QUT School of Economics and Finance

Discussion Paper and Working Paper Series

Socialism, Capitalism, and Transition - Coordination of Economic Relations and Output Performance

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We argue that the destruction of some contacts in search for better ones is an integral part of technological advancement. This destruction carries a negative externality on former business partners.

Socialist economies restricted such creative destruction, which we argue lead to their increasing technological backwardness. This is our explanation of the output fall during (unrestricted) transition: the technological catch-up implied high levels of destroyed and replaced relational capital. This not only had high direct opportunity costs (more labor is used for the production of relational capital) but also led to a loss in overall relational capital. The basic model is used to simulate plausible transition paths which appear compatible with many stylized facts of the transition experience. Finally we discuss empirical observations as well as policy issues brought up in the literature.

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November 2003

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Keywords: Transition, Economic Systems, Relations, Innovation

JEL: P21, P51, O33

The carrying out of new combinations we call 'enterprise'.

Joseph Schumpeter (1934:74)

1   Introduction

One of the most far-reaching economic developments of our time is the transition in Central and Eastern Europe and the former Soviet Union, of socialism to capitalism. The major surprise was that those countries with arguably most to gain from the transition - those with lowest initial GDP - experienced the worst GDP falls of a magnitude 'never before experienced in the history of capitalist economies' (Mundell, 1997).

The questions we address are what characterized and caused economic circumstances before transition[1]; how the output fall is related to the nature of the transition from capitalism to socialism; and whether such an output fall can be avoided in ongoing and future transitions?

Our paper is inspired by Blanchard and Kremer's (1997) and Roland and Verdier's (1999) disorganization theory. These authors argue that the output fall was caused by the negative externality of firms breaking off previous contacts with other firms replacing them with more productive partners. However, in these articles there are no labor costs of making contacts, technological gains from destroying contacts are an one-off event, and the opportunities for gains arrive exogenously. Our model formalizes the role of contacts, introduces labor costs of making and replacing contacts, conceptualizes technological growth and the role of contacts in a continuous process, and draws in the socialist experience. Doing so, we endogenize the origin of the potential technological gain at the start of transition and draw implications of the transition beyond a one-off event.

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[1]The key stylised fact about socialist countries to be explained is that they did well when they were 'young' but showed from the eighties onwards a disappointing performance in terms of output.

The key element in our story is the role of what we call 'relational capital' (RC) in sold production and technological progress.[2] RC is the stock of business relations and contacts necessary to procure inputs and to sell output.[3]

On the one hand, RC is a direct input into the production of *sold* output. To sell outputs and buy inputs, contacts with suitable trading partners need to be found and maintained whenever markets are less than perfect. This is typically a white collar job that complements physical production. Both, a market economy and a planned economy need RC to function, economic systems differ in who decides about what links are formed and severed.

On the other hand, innovations need the destruction and replacement of some relations. An improved product needs new suppliers to make and new customers to buy it. Economies of scale to specialization make it inefficient for an individual firm to continue making the old product alongside the new one. We name the destruction of old contacts and old ways of organizations in order to find better technologies *'creative destruction'*, in line with Schumpeter's view that invention and innovation is crucial to economic advancement.[4] This creative destruction comprises of many small advances made by large numbers of firms, involving negative externalities on the RC of other firms.

The socialist and capitalist system differ in the extent to which they

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[2]In the social capital literature (see for example Sobel, 2002) one distinguishes between an individual and communal aspect of social capital. Our concept relates to the individual aspect. See Frijters et al. (2003) for a discussion of the relation between RC and social capital. To avoid confusion, our concept of relational capital is unrelated to the 'relational theory of contract law' (see for example Macauly, 1963, or Williamson, 1985) which discusses certain aspect of communal level social capital, namely norms and laws and how they affect economic development.

[3]Frijters(2000) introduces a related concept of relational capital on the firm level and analyses the consequences for the wage and age structure of employees within a firm.

[4]Our notion of creative destruction is not related to the neo-Schumpeterian literature because we do not explicitly model monopoly rents. Given that we focus mostly on small advancements, our use of the term best fits Schumpeter Mark I technologies.

allow creative destruction. Destruction of relations was almost impossible under socialism: firms were simply not allowed to change trading partners (Braguinsky and Yavlinsky, 2000). This implied a large technological gap at the start of the transition, giving firms strong incentives to engage in creative destruction. The negative externalities of excessive creative destruction is our 'disorganization' explanation for the initial output collapse. An additional output-decreasing effect of massive creative destruction in our model is the large-scale re-allocation of labor towards finding new contacts and away from physical production during transition.

A real-life example of our arguments on RC is provided in Meyer's (2000) analysis of the automotive industry in Central Europe. Prior to 1989, nine independent manufacturers in Central Europe (among them Wartburg and Trabant in East Germany, Skoda in Czechoslovakia and Dacia in Romania) were producing some 3.2 million cars annually, primarily for the CoMEcon (Council for Mutual Economic Assistance) market. Soon after 1989, all major producers of passenger cars in Central Europe formed joint-ventures with, or were taken over by, Western partners. The most successful one was the Czech car manufacturer Skoda, which was taken over by the VW Group. While the change in ownership brought an increase in FDI in Skoda, the main benefits of the change came through new business links. Skoda pressured its local partners to link up with Western partners, while VW urged its global suppliers to form joint-ventures with, or acquire local Czech firms. About 50 multinational automotive suppliers did so, among them the British Lucas Group (providing brake systems) and Rockwell (sun roofs), and the German Siemens/Sommer-Allibert (cockpits). The Skoda-VW deal brings out the contrast between those local enterprises who benefitted from this new Relational Capital and those who didn't. As Meyer (2000:141) notes, 'great opportunities emerged for local suppliers to become global suppliers through the VW group', but '(o)ther Czech suppliers who did not succeed in securing contracts ... struggled for survival ...'. This case of RC replacement yielded gains for new Skoda-VW suppliers and losses for those Czech suppliers losing

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their 'old' RC.

The organization of this article is as follows. In Section 2, the literature on the output fall is reviewed. Section 3 contains a general equilibrium growth model of RC, creative destruction, socialism and capitalism. Section 4 presents a series of simulations. We simulate 'typical' growth paths of socialism and transition, and then explore robustness and optimal transition design. In Section 5, the findings are related to the stylized facts of transition and to policy questions. Section 6 discusses extensions. Appendix 1 provides micro arguments for the main aspects of the model and Appendix 2 contains steady state properties.

2   Literature on the Output Fall

Figure 1 depicts the fall and recovery of output in the Central and Eastern European Economies and in the former Soviet Republics. Developments in GDP are presented as regional aggregates, but the pattern of a drop in GDP followed by recovery is observable in each of the 25 transition countries represented in Figure 1 (see EBRD, 2002).

Figure 1: Development of GDP in Transition Regions, 1989-2002
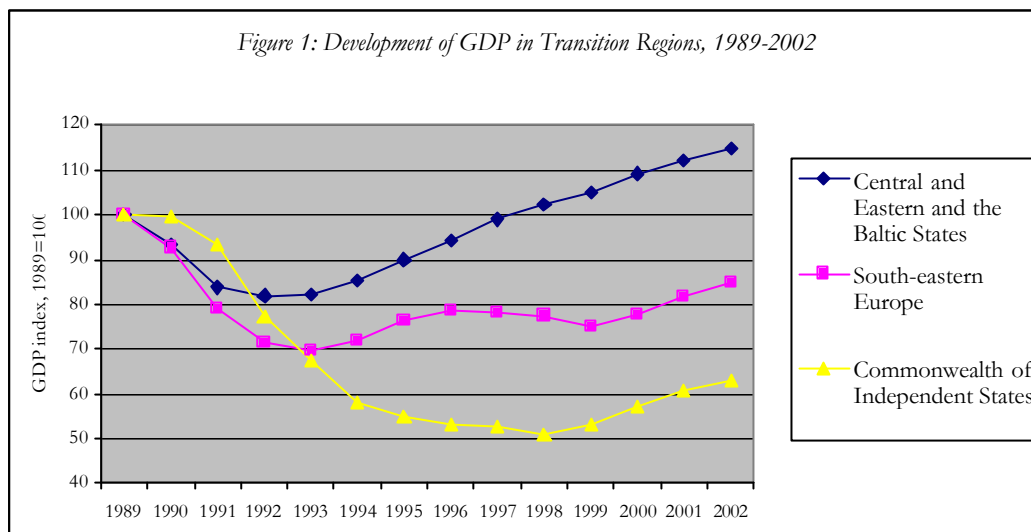
Notes: data for 2001 are preliminary, mostly official government, estimates.

Data for 2002 represent EBRD projections. Source: EBRD (2002:17)

These figures are not uncontested: the method of measuring the size of the economy changed from Net Material Product to Gross Domestic Product, and from administrative to market prices; the accuracy of these measures may have been limited during this period; and not all of the decline in physical output represented a decline in welfare, as part of socialist production was characterized by negative value-added at market prices (Gaddy and Ickes 2002). However, studies with alternative measures than GDP, using consumption rather than production data, confirm that the fall in output amounted to a true collapse (Gavrilenkov and Koen, 1995).

