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Abstract

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Productivity effects of innovation, stress and social relations *

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Abstract

Innovation is a source of increasing productivity, but it is also a source of stress. Psychological research shows that moderate stress increases the productivity of an actor, but above a certain level, additional stress decreases productivity. Stress is reduced by coping behaviour of the actor, and in addition it is buffered by social relations. However, high levels of stress negatively affect social relations, causing social erosion. In a formal model including inter-agent dynamics, we show that the variables moderating stress levels are of crucial importance for identifying the overall effects of different rates of innovation on productivity. The model shows among other things that the existence and nature of relationships of people determine the extent to which a certain rate of innovation effectively results in increasing productivity. In addition, it shows the possibility of multiple equilibria - under some parameter values both high- and low-stress steady states exist; and the dynamics exhibit hysteresis. At very high levels of stress, innovation can result in a dissolution of social relations, and has a negative relationship with the rate of economic growth.

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1 Introduction

It is generally assumed that innovation leads to higher productivity and more economic growth, and that economic growth leads to increased well-being. These assumptions form the implicit and explicit basis for the justification of a vast array of policy aimed at increasing innovation to increase competitiveness and welfare. There are, however, several observations that suggest that this conclusion may be hasty. Innovation involves change and novelty, and these are associated with stress. Stress, as of some level, is associated with deteriorating performance and mental and physical health problems; and this in turn is associated with reduced productivity. This suggests that blindly pursuing higher innovation rates may eventually back-fire: the increased amount of change that workers have to deal with will eventually reduce their productivity, and so defeat the purpose of the innovation. In addition, stress spills over to other actors and has a negative effect on social relations, which in turn can lead to yet more stress. Policy aimed at more innovation and more creative destruction in order to strengthen economic growth, may thus have unintended effects not only on social well-being but also on economic growth itself.

In this paper, we model a group of agents subject to external stressors, but involved in social relationships which include both stress spillover, and stress buffering. We show that variables moderating stress levels through that relationship affect the relationship between innovation and productivity. In addition, it shows the possibility of multiple equilibria in stress levels and that the dynamics exhibit hysteresis.

The paper is organized as follows. First we will identify and discuss the different variables at stake, and their relationships (section 2). Next we will formalize these in a model and show results relating interaction effects on overall stress levels and on the effect of innovation on productivity growth (section 3). In section 4 we discuss some comparative static effects, in order to get an idea about the possibilities for interventions. Section 5 concludes.

2 Innovation, stress, and social relationships

Innovation and stress A standard, well-accepted model describes stress as the consequence of the discrepancy between (perceived) demands and (perceived) control (Karasek, 1979). Thus when demands are increased, all else equal, the discrepancy increases, and a higher level of stress follows.

Innovation by definition involves change and novelty, and there is a large body of empirical evidence showing that change induces stress. There are several ways in which innovation leads to stress.

Firstly, change tends to increase uncertainty and unpredictability, which is experienced by actors as an increase of (potential) threat, causing stress - even if it concerns change for the better (e.g. Homes and Rahe 1967; Monat et al. 1972; Rabkin and Struening 1976; Mantler et al. 2005; Rafferty and Griffin 2006).

Secondly, innovation implies novelty and novelty reduces the extent to which an agent can rely on routines/ Routines economise on scarce information processing and decision-making capacity of agents (Simon 1947, 1955, 1977); routines are "mindsavers" (Sinclair-Desgagne and Soubeyran (2000). Routines embody cumulative learning, they co-ordinate behaviour and bring predictability and implicit agreement on how to act (Nelson and Winter (1982), thereby smoothing interaction, enabling efficient and effective cooperation (March and Olsen 1989) and lowering transaction costs (Langlois 1992). When circumstances change, existing routines will be less effective or possibly even counterproductive. Novelty reduces the extent to which routines can be used and demands more effort in terms of time and (mental) resources (Alterman and Zito-Wolf 1993).

Thirdly, innovation leads to an 'intensification of work', thereby increasing the demands workers face (e.g. Green and McIntosh 2001; Burchell et al. 2001), in terms of non-routine tasks per hour and in terms of mental effort per task. Historically, an important form of innovation has been to replace repetitive, routine manual tasks, and increasingly also repetitive mental tasks) by mechanization—machines take over operations that involve enough regularity. From the point of view of a labour force, if routine tasks are successfully mechanized, the ratio of non-routine to routine tasks increases. In combination with complementary changes in management practices this makes work on average more demanding, both mentally and emotionally (Hochschild 1983; Morris and Feldman 1996; Glomb et al. 2004).

Hence, innovation increases uncertainty and job demands which in turn leads to stress, and can thus be justifiably described as an important source of stress.

Stress and productivity Stress is not necessarily bad for an actor; a certain level of stress is needed to get an actor to deal with emerging threats and to make use of emerging opportunities. In a broad sense, stress can be understood as a measure of arousal; it is the result of a discrepancy between a desired and an actual situation, activating an actor to act so as to reduce this discrepancy in his favour (Seyle 1956). In a more narrow sense, stress is related not to demands in general but to the inability to meet demands (e.g. Karasek 1979); this is also referred to as 'distress'. In this paper we adhere to the broader, stimulus-based definition of stress (Cox, 1978).

The relationship between an agent's level of "activation" or "arousal", reflected in his level of stress, and his or her performance in a given task, has generally been described as curvilinear. The most well-known finding of curvilinearity is the inverted U, which is often referred to as the"Yerkes-Dodson law" (Yerkes and Dodson, 1908). Too little activation (low stress) implies lethargy and boredom, leading to low performance. Too much activation (high stress) implies an over-taxation of abilities, and again, under-performance. Intermediate levels of activation provide enough stimulus to alleviate boredom (and hopefully spark interest) without over-taxing the coping abilities of the actor.

In line with its intuitive appeal, an inverted U shape relationship is generally confirmed in empirical research.[1] There is a biological basis for the curvilinearity; research shows that up to a certain level stress hormones are effective in preparing body and mind for action (increased heart rate, more focused attention, etc.), but at high levels they have a negative effect on the parts of the brain involved in planning, memory, reasoning and emotion regulation (e.g. (e.g. McEwen and Sapolsky 1995; Sapolsky, 1996; Liston et al., 2006; Radley et al., 2006).

Stress and coping The physiological role of the stress response is to activate the agent to deploy his resources to deal with emerging demands (e.g. Seyle 1956; Karasek 1979). Stress activates coping behaviour, aimed at reducing or eliminating the stressors. Not all stress-generated behaviour is effective coping behaviour; at high levels of stress judgement deteriorates, behaviour increasingly gets misdirected, and very high levels of stress can be paralysing preventing any behaviour that could help to cope. In the absence of effective coping, the external stressors will not be reduced or eliminated,

[1]Though not universally e.g. Neiss (1988).

stress will increase and overall performance levels will drop, resulting in further stress. Additional stress will then lead to an increase in coping effort but a decrease of actual effective coping. This is described in research as “loss spirals” (e.g. Hobfoll 1989) and this is consistent with the downward turn of the “inverted-U” relationship between stress and performance.

Stress and social relationships: buffering effects So far we have discussed effects of stress on an individual. Now we turn to the situation in which individuals are engaged in social relationships. Being in a social relationship (e.g. spouse, colleague)generally is beneficial, increasing well-being and reducing stress. Being in a relationship generally absorbs stress and has important *buffering* effects, which depend on the level of responsiveness of the individuals to each others’ needs. There is an extensive literature on this in psychology under the label of “social support”.

Social support from spouses, friends, colleagues and family can help to reduce stress and psychological strains (Glowinkowski and Cooper, 1985). Social support is one of the main mechanisms of buffering (e.g. Cohen and Wills 1985; Lepore 1992, Florian et al. 2002).[2]

Stress and social relationships: stress spillovers Although relationships generally are beneficial, being in a relationship with a stressed person can cause stress for an agent. The stress level of one agent, through a variety of pathways, affects the stress level of the other. The extent to which this happens again depends on the strength of the social relationship, the responsiveness of actors to each other. The closer a relationship, the more spill-over will take place. As stress levels increase, relationships get more strained and responsiveness decreases.

Stress crosses over from one domain to another (e.g. Beehr et al. 1995, Stephens, Franks and Atienza 1997; Linville, 1987). At the core of the effect is the non-specificity of the stress system. This means that even though the cause of stress may be specific to a particular domain (a difficult innovation process in the domain of work), the effect is non-specific (stress) and can affect a variety of specific factors, both in the same domain but also in other domains in which the person operates (for example, marital problems in the domain of home). There is some compartmentalization between a person’s

[2]The relationship between social support and stress is complex (e.g. Beehr et al. 2003) and different pathways and dynamics play a role (e.g. Bolger and Eckenrode 1991).

different roles, which means that a person can to some extent isolate different parts of his or her life, but it is never complete. Thus events in one domain will have an effect in another domain. (e.g. Bolger et al. 1989). Research indicates that stress spillovers from work to home are generally larger when work is high-skilled, when a job carries high responsibility and decision power, and when the worker is highly involved in his or her work (Ginn and Sandell 1997, Scase and Goffee 1989, Glowinkowski and Cooper 1985).

Stress not only spills over between domains but also between persons. This phenomenon is investigated in psychological research under two labels: crossover and contagion.[3] *Crossover* refers to the process that occurs when a psychological strain experienced by one person affects the level of strain of another person in the same social environment (Westman, 2001; Westman and Etzion, 1995). *Contagion* is the process by which one individual's mood and/or perceptions seem to "spread" to those in close proximity (Hatfield, Cacioppo and Rapson 1994; Sullins, 1991).

Responsiveness Both social support and stress spill-over via for example emotional contagion are found to follow patterns of affiliation and the impact depends on the strength of the affiliation (Gump and Kuliks 1997).

The extent to which relationships have a buffering effect on stress depends on the intensity of the relationship. Social support is causally related to lower stress levels, while high stress levels are causally related to reduced social support (e.g. Procidano and Smith 1997, Silverstein et al. 1996). Wheeler (1966), in an early study on contagion of behaviour and emotions, found that behaviour spreads out along sociometric and communication networks, and that norms about behaviour change toward acceptance as the behaviour becomes more widespread. Crossover and contagion of emotions show a "ripple effect" (Barsade 2002). Stress generally has negative impact on the quality of a relationship, and thereby on the buffering effect of a relationship. Stress diminishes responsiveness to family members (e.g. Repetti 1989, 1997), and stressed partners are less effective at social buffering than nonstressed partners (Kiyokawa et al. 2004)

The extent to which spill-over between agents in a relationship takes place depends on the intensity of the relation between the agents, the level of mutual responsiveness. Cross-over and contagion effects are more likely to

[3]See also related literature on social information processing theory (e.g. Hubbard et al.2001; Coie et al. 1999, Dodge et al 1990).

occur when people pay attention to, care for, identify with, or feel responsible for others (Hatfield et al. 1994, Sullins, 1991; Benazon and Coyne 2000). Interpersonal responsiveness or sensitivity is found to increase reactivity to stressful events, especially those that are interpersonal in nature (Smith and Zautra 2001).

The extent to which persons are responsive to each other is not constant; it can diminish as stress levels go up (e.g. Conger et al. 1999, Westman et al. 2004). Empirical research shows that the more stressed a person becomes, the more maladaptive his relationship with his partner (e.g. Davila et al. 2003) less other-focused and the more self-focused his behaviour will become. So, responsiveness of persons to each other is a function of the stress levels of these persons, and goes down as stress levels goes up (e.g. Vinokur at al. 1996; Conger et al. 1997; Davila et al. 1997).

To summarise this section briefly, we conclude with following: innovation intensifies pressure of stress on working population and affect their productivity; individuals can reduce some of their stress activating coping mechanisms; individual occupational stress crosses to other domains and other individuals; social support helps buffering individual stress; both responsiveness and efficiency of buffering depends on the strength of relationships; quality of a social relationship is negatively affected by the level of stress in the relationship.

3 Model

In this section we examine the relationships between the innovation rate, the intensity of interpersonal relationships, and productivity growth. For that we set up and analyze a simple model that brings together the key relationships discussed in the previous section.

3.1 Agents

The population is composed of groups of individuals engaged in social relationships (e.g. organizations, families, neighbourhoods). Because our interest lies in the role that social relationships play in the dynamics of the stress we classify the sources stress into those internal to the relationships between the members of the group and all other factors which are external. Therefore individual i belonging to a group of size n experiences stress both due to

$(n-1)$ social relationships he has with other members of the group and due to factors external to those interactions. We assume a single source of external stress, innovation, which can affect different agents differently. Assume a positive, monotonic relationship between the rate of innovation, m, and individual stress levels from external sources: $S_i = S_i(m)$ and $S_i'(m) > 0$.

We describe the state of the individual i by his total stress level s_i. As has been discussed in section 2 individuals handle part of their stress via self-control. In our model the coping ability, c, is the rate at which an individual can reduce stress level on his own.

But another way to channel off individual stress is to share it with the others.

3.2 Relationships

Central to our analysis is the role that social relationships play in contagion and absorption of stress. The results of empirical studies cited in the previous section suggest that the intensity of stress spill-over and stress buffering are functions of quality of relationships between individuals. At the same time the strength of a relationship depends on the level of the stress within the relationship.

For simplicity and tractability, let us assume that all relationships between the members of a group are of the same strength and depend only on the average stress ($z = \frac{1}{n}\sum_{i=1}^{n} s_i$).[4] Formally, we introduce parameter $a \in [0,1]$ describing strength of social bonds between the members of the group: $a = 1$ corresponds to normal functioning relationship, while $a = 0$ corresponds to the situation in which all social relationships within the group effectively break down. Furthermore, we assume that a is a twice continuously differentiable function of z. As additional stress in a relationship is damaging the relationship let us assume that $a'(z) < 0$. When there is no stress, relationship strength is at maximum ($a(0) = 1$); as the stress level increases relationship strength decreases and the relationship eventually ceases ($a(\infty) = 0$).

Sharing individual stress with one's partners has two effects. First, social support from the other members of the group reduces individual stress. In

[4]More generally we could allow the relationships between different pairs of individuals vary in strength and introduce what is known as "adjacency matrix" in the social network literature to describe the structure of interactions within the group: $A = \|a_{i,j}\|$ ($a_{i,j}$ characterizes strength of relationship between agents i and j).

our model we refer to this "buffering" function of social relationships as b, which is the rate at which individual stress is reduced by sharing stress with the others. Buffering, however, is a function of the quality of relationships between the partners: the stronger are the social bonds within the group, the stronger is the buffering effect; $b = b(a)$ and $b'(a) > 0$ ($b(a)$ is twice continuously differentiable on [0,1]). We also assume that the existence of social relationships is a prerequisite for buffering to be activated ($b(0) = 0$), and the rate of buffering is finite $b(z) < \infty$ for all z.

Second, due to the spillover effect discussed in the previous section, sharing stress with one's partners causes them stress. The intensity of this spillover effect again depends on the strength of social relationships: individual stress hardly passes from one partner to another if partners care only little about each other ($a \approx 0$), whereas by contrast a strong relationship between partners ($a = 1$) implies that stress of one partner becomes a significant stress factor for the other. We characterize the spillover effect by responsiveness, $r > 0$ and $r < \infty$, the rate at which stress of one partner spills over to the other partner. It is a twice continuously differentiable increasing function of the relationship strength: $r = r(a)$, and $r'(a) > 0$, and the absence of a relationship implies no spillovers ($r(0) = 0$).

3.3 Dynamics of stress

We formalize dynamics with the following system of differential equations.

$$\begin{cases} \dot{s_1} = -c \cdot s_1 - b(a) \cdot s_1 + r(a) \cdot s_2 + \cdots + r(a) \cdot s_n + S_1, \\ \dot{s_2} = -c \cdot s_2 - b(a) \cdot s_2 + r(a) \cdot s_1 + \cdots + r(a) \cdot s_n + S_2, \\ \cdots \\ \dot{s_n} = -c \cdot s_n - b(a) \cdot s_n + r(a) \cdot s_1 + \cdots + r(a) \cdot s_{n-1} + S_n, \end{cases} \tag{1}$$

where the strength of social relationships within the group, a, is a function of the average stress: $a = a(z)$. According to (1) individual i can reduce his stress, s_i, through the mechanism of self-control (at the rate c) as well as via sharing stress with i's partners (at the rate $b(a)$). At the same time i's stress level is increasing due to spillovers of stress from i's partners.

Summing up equations of (1) and dividing by n we can write the dynamics for the average stress, z, as

$$\dot{z} = -cz - b(a)z + (n-1)r(a)z + S_0, \tag{2}$$

where $a = a(z)$ (strength of social relationships is a function of average stress level), and $S_0 \equiv \frac{1}{n}\sum_{i=1}^{n} S_i$ is average external stress. Average external stress is a function of innovation $S_0 = S_0(m)$.

In what follows, we leave the level of the separate individuals, and examine them as a whole, the group being the unit of analysis.

3.4 Productivity and economic growth

Consider a simple one-factor growth model with exogenously given rate of technical change. The output in the economy is

$$Y = AL, \tag{3}$$

where A is the factor describing state of technology and for simplicity we assume that the technology is upgraded linearly in time

$$A = A_0 + mt,$$

where m is the rate of innovation (exogenous). The other factor in (3) is labor L. Hold population constant, but assume that the productivity of labour is a function of stress level. In accordance with the literature cited in the previous section we assume an inverted-U relationship between labour productivity, l, and stress z (Yerkes-Dodson Law). We can rewrite (3) in output per capita terms as

$$y = (A_0 + mt) \cdot l(z(m)),$$

where $l(z)$ has shape of inverted U with 'optimum stress' level z_L^*: $l'(z_L^*) = 0$, $l''(z_L^*) < 0$.

Differentiating this equation with respect to time we find that the pace of economic growth is

$$\dot{y} = m \cdot l(z) + (A_0 + mt) \cdot l'(z)\dot{z}.$$

In the long-run steady state of the system ($\dot{z} = 0$) this equation becomes

$$\dot{y} = m \cdot l(z(m)). \tag{4}$$

In order to understand the relationship between innovation and economic growth, we first analyze the dynamics of innovation-induced stress.

4 Analysis

4.1 Dynamics of stress

To clarify the roles of different forces in the model we begin by discussing individually the roles of coping, buffering, and responsiveness in the dynamics defined by equation (2).

Coping Suppose there is no relationship ($a = 0$), so that the second and the third terms of (2) are equal to 0. Then equation (2) is simply

$$\dot{z} = -c \cdot z + S_0, \tag{5}$$

The phase diagram corresponding to (5) is a straight line with vertical intercept at S_0 and negative slope $-c$. The only steady state of (5) is at $z_c = S_0/c$. The steady state is stable, since at this level of stress $\dot{z}$ changes its sign from positive for $z < z_c$ to negative above this value. It implies that as long as the long-run values of the parameters (external stress, S_0, and self-control, c) stay the same the system always returns to the long-term level of stress, z_c, regardless of the magnitude of the disturbance that has taken the system away from the steady state.

Better coping abilities correspond to steeper slope of the line and reduce steady state stress level, z_c, while an increase in the inflow of the external stress (related to innovations) shift the line upwards and increases z_c. Furthermore, (5) implies that an increase of 1 percent in external stress lead to 1 percent increase in the steady state stress, z_c (similarly for coping).

Stress spillovers Consider the system (2) without stress absorption mechanisms, that is, with neither buffering nor coping ($b(a) = 0$, $c = 0$). Then the system's behaviour is determined by the dynamics of stress spillovers alone:

$$\dot{z} = (n-1)r(a(z)) \cdot z + S_0. \tag{6}$$

Stress spillovers are positive for any non-zero z: $(n-1)r(a(z))z > 0$, and become zero only at $z = 0$ (no stress spills over when no one is stressed). The inflow of external stress is always non-negative ($S_0 \geq 0$). Hence the right hand side of (6) becomes zero only when $S_0 = 0$ and only at $z = 0$; otherwise it is always positive. Thus the system has a unique (unstable) steady state with zero stress level only when there is no inflow of external stress. Any (even temporary) disturbance would lead to accumulation and magnification of stress due to interpersonal spillovers of stress within the group.

Buffering Consider equation (2) with neither coping ($c = 0$) nor stress spillovers ($r(a) = 0$):

$$\dot{z} = -b(a(z)) \cdot z + S_0. \tag{7}$$

The dynamics of the system are determined by the shape of the function $B(z) \equiv b(a(z))$. Notