the social capital externalities introduced in this article are able to generate overinvestment in R&D. This complements the recent literature (Strulik 2007; Reis, Sequeira 2007) that present more arguments in favour of overinvestment. Moreover, our results point out a share of human capital in social capital accumulation that oscillates in the decentralized equilibrium from 3% to near 17%, which is an additional quantitative reason to integrate social capital in an endogenous growth model with R&D and human capital accumulation, as we do in this article.

We devise an endogenous growth model with social capital that contributes to production and utility simultaneously, and evaluate both analytically and quantitatively the distortions that are present in its market equilibrium. This shows the importance of considering social capital in the endogenous growth theory.

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