Campos and Coricelli (2002) review the many, often country-specific, factors that may have contributed to the output fall discussed in the literature. One factor is institutional difficulty in setting up new enterprises and effectively privatizing old ones (Swaan and Lissowska, 1992; Lieberman and Nellis, 1995; Bornstein, 1999). Another factor is the fall in demand due to monetary stabilization policies (Rosati, 1994). Blanchard (1997) finds these factors insufficient as a general explanation, arguing that many countries were not institutionally constrained and many sectors were little affected by

monetary policies.

Another explanation is that the output fall was due to new opportunities in different sectors, which involved large-scale capital depreciation and large-scale labour re-allocation. Campos and Coricelli (2002) however point out that returns to capital actually fell, that foreign investment was low, that 'old firms' accounted for much of new growth, and that there was little labour re-allocation between sectors. Campos and Coricelli (2002) hence dismiss this sectoral re-allocation explanation, for which they also use the term creative destruction. In contrast, we use the term creative destruction for processes that mainly occur within sectors and firms.

Finally, several authors have blamed the output fall mainly on 'disorganization' (Schmieding 1993; Kornai 1994; Blanchard 1997; Blanchard and Kremer 1997; Roland and Verdier 1999). These authors note the large-scale breakdown in contacts between organizations, their suppliers and their clients. Reasons given for this breakdown not only include the 'endogenous' break-ups by individual firms (Blanchard 1997) triggered by the exogenous arrival of more profitable opportunities, but also the breaking up of trade blocks and the dismantling of the control apparatus. In contrast to our model, the disorganization literature has ignored labor costs of making contacts. It has also implicitly assumed that the transition markets are less 'developed' (i.e. thinner) than capitalist markets, which means these models become invalid if firms were allowed to tap into developed markets via foreign partners. Our model makes no such 'developed market' distinction and is hence robust to the observation that foreign enterprises formed a rich source of partner firms in the actual transition.

3 A Model of the Real Economy

3.1 Introducing Relational Capital

We introduce Relational Capital (RC_t) as an input in *sold* output y_t of a representative firm. Relational capital represents the stock of business

contacts and the network of the firm. As the New Institutional Economics literature (see for example Williamson and Masten, 1999) argues, business contacts are needed to buy inputs and sell outputs. Also, the more business contacts a firm has, the more it can specialize in what it is good at and hence reap economies of scale, i.e. outsource what it is not good at. We take the following production function:

$$y_t = y(A, L_t - L_t^{rc}, RC_t, K_t) \tag{1}$$

where y_t is sold production at time t; L_t is the labor force, $L_t - L_t^{rc}$ is net labor input into physical production (blue collar labor); L_t^{rc} is (white collar) labor devoted to the creation of RC_t; A_t is the technology parameter; K_t is physical capital. $y(.)$ is a constant-returns-to-scale function with all the usual Inada-properties: any input faces decreasing positive marginal returns and is technically complementary to any other input.

The economy has a continuum of such firms with a measure of 1. This allows us to use $\bar{y}_t$, L_t, K_t, and $\overline{RC}_t$ as the total amount of output, labor and capital stocks in the whole economy. Similar to standard macroeconomic growth models we assume the following functional form for our analysis

$$y_t = y(A_t f(L_t - L_t^{rc}, RC_t), K_t) \tag{2}$$

where $A_t f(L_t - L_t^{rc}, RC_t)$ is a single composite input: technology A_t is the productivity of the combination of labor and contacts, similar to labor augmented (or Harrod-neutral) technology. Assumptions on $f(.)$ are implicitly given by the assumptions on $y(.)$.

The replacement value of business contacts lies in the heterogeneity of trading parties: parties cannot easily find other suppliers and clients once a relation is discontinued, because they can only buy their inputs from specific groups and sell their output to other specific groups. Finding contacts incurs transaction costs for information search and sharing, bargaining, and defining property rights (North, 1990). Underlying heterogeneity is basic to all models with search frictions, although usually not modelled explicitly (e.g. Pissarides, 1990).

Contacts between firms change dynamically. We distinguish between D_t^{rc}, the amount of relational capital replaced (destroyed), and N_t^{rc}, the amount of extra (new) relational capital built up. Because of search frictions, it takes labor to find replacement contacts and extra contacts:

$$\lambda_t L_t^{rc} = D_t^{rc} + N_t^{rc} \tag{3}$$

where λ_t denotes the conversion rate of (white collar) labor L_t^{rc} into relations. It can be interpreted as the arrival rate of contacts. The circumstances that affect contact rates in search theory (e.g. Pissarides, 1990) would seem to carry over to λ : smaller geographic or cultural distances increase λ; the more complex and specific production, the lower λ.

D_t^{rc} has different economy-wide implications than N_t^{rc}. Replacing old contacts carries an externality since it implies destroying old relationships. While the amount of own RC remains constant for the firm doing the replacing, the former trading partner's RC_t diminishes and hence also the total amount of RC in the economy. We capture this process by

$$RC_t = RC_{t-1} e^{-\beta \frac{\bar{D}_t^{rc}}{RC_{t-1}}} + N_t^{rc} \tag{4}$$

where the term $e^{-\beta \frac{\bar{D}_t^{rc}}{RC_{t-1}}}$ equals the probability of an old contact being destroyed by the creative destruction decisions of other firms. In appendix 1 we derive this probability, based on a simple stochastic process of contact destruction on the micro level. The parameter β equals the net number of contacts that get destroyed when one firm replaces an old contact. When a firm is part of a large chain of firms whose production depended on this firm, β will be large. This applies when the chain of forward or backward linkages is long. If production is only pair wise, chains have the minimal length of 2 firms or workers and β will take its minimal value of 1.

Our argument is that firms replace relations to improve their technology A_t. Technological progress involves changing the production process. This involves new clients and new suppliers. Adopting new technologies or new market partners therefore renders some of the previous contacts obso-

lete. These have to be replaced. We name this replacement of RC *creative destruction* and model technological progress as

$$A_t = A_{t-1} + (A^*_{t-1} - A_{t-1})g(\frac{D^{rc}_{t-1}}{L_t}) \qquad (5)$$

where A^*_t denotes the production frontier at time t and $1 > g(.) \geq 0$ denotes technological 'catch-up' resulting from the replacement of relational capital per unit of L_t. The lag between D^{rc}_t and A_t reflects the fact that it takes time to adapt to new technology. We assume that there are decreasing returns in technological investment: $\frac{\partial g(.)}{\partial D^{rc}_t} > 0$, and $\frac{\partial^2 g(.)}{\partial^2 D^{rc}_t} < 0$.

The example below graphically illustrates the different effects of D^{rc}_t and N^{rc}_t on the total level of RC_t.

Example 1: Creative destruction and network expansion

How destruction and creation of contacts works on the micro level
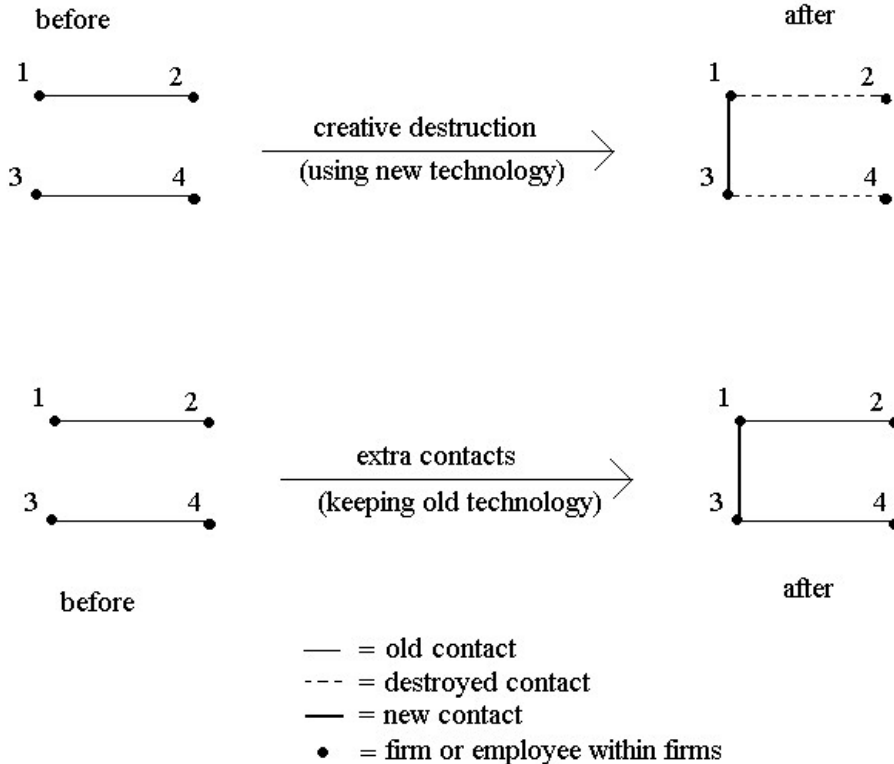
In Example 1, there are 4 entities such as enterprises, or workers within

an organization. Initially, there are productive contacts between entity 1 and 2, and between entity 3 and 4. The top example shows what happens with creative destruction: entity 1 and 3 form a new productive contact and simultaneously change their production process leading both to abandon the contact they previously had with other entities. The net effect of this creative destruction is thereby a loss of one contact ($\beta = 1$). The bottom example shows what happens with making extra contacts: without changing production processes, both entity 1 and 3 try to increase their amount of contacts. The new contact between these entities does not force either of them to abandon their previous contacts. The net effect is an increase in the number of contacts by one.

We can extend this example to situations where β is larger: if some of these entities are part of a whole chain of contacts ($\beta > 1$), the whole chain suddenly becomes worthless when a single entity in the chain pulls out. In Appendix 1 we present a micro-economic model in which equations (1) to (4) arise from search arguments and firm-level processes.

To close our model, we make assumptions about the movement of total labor units, the technological frontier and physical capital formation:

$$L_t = L$$
$$K_t = (1 - \delta)K_{t-1} + sy_{t-1}$$
$$A_t^* = (1 + a)A_{t-1}^*$$

Labor is constant; capital follows the Swan-Solow-assumptions of fixed depreciation and constant savings rate; the technological frontier increases with a fixed percentage over time, again the standard Swan-Solow-assumption. These assumptions imply we do not analyze endogenous savings behavior or the development of the technological frontier. We did endogenize savings in earlier versions of the paper, but found them to be irrelevant: even saving rates of 0 percent would not, in our simulations, lead to more than a fraction of the 50% output fall in 5 years. Empirically also, saving rates have been

found to be unimportant. Indeed, they were unexpectedly high during the transition (see Gros and Steinherr, 1995). Because the technological frontier is largely related to technological advancements in the whole world, it does not appear restrictive to treat its dynamics as given for the transition countries.

3.2   The difference between capitalism and socialism

The variable via which we distinguish economic systems is D_t^{rc}. Whilst no institution constrains D_t^{rc} under capitalism, there are several reasons why D_t^{rc} was small in the socialist system. The simplest reason is that economic coordination in the socialist system was based on enforcement of business contacts and hence ruled out or hindered the unilateral destruction of old contacts by individual firms. It is furthermore in the interest of each individual firm to prevent creative destruction in other firms because of the externality. Firms lobby the center to prevent their suppliers and clients from breaking up with them. Such lobbying indeed seems to have been prevalent in socialist systems (e.g. Braguinsky and Yavlinsky, 2000; Nove 1987): in the old Soviet Union, there was a system known as '*tolkachi*' where firms sent envoys to prevent other firms severing ties with them.[5]

A second reason for low D_t^{rc} under socialism is that technological progress consists of very many small advances. The 'span of control' of the socialist center is not large enough to mimic this, i.e. it is not logistically possible to collect and digest the amount of information necessary to recognize each small possible advance at the micro-level.

A final reason is that technological progress occurs at the level of the individual firm, which means that firms will invest in technological progress only if they have technological property rights. Without technological property rights, no firm individually engages in creative destruction because it would

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[5]We interpret the resources spent on lobbying as of the low technology variety in our model. An alternative (to be explored in future work) is to introduce and endogenise a 'cost of keeping contacts'.

contribute to a public good with little private returns.

To capture the distinction between socialism and capitalism in our model, we assume that under socialism $D_t^{rc} = 0$. This simplifying assumption amplifies the effect of lower replacement of contacts under socialism. The main point is that any restriction on contact replacement in our argument leads to a less technological progress under socialism.

This endogenous lack of technological progress has been noted by the literature on command economies (e.g. Gros and Steinherr, 1995; Aslund, 2002). Especially inside organizations, production was inefficient because managers had no incentive to improve technology by breaking up contacts. In the words of Braguinsky and Yavlinsky (2000:31): ' ... the totalitarian state (and the SOE manager, as its agent) used to run into almost insurmountable difficulties to fire just one single drunkard. [...]. It was by no means a predetermined result which of the two would end up in a labor camp - the lazy drunkard or the official for an alleged "alienation from the working class"'.

3.3 Firm Behavior in Transition

We make the standard assumption (e.g. Roberts and Rodriguez 1997) that under socialism, the central planner maximizes the discounted stream of average output equal to $\sum_{t=0}^{\infty} (1 - \rho)^t \bar{y}_t$.

Under capitalism, firms are assumed to maximize the discounted stream of profits[6] equal to $\sum_{t=0}^{\infty} (1-\rho)^t \{y_t - w_t L - r_t K_t\}$ with $\rho > \alpha$. The difference in socialism and capitalism we allow for is not the absence of maximizing behavior, but constraints on D_t^{rc}.

The steady-state equilibrium of the model is derived by standard endogenous growth arguments. In the steady state under socialism, there is no technological progress and hence all long run stocks are stationary and there is no investment in extra relational capital. The level of RC is solely determined by the opportunity costs of labor. Socialist countries with higher

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[6]One can equivalently think of discounted consumption maximising consumers to be the recipients of wages, capital rents, and profits.

initial levels of technology do better in the long run. Under capitalism, there is perpetual creative destruction and investment in new relations to compensate for the losses of RC due to creative destruction. Hence the long-run gap between capitalism and socialism grows at the same rate as technological progress.[7] Because in this paper we are interested in transition paths and not in steady-states, we relegate a brief discussion on how to find steady states to Appendix 2.

At the beginning of transition firms face given stocks of RC. They behave like the firm in the capitalist system. We restrict ourselves to symmetric transition paths. This means L is going to be constant for each firm over time. We can then write the maximization problem at the beginning of transition $(t = 0)$ as

$$\max_{D_t^{rc}, N_t^{rc}} \sum_{t=0}^{\infty} \{(\frac{1}{1+r})^t (y_t - w_t L - r_t K_t\}$$

$$\text{s.t. } D_t^{rc} \geq 0, N_t^{rc} \geq 0,$$

$$K_t \geq 0, L - L_t^{rc} \geq 0,$$

$$A_t \leq A_{t-1} + (A_{t-1}^* - A_{t-1})g(\frac{D_{t-1}^{rc}}{L}),$$

$$D_t^{rc} + N_t^{rc} \leq \lambda L_t^{rc},$$

$$RC_t \leq RC_{t-1} e^{-\beta \frac{\bar{D}_t^{rc}}{RC_{t-1}}} + N_t^{rc}.$$

Given basic economic reasoning we know that the latter three conditions will be binding and the non-negativity constraints on K_t and productive labor $(L - L_t^{rc})$ are non-binding. N_t^{rc} and D_t^{rc} may be 0 or positive depending on the stocks in the economy. The first-order conditions for an interior D_t^{rc} and

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[7]In Frijters et al. (2003) we analyze and discuss a case where contact rates for D^{rc} are lower than for N^{rc} based on differences between economic systems.

N_t^{rc} at each time t are then

$$\sum_{s=0}^{\infty}(\frac{1}{1+r})^s\frac{\partial y_{t+s}}{\partial D_t^{rc}} = \frac{\partial y_t}{\lambda\partial(L-L_t^{rc})} = \frac{w_t}{\lambda}$$

$$\sum_{s=0}^{\infty}(\frac{1}{1+r})^s\frac{\partial y_{t+s}}{\partial N_t^{rc}} = \frac{\partial y_t}{\lambda\partial(L-L_t^{rc})} = \frac{w_t}{\lambda}.$$

We are interested in a rational expectations equilibrium. The conditions for such an equilibrium are that $\bar{D}_t^{rc} = D_t^{rc}$ and $\overline{RC}_{t-1} = RC_{t-1}$. The problem is bounded by the assumption that $\frac{1}{1+r} > \alpha$. The existence of a rational expectation equilibrium is guaranteed by the smoothness assumptions on y_t. To generate numerical solutions we follow standard procedures: we solve for the steady state, presume the economy to hit the steady state at some date in the far future and then solve backwards for all prior transition decisions. The only 'special' difficulty is that the many multipliers force us to simultaneously solve for all transition choices at once.

4   Simulations: Socialism and the Transition to Capitalism

We present our analysis in a series of simulations. Our functional form specification is:

$$y_t = [A_t(L(1-\frac{D_t+N_t}{\lambda_t}))^{\gamma_0}RC_t^{1-\gamma_0}]^{\gamma}K_t^{1-\gamma}$$

$$A_t = A_{t-1} + g_1(1-e^{-g_0 D_{t-1}})(A_{t-1}^* - A_{t-1})$$

which presumes a standard Cobb-Douglas production function and a simple catch-up process for technological progress. Our dynamic assumptions are that at t_0, socialism starts with initial conditions A_0^*, A_0, K_0, RC_0, L. During socialism $D_t = 0$. After T_s periods, socialism collapses and the transition starts. After time $t_0 + T_s$, D_t is unconstrained. We take: $\gamma_0 = 0.65$,

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$\gamma = 0.7$, $\delta = 0.1$, $g_0 = 0.2$, $g_1 = 0.8$, $T_s = 60$, $\lambda(.) = 1$, $\rho = 0.06$, $s = 0.3$, $\beta = 5$, and $\alpha = 0.02$.

These parameter assumptions are selected to reflect reality in various ways. First, they imply that physical capital accounts for 30% of output, production labor 45% and RC 25%. This measure of the importance of RC is conservative. In a pioneering study, Machlup (1962) estimated the share of all economic activity in the United Sates devoted to discovering and distributing information at 29 %. Porat (1977) puts it close to 50 %. Second, values for λ and g_0 are sufficiently high for the transition economy to be able to catch up with the technological frontier within two decades. Third, parameter values reflect standard assumptions about discount rates (6% a year), saving rates (30% a year), and technological progress (2% a year). Some arbitrariness remains, to which we will return later.

4.1 The Socialist Expansion

We first comment on the dynamics of early socialism. The parameter values at the starting point for socialism are selected so as to fit the USSR in the 1920's. It was then the largest peasant nation in the world recovering from the first World War: up-to-date technology and an abundance of labor, but only minimal levels of capital and RC. This is reflected in $A_0^* = 0.2$, $A_0 = 0.15$, $L = 1$, and $K_0 = RC_0 = 0.5$. Figures 2a and 2b show a simulation of the development of the economy after the start of socialism. Figure 2c shows the development of the technological frontier and the development of technology under socialism and capitalism.
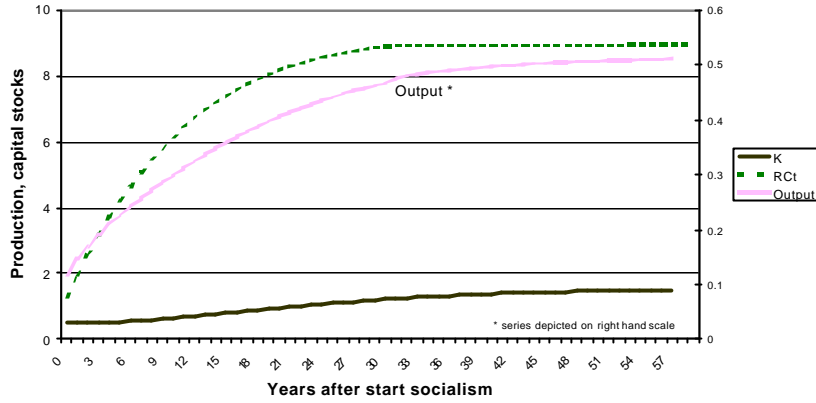
Figure 2a: The centralised socialist expansion

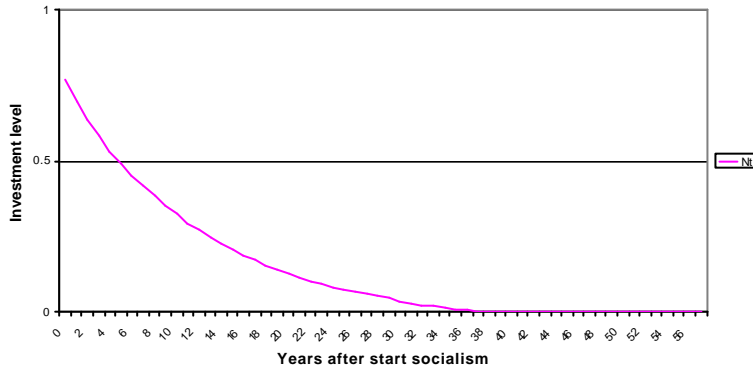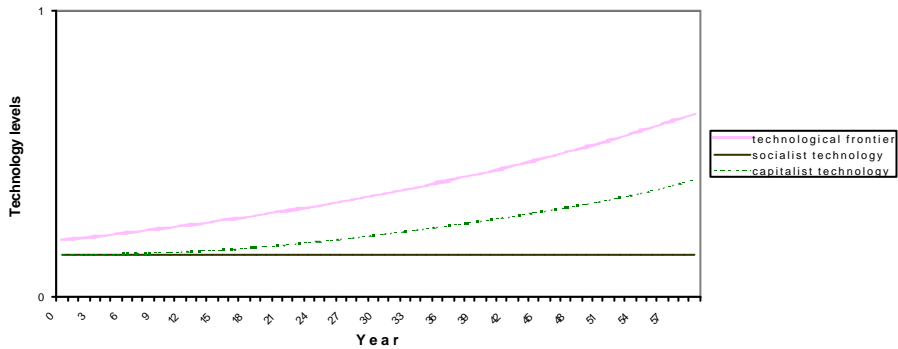**Figure 2b: Relational capital investments during the expansion**

Figure 2c: technological development after WW I

In this simulation we have assumed a discounted-output maximizing social planner.[8] Economic growth is very high in the first few years, i.e. about

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[8] The results are the same if we assume that individual socialist firms with rational

12% a year. This level drops to about 4% per year after a decade, further dropping to about 1% a year after 3 decades, and then gradually tails off to zero. This pattern is in line with the impressive performance of the Soviet economy during industrialization in the late 1920s and 1930s (the first 5-year plans), and its weak growth record during late socialism (Harrison, 2000; Easterley and Fischer, 1995). The main thing our model does not fit is the Soviet growth decline in the 40's and its high growth in the 50's, which were intimately connected to the capital and labour destruction during the second world war.

The reasons for the initial growth is the high level of N_t^{rc} (growth rate of RC) and the growth in the stock of physical capital. Eventually however, the economy slows down as the value of more contacts diminishes. The lack of creative destruction then leads to zero long term growth rates. As shown in Figure 2c, the technological gap between capitalism and communism is ever increasing in this period. One can relax this assumption such that there are incentives in some sectors for technological advancement but not in other sectors. One would then obtain a steady state in which there is growth in some sectors (for instance the military sector), but not in others. In fact, there is evidence that Soviet growth was simultaneously negative in some sectors and positive in others (Aslund, 2002).

4.2   The Transition

We now turn to the transition, where we assume firms maximize discounted-profits and have rational expectations.[9]

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expectations maximised profit given $D_t^{rc} = 0$. This is because without creative destruction, there are no externalities in the model.

[9]Myopia can be argued to be a more reasonable behavioural assumption during the transition. We tried various simulations with different myopic expectations. These showed very similar initial transition dynamics. These are available on request.

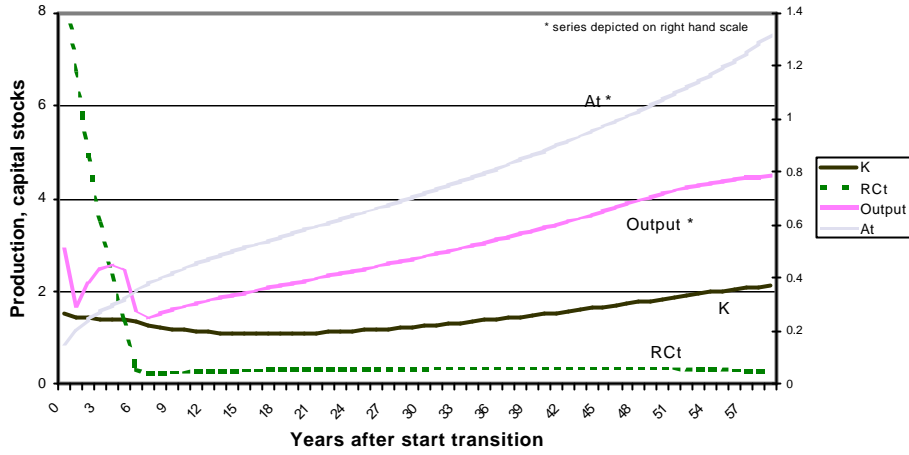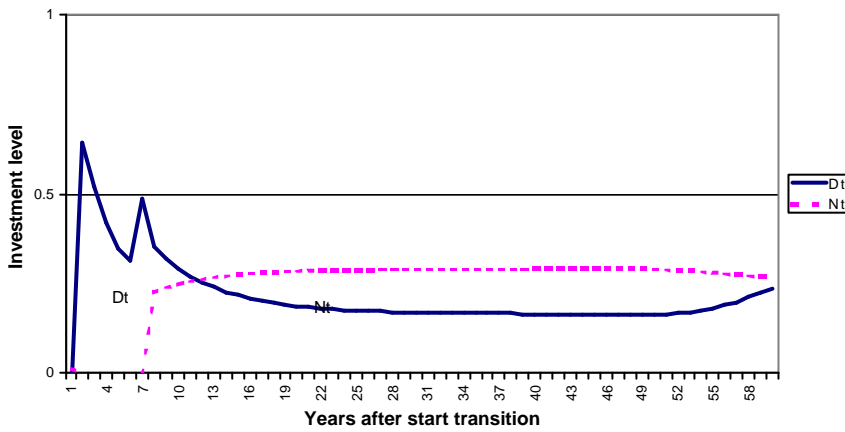**Figure 3a: the decentralised capitalist transition**

Figure 3b: relational capital investments during the de-centralised transition

The transition is characterized by a large decline in output, sustained over several periods. The decline in output in the first period is about 40%, which is partly due to the reduction in RC and partly due to labor used in creative destruction. There is a recovery after this initial output fall, due to the fact that less labor is used in creative destruction. After 5 periods another fall, caused by the further collapse of the RC network, leads to a cumulative output decline of 50%. As the stock of RC falls and firms have made large technological advances, firms get an incentive to reduce the amount of creative destruction they engage in and invest in extra contacts.

This stabilizes the total amount of RC in the whole economy and starts the recovery after 7 periods. After about 25 periods, the technological level is the same as under capitalism, after which the economy grows on average at the same rate as the technological frontier. The economy returns to the initial output level after 30 periods. These figures qualitatively mimic the real patterns of output fluctuation given in Figure 1.

These simulations also predict specific changes in factor prices which can be empirically observed. The RC collapse due to excessive creative destruction in the first 7 periods is accompanied by a reduction in the marginal value of other production factors, i.e. labor and capital. The returns to labor and capital indeed dropped early in the transition, as is discussed below.

An indirect implication is about the price of certain types of labour. In the first period of transition, capitalism inherits a large network and backward technology. Maximizing firms have an incentive to upgrade their technology via high D_t^{rc}. The lifting of barriers to creative destruction leads to high demand for labor involved in networking, i.e. L_t^{RC}. Such an immediate change has indeed been documented for Slovenia (Orazem and Vodopivec 1997), Russia (Brainerd, 1998) the Czech Republic (Flanagan, 1998) and China (Lee, 1999). These demonstrate that the returns to 'managerial skills' rose quickly and immediately after the start of transition.

4.3 The Optimal Transition

To address the question of what the optimal policy could achieve, we analyze a benchmark case in which an imaginary 'super-planner' decides everything (including D_t^{rc}). This super-planner maximizes discounted output taking all externalities into account.

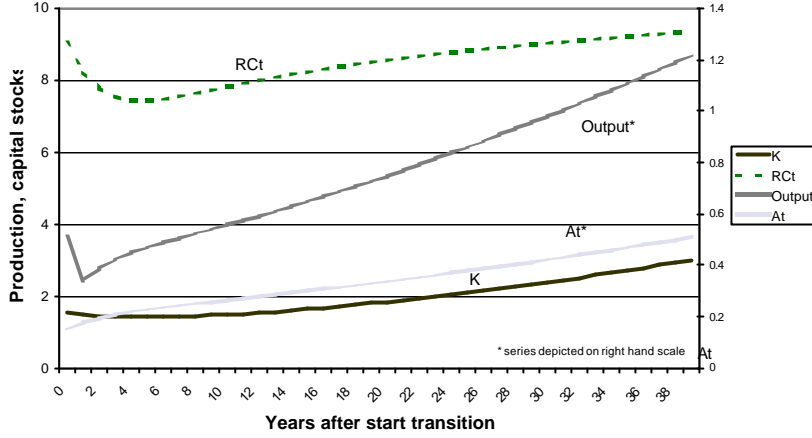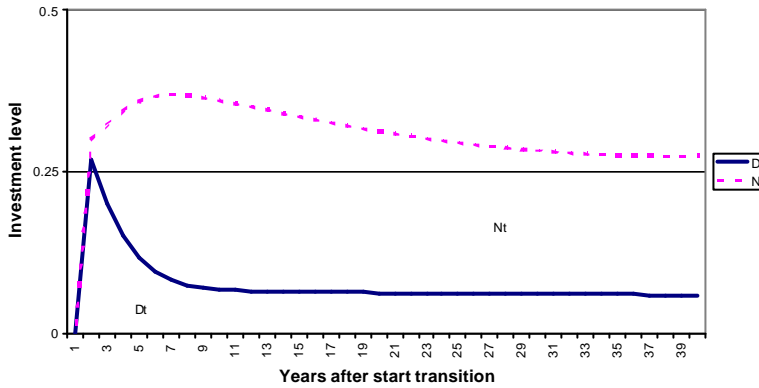**Figure 4a: 'the optimal' capitalist transition**

Figure 4b: relational capital investments and contact rates during the 'optimal' capitalist transition

In Figure 4a, the super-planner chooses D_t^{rc} such that there is an initial output fall of about 25%. The initial level of creative destruction is about 30% of that of the decentralized transition. The economy recovers to its old level after 10 periods, with a high growth level recorded in the early years. Growth in this period is fuelled by growth in the technology used. As in the earlier simulation, output growth eventually tails off to the level of the exogenous progress of the technological frontier.

The interesting question is how any realistic policy can mimic the super-planner solution. The dilemma is that in practice no planner can engage in creative destruction since this requires decentralized information; but decentralized creative destruction overshoots, as shown in the previous subsection.

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One would like to prevent the massive destruction of contacts that would ensue if all firms were able to decide their investments for themselves. An obvious way would be to restrict the actions of a sizeable proportion of the firms in the economy, allowing only a fraction to engage in creative destruction.

Restricting creative destruction in some firms but not others requires restrictions on labor and capital as well. This is because the profits of unrestricted firms are necessarily higher than that of restricted ones. The unrestricted firms would thus immediately take over the rest of the economy, leading to an unrestricted transition. Combining laissez-faire policies on a fraction of firms whilst maintaining some restrictions on the mobility of labor and capital, is what China seems to have done.

4.4   Alternative Specifications and Extensions

The simulations above showed that our simple model is capable of simultaneously capturing economic dynamics under socialism and during the transition. To examine robustness, we varied the main parameters of the model above.[10] In each simulation however, the socialist era is characterized by high initial growth and eventual stagnation. Also in each case, the 'super planner' outcome shows an initial period of output decrease followed by sharp growth. We did not find a reasonable parameter set under which there was no initial output collapse in the decentralized transition.

As a means to examine the range of alternative phenomena that can arise under our model, we below show simulations with changes in key parameters.

4.4.1   Downward Spirals: Diamond's Thick-Market Externality

We first endogenize the contact rate λ_t to allow for network externalities. This is a way in which lock-in effects can appear. Negative lock-in effects

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[10]We searched amongst the grid defined by $\gamma_0 \in \{0.5, 0.65, 0.8\}$, $\gamma \in \{0.6, 0.7\}$, $g_0 \in \{0.2, 0.5, 1\}$, $g_1 \in \{0.5, 1.5, 4\}$, $\lambda(.) \in \{0.2, 0.4, 0.8\}$, $\beta = \{1, 5\}$, $y(.) \in \{$Cobb-Douglas,CES$\}$.

of the initial output fall can prevent technological catch-up and leads to downward spirals.

In a seminal paper, Diamond (1982) argued that the arrival rate of contacts in search economies is likely to be linked to the number of units in the market; the more buyers and sellers in a market, the more likely one is to find someone to match with. Such a thick-market externality, which can also be termed a networking externality, also appears in Howitt and McAfee (1992). The argument carries over to relational capital build-up in transition economies. If the contact rate depends positively on the stock of relational capital in the economy, then the initial decrease in the stock of relational capital at the start of the transition can lead to further reductions in contact rates.

The importance of quality institutions in market economies leads to a similar argument. Heterogeneity in the quality of firms (such as their creditworthiness or their reliability) invites free-riding behavior of low-quality firms on the existence of high-quality suppliers or clients, similar to the Akerlof (1970) lemons mechanism. Market solutions to both problems include clubs which concentrate more homogeneous agents. Other solutions include quality-control institutions (e.g. banks) which use increasing returns to screening to reduce information problems. Such market based organizations have set-up costs and therefore will not appear until the market is sufficiently large. This causes λ to increase with RC. Hence, in the presence of a thick-market externality the economy may get stuck in a low-growth trap.

To simulate this possibility, we endogenize λ_t by the function $\lambda_t = \lambda_0(1 - e^{-\lambda_1 RC_{t-1} - \lambda_2})$ with $\lambda_0 = 2$, $\lambda_1 = 0.8$, and $\lambda_2 = 0.1$.[11] Hence, λ_t increases in RC at a decreasing marginal rate. In Appendix 1 we provide a micro-basis for this specification. Figure 5 shows the transition path.

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[11] Including λ_2 means we have a positive lower bound on λ_t.

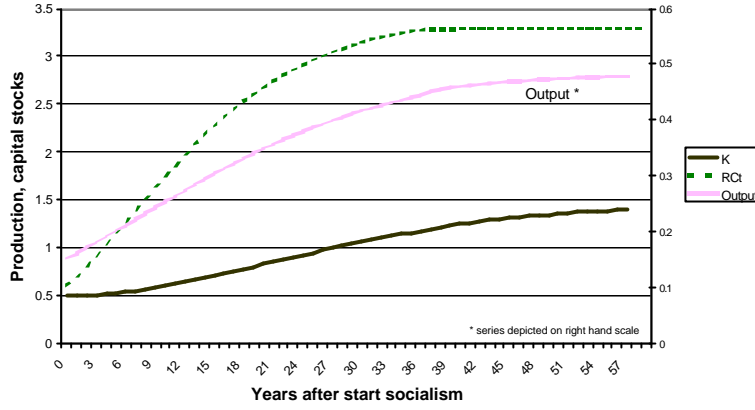**Figure 5a: The centralised socialist expansion**

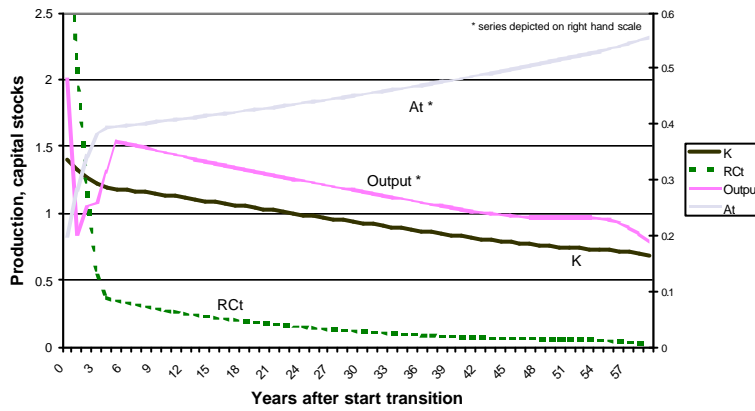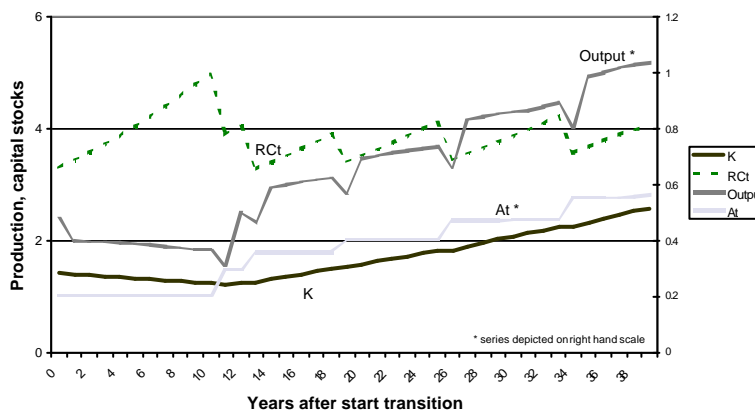**Figure 5b: the decentralised capitalist transition**

Figure 5c: 'the optimal' capitalist transition

The simulations confirm our intuitive reasoning. Under socialism, rapid initial growth can be obtained by increasing the total stock of relational cap-

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ital (Figure 5a). Because of the feedback-effect of this increase in RC on the contact rate, the expansion takes longer to tail off. The 'super-planner' would again limit creative destruction during a transition and maintain growth rates indefinitely (Figure 5c). An unrestricted transition would however lead to a collapse in relational capital, leading to stagnation despite large initial increases in the technology used. The collapse in relational capital is not reversed within any reasonable time-frame because of the lock-in effects of this collapse on contact rates (Figure 5b).

This illustrates that in case Diamond's thick market externality is important, both further technological progress and economic growth may be very slow to appear after the initial output collapse. Thick-market externalities are probably not very important in economies with many social networks (civil society) that provide ways of making contacts independent of existing contacts. In economies with few social networks, where the existing economic network may be the only way to make new contacts, such thick-market externalities may be much more important. We will return to the relation between networks and growth in the discussion.

4.4.2 Recovery Time and Smoothness of Transition Paths

The robustness question we look at is the length and smoothness of the recovery. We introduce two deviations from the simulations above. First we choose a lower β which leads to a lower drop in RC and hence to faster recovery. Second we specify the function $g(.)$ to be less sensitive. Assuming this function to be less sensitive leads to more variation over time in both D_t and N_t and hence to different transition paths. For the simulations in Figure 5, we assume $g(D) = (1 - e^{-0.25D})$, $\lambda_t = 0.6(1 - e^{-0.8RC_{t-1}})$, $\beta = 1$.

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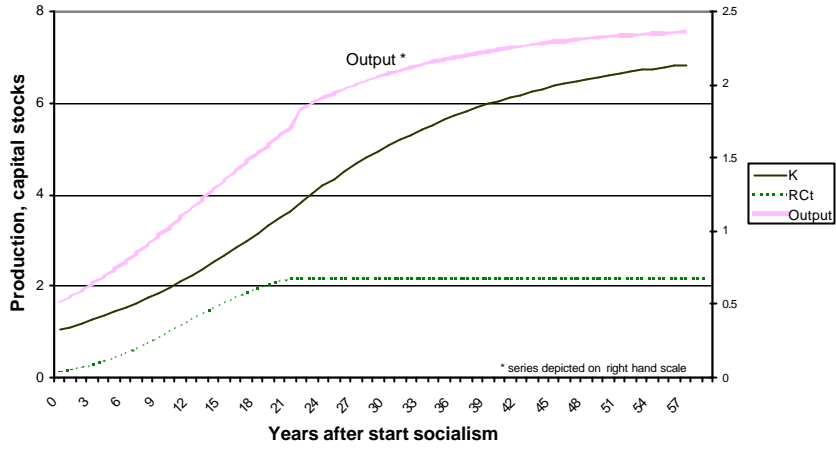**Figure 6a: The centralised socialist expansion**

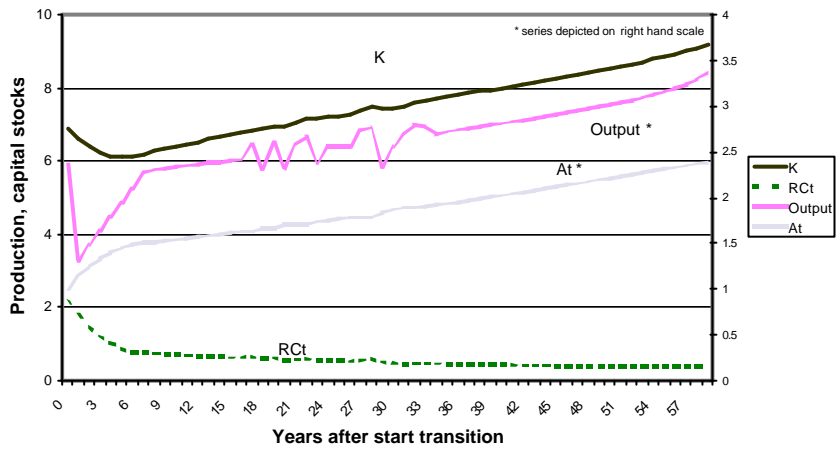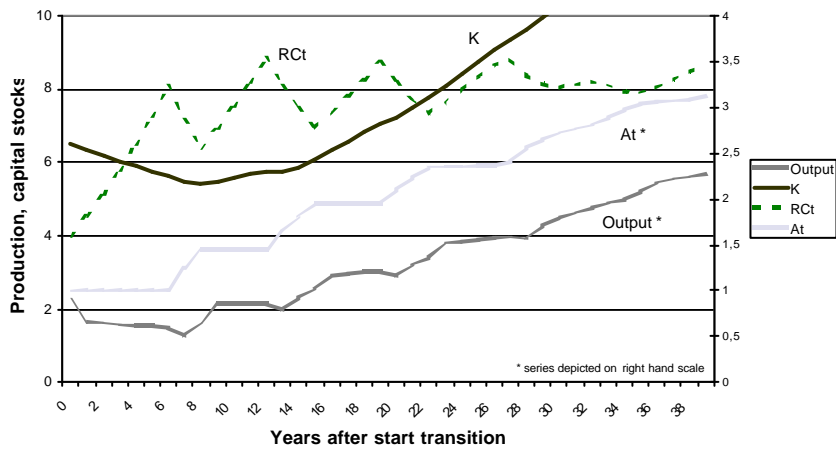**Figure 6b: the decentralised capitalist transition**

Figure 6c: 'the optimal' capitalist transition

The socialist expansion is now similar to that of the main simulation. The initial output drop during the transition is smaller and the recovery quicker. The transition paths are not only shorter; they are also less smooth. The 'optimal' super-planner transition is characterized by growth cycles: periods of high D_t, low N_t, and low growth, alternate with periods of low D_t, high N_t, and high growth.

We see erratic business cycles some 15 periods after the start of the decentralized transition. The cycles are not unique and are self-fulfilling expectations. They emerge because it is unprofitable to invest in extra contacts when other firms are destroying old contacts: the expected life of an extra contact is higher in periods with low creative destruction. This leads firms to coordinate their D_t and their N_t. The resulting cycles resemble the Keynesian demand-side variety in the sense that there is a difference between produced and sold output.

Consider what a depression would look like according to our model. In a depression, D_t turns out to be high, implying that firms have few contacts. This means that firms cannot sell their output: they simply lack the clients. The reason why it is not optimal to search for new clients is precisely because D_t is high: clients can be expected to be gone quickly. In this situation, firms replace their trading partners in order to improve productivity. After some time, there is little scope for further technological improvements, which leads firms to expand their numbers of clients and suppliers again. This signals the end of the depression and is the point in time when sold output growth is highest. The emergence of these business cycles under capitalism will be studied further in future work.

In conclusion, the model can accommodate a wide range of transition and capitalist growth paths. The output collapse appears in all our simulations however. Thus our approach includes the one feature that all transition economies have in common.

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5   Discussion: Evidence and Policy Issues

5.1   The fall in RC and the Transition Experience

We here want to substantiate the empirical plausibility of the fall in RC during the transition. In our model, the fall in RC is due to the retraction of official control mechanisms and technological catch-up.[12] Other phenomena that may have aggravated this collapse of relational capital include the following (see Gross and Steinherr, 1995; Ellman 1997; Aslund, 2002).

First, there is ample evidence that directly after the start of transition, bureaucrats and managers cashed in on their control over firms by asset stripping (see e.g. Cull et al, 2002). This effectively separated production factors from relational capital, implying an exogenous drop in RC.

Second, the collapse of the CMEA trade area that spanned the socialist block, led to a decrease in intra-regional trade. For some countries in Central Europe this lost trade volume was replaced by trade with the West; for most it was not. Another reason for reduced trade is that local governments implemented policies which effectively created barriers to trade by requiring pre-payments in national banks, payment of high tariffs at (sometimes new) borders, etc. These policies were rife at the beginning of the transition, and continue to be so in Russia and other former USSR states (see Tikhomirov, 2000, for Russia). This can be interpreted as a direct destruction of RC.

The drop in RC at the start of the transition has several implications not yet discussed, which are among the stylized facts of the transition.

First, because L, K, and RC are technically complementary, $\frac{\partial u}{\partial L}$ and $\frac{\partial u}{\partial K}$ drop. This means wages drop and returns to capital drop. This, in turn, causes reduced investments into and flight of physical, financial and human capital, for which there is ample evidence (Gros and Steinherr 1995; and

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[12] We found no empirical work on the actual extent of technological catch-up in transition countries. It is the case thought that the transition countries are major importers of modern computers and communication equipment, which is a direct indication of technological catch-up in some areas at least.

Aslund 2002).

Second, if the costs of building local contacts are greater for foreigners because they lack RC, one would not expect foreign investments to be in the form of new physical capital. Indeed, foreign investment mostly took the form of buying stocks and financing ongoing enterprises.

Third, less relational capital implies that people and organizations move into activities that require fewer contacts: organizations become less specialized. Complex production and sale processes will then be the first victims of transition. This process was aptly termed 'primitivization' by Hedlund and Sundstrom (1996), commenting on the Russian economy. This included an increase in bartering, home production, and the 'Kiosk economy', observable throughout the former Soviet Union (Seabright, 2000). In the extreme, persons and households may retreat into near-autarky by producing their own food - as many households in Russia have indeed done (Caskie, 2000; Bezemer, 2002)

5.2   Policy Issues

The present study would lead to very similar recommendations on the design of the transition as those advocated by Roland (2002): having a dual track approach allows the emergence of a capitalist sector where creative destruction provides high growth and the development of a network, whilst the effective freezing of relations within the state sector prevents a large output collapse.

The second major policy issue is enterprise governance. Our analysis suggests the merits of insider privatization: if the *de facto* possessors of enterprise RC are not made its official owners, the enterprise as an entity suffers a loss in RC. The insiders either move out of the organization, directly giving up their RC, or they feel forced to sell off the assets illegally, which also amounts to a separation of other production factors from RC. This principal-agent aspect of insider control was also put forward by Blanchard and Aghion (1996), who made the point that insiders could sell off the enterprise if they

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would truly not be best placed to lead them.

There is some empirical work on this issue. Moers (2000) analyses a large survey of Russian firms in the 1992-1999 period and concludes that those firms that experienced outsider takeover via voucher schemes fared much worse than firms under continued management. Walsh and Whelan (2001) surveyed firms in Bulgaria, Hungary, Slovakia and Slovenia, and conclude that those firms that did best were those that resisted outsider takeover. Whilst alternative explanations for the findings of both studies are possible, they do give tacit support for the argument that insider takeover preserves RC and thereby fosters enterprise profitability.

The Chinese experience suggests the benefit of a dual track approach (Tian, 1999) *and* of insider takeover: in China, most 'new' companies are run by local party members who often obtained the means of production of local state companies (Lin, 2001). Lee (1999) finds that these companies have very high growth rates.

6   Summary and Conclusion

In this paper, we introduce the notion of relational capital to capture the importance of contacts. Contacts, as a form of information, are an input into sold output in our model. This follows the suggestion by Stiglitz (1995) and others that information should be viewed as a separate factor of production.

We argue that under capitalism, the destruction of some contacts in search for better ones is an integral part of technological advancement. Socialist economies restricted such creative destruction, which we argue lead to their increasing technological backwardness.

In our explanation, the output fall during an unrestricted transition was inevitable: technological catch-up implied high levels of destroyed and replaced relational capital. This not only had high direct opportunity costs (more labor is used for the production of relational capital) but also led to a loss in overall relational capital, since there is a negative externality of

creative destruction.

Our model leads to support for dual track approaches and insider take-over. Dual track approaches avoid some of the negative externalities. Insider take-over prevents exogenous loss of RC.

It seems very likely that changes in RC are linked to and have consequences for other networks. One can for instance argue that criminal networks serve as a substitute for networks in the formal economy. The fall in RC in the official sector then leads to criminalization of the economy because the criminal network survived the collapse of official RC. This is consistent with the initial, and in many cases not reversed, rise in organized crime everywhere in Eastern Europe (see Braguinsky and Yavlinsky, 2000; and Ledeneva and Kurkchiyan, 2000).

Complementarities between formal and informal networks may also be important. Sobel (2002) reviews the argument that social networks in general facilitate coordination between economic agents because of information transfers within the network. This is an argument for a positive relation between 'civil society' and λ, where a higher λ leads to quicker technology adoption and network build-up. This is one explanation for why those countries with more developed civil societies, i.e. Poland, the Czech Republic and Hungary, experienced quicker recoveries. In Frijters et al. (2003) we use a related model to discuss the relation between the concepts of social capital and our concept of relational capital.

An interesting direction for future theoretical work is the interaction between politics and relational capital. In this respect, Dulleck and Frijters (2003) argue that the crux of many development problems lies in the reluctance of those currently in power to allow growth of the relational capital of others because the growth of a rival network would lead to shifts in the balance of power.

The article gives rise to several empirical questions. Measuring the stock of contacts in an economy, and labor devoted to their creation, is obviously the first task. In the spirit of Porat (1997) and Machlup (1962), who pi-

oneered the empirics of information processing in the economy, one could attempt to count the number of employees involved in the various information gathering tasks. Another approach is to directly survey managers about how often they replace contacts or are being replaced themselves, and whether they add contacts to their 'stock'. While defining and recording contacts may prove challenging and time-consuming, there is no conceptual reason why collecting such data would be impossible.

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Appendix 1: A search model of relational capital.

In this appendix we motivate the macro-model of creative destruction by a micro-search model. We will borrow arguments from the search literature by exploiting the analogy with the matching process of vacancies and job-seekers (Pissarides, 1990 and Petrongolo and Pissarides, 2001).

Denote the number of contacts a representative individual firm i has by C_i. Denote the number of extra contacts a firm makes by N_i and the number of contacts it replaces by D_i. Take the number of firms M to be large, such that the proportion of contacts any firms has is approximately zero. When firm i replaces an old contact with a new one, it loses a previous contact. The firm j with whom firm i makes a replacement contact also loses a previous contact. Hence both firm i and j remain with the same number of contacts as before. The externality is that the two firms that i and j were previously connected to, lose a contact. If these former contacts were both necessary links, each in a network of k contacts, the net loss of contacts is $\beta = 2k - 1$. The number of existing, new, and destroyed contacts is assumed large enough to be able to abstract from indivisibilities.

The timing is as follows. At the beginning of the period, firms seek extra contacts and replacement contacts. Then, these latent contacts materialize, after which production takes place. Finally, the technology to be used next period is updated.

Assume first that only one contact in the economy is severed, then the probability that one specific contact is affected is equal to $\frac{1}{\sum_i C_i}$. Firm i is affected by creative destruction by all other firms $j \neq i$ in the economy, directly or indirectly. Hence, the probability of any contact surviving the process of creative destruction is equal to $(1 - \frac{1}{\sum_i C_i})^{\sum_{j \neq i} \beta D_j}$ which is in the limit of a large M equal to $e^{-\beta \frac{\bar{D}}{\bar{C}}}$. The number of contacts of firm i after creative destruction and extra contacts is thereby equal to $C_i * e^{-\beta \frac{\bar{D}}{\bar{C}}} + N_i$. Adding time subscripts and re-labelling, this is the same as the formula for RC_t given in the main text. Note that here the replacement contacts are treated as cumulative, i.e. it is possible to replace the same initial contact

several times in one period, leading to a larger technological improvement. In contrast, extra contacts are additive.

We can similarly give a micro-foundation for $\lambda(.)$, i.e. the relation between labor invested into making new contacts, the number of old contacts and the number of new (extra and replacement) contacts. We exploit the analogy with job search and envisage the process of finding contacts as follows: denote the amount of labor firm i allocates towards creating extra contacts by $L_{N,i}$ and the amount allocated towards replacing contacts by $L_{D,i}$. This labor is directly and linearly transformed into 'active contact vacancies' whereby the old contacts involved in replacements are only actually destroyed if a partner for the replacement contact is found. We can hence also use $(L_{N,i} + L_{D,i})$ to denote the number of contact vacancies firm i has. We then have a symmetric matching situation whereby $L_{N,i}$ number of potential contacts of each firm get matched to the $\sum_{j \neq i} L_{N,j}$ potential extra contacts of other firms. The total amount of extra contacts can then be represented by a matching function $m(\sum_{j \neq i} L_{N,j}, \sum_{j \neq i} L_{N,j})$. As Petrongolo and Pissarides (2001) show, there are several micro-mechanisms via which we can arrive at a linear matching function, implying that the total number of extra contacts is linear in the number of potential extra contacts. One such possible mechanism is that each individual latent contact has a fixed probability λ of being 'noticed', which is a 'fixed advertisement space' assumption. All these 'noticed' latent contacts then get randomly matched to each other. This then indeed would imply a constant returns to scale matching function and a linear relation between the amount of labor devoted to making extra and replacement contacts and the number of new extra and replacement contacts.

We can also endogenize λ in a way that links it to the number of contacts already existing in the economy. A natural possibility is to assume that it is the two sides of an 'old' contact via which latent contacts get noticed. Assume for instance that there is a constant probability termed λ_0 that a latent match is productive. The probability that a latent contact is observed by an existing contact is infinitesimally small and denoted by λ_1. The probability that an

individual latent contact gets labelled as a 'noticed and productive' contact is then equal to $\lambda_0 * (1 - (1 - \lambda_1)^{\sum_{j \neq i} C_j})$ which converges to $\lambda_0 * (1 - e^{-\lambda_1 M\bar{C}})$. In terms of the formulas in the text, this would mean the function $\lambda(RC_{t-1}) = \lambda_0 * (1 - e^{-\lambda_1 RC_{t-1}})$ is a natural candidate which has the standard convexity properties.

Various other micro-mechanisms leading to such relations also exist however. The key aspect is that the thick-market externality of Diamond (1982) is incorporated. In the example above, this thick-market externality is incorporated in the assumption that each side of an existing contact has an independent probability of noticing a latent contact. This is a network externality of having many existing contacts.

Finally, we can think of the following stylized micro-foundation to our process of technological change. Take each representative firm to consist of a fixed number of labor units, say Z units. The technology used by each labour unit i depends on one contact (eg. the machine provider or the service department of another firm). Different units in the same firm may or may not use the same contact as the technology source. Each labour unit i then combines the other contacts and capital to produce sold output. Economies of scale ensure that at the firm level y_t increases with RC_t. Now, the technology of the match between unit i and her contact is on average A_{t-1}. The firm can search for more contacts (N_t) and/or to find different technology contacts (D_t). If a unit i changes a technology contact, her previous technology contact becomes redundant because economies of scale in doing any specific task make the productivity of unit i highest when working only with one technology contact (eg. using one word processing program is more efficient that working with two simultaneously). The firm observes two equally sized sets of candidate contacts it can search from, one for D_t and one for N_t. The equal size assumption means the symmetry assumed in the matching stories above between D_t and N_t remains valid, and the previous matching arguments go though after appropriate normalisation. The distribution of technical productivity of potential 'different' contacts is in continuous flux: every period, the productiv-

ity that unit i would have with a different technology contact j is drawn from a c.d.f. $H_t(.)$, where $H_t(A_{t-1})=0$ and $H_t(A_{t-1} + g_a(A_{t-1}^* - A_{t-1}))=1$. This means a firm can observe 'a region of potential better matches' that lie within a fraction g_a between the productivity of a current match and the technological frontier. One can think of $H_t(.)$ as the result of an exogenous, random, and continuous learning process that other potential matches undergo whilst they are inactive. The expected technical productivity of the 'different' technology contacts would thus be $A_{t-1} + E[\frac{H_t(.)-A_{t-1}}{A_{t-1}^* - A_{t-1}}](A_{t-1}^* - A_{t-1})$. The process of finding a different set of matches starting from the current (potentially latent) technology can be repeated many times in the same period until the eventual set of contacts is finally effectuated and the old ones are severed. If g_0 is small, then the expected result of one period of technological change goes to $A_{t-1} + (1 - e^{-g_0})(A_{t-1}^* - A_{t-1})$ where $g_0 = \kappa_t E[\frac{H_t(.)-A_{t-1}}{A_{t-1}^* - A_{t-1}}]$ and κ_t is the number of 'rounds of innovation' per labour unit in the period. When κ_t is reasonably small, the probability of any contact surviving the contact destruction by other firms will approach $e^{-\beta\frac{\bar{D}}{C}}$.

If we add an exogenous probability $(1 - g_1)$ that the firm is completely mistaken about each unit's set of potential new technology contacts (where the mistake is revealed only after all rounds of innovation), and relate κ_t to D_t, then we get the technological progress function specified in the simulations.

Appendix 2: Steady states.

(i) socialism

In the steady state under socialism there is no creative destruction: D_t^{rc} equals 0. This means there will be no growth in the steady states, and N_t^{rc} will equal zero. The solutions to the first-order conditions in the steady state (denoted by $*$) then read

$$r^* = \frac{\partial y^*}{\partial K^*}$$

$$w^* = \frac{\partial y^*}{\partial L^*}$$

$$\frac{1}{\rho}\frac{\partial y^*}{\partial RC^*} = \frac{w^*}{\lambda}$$

The first two equations yield wages and rental prices of capital, whereas the third equation solves the steady state level of RC at which further accumulation of relational capital is worth precisely the opportunity cost of labor and hence the point at which relational capital accumulation stops. Uniqueness of this solution follows from the convexity of y (and λ) with respect to the equilibrium level of RC.

(ii) steady state capitalism

We define the (symmetric) steady state under capitalism as the fixed level of D^* and N^* at which no individual firm can make a further profit by changing D_t and/or N_t. The steady state under capitalism has long term technological progress equalling the rate of progress in the technological frontier when $D^* = N^* > 0$.

We again denote by $*$, the solutions to the first order conditions in the steady state for $D_t, N_{t,} K_t$ and RC_t. For labor and capital we find the standard solutions:

$$r_t = \frac{\partial y_t}{\partial K_t} \tag{6}$$

$$w_t = \frac{\partial y_t}{\partial (L - L_t^{rc})}. \tag{7}$$

Note, this determines also the marginal product of L_t^{rc}, because labor must have the same productivity for both physical production and contacting. In a steady state, technological progress will follow: $\frac{A_t}{A_t^*} = \frac{(g(D^*)}{\alpha + g(D^*)} = 1 - \frac{\alpha}{\alpha + g(D^*)}$, which implies $\frac{\partial A_t}{\partial D_s} = (1 - g(D^*))^{t-s-1}\frac{A_t^* g'(D^*)\alpha}{\alpha + g(D^*)}$ for any $s < t$. We presume the steady state to start at time T: this implies that wages in period

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t are given as $w_t = (1+\alpha)^{t-T}w_T$, interest as $r_t = r^*$, and $A_t = (1+\alpha)^{t-T}A_T$. The first order conditions for D and N after simple manipulations read:

$$\frac{1-\rho}{\rho + g(D^*)}\frac{\partial y_t}{\partial A_t f(L - \frac{D^*+N^*}{\lambda}, RC^*)}f(.)\frac{A_t^* g'(D^*)\alpha}{\alpha + g(D^*)} = \frac{w_t}{\lambda} \tag{8}$$

$$\frac{1}{1 - (1 - \rho + \alpha)e^{-\beta\frac{D^*}{RC^*}}}\frac{\partial y_t}{\partial RC^*} = \frac{w_t}{\lambda} \tag{9}$$

Given that the marginal productivity of L^{rc} is determined by the wage solution, equation (8) solves for the level of D^* given that marginal productivity must again equal the wage cost of D. Because maximization is done on the individual firm level, the cost an individual firm uses does not include the externality of D^* on the level of RC of others. Equation (9) solves for the optimal RC^* given the equilibrium level of D^* and thereby determines N^* by equating the discounted benefits of extra RC_t to the wage costs. Because of the convexities in $g(.)$, and $y(.)$, existence of equilibrium is assured. We make no claim about the stability of the economy at or close to this steady state, or indeed *about the uniqueness of the transition paths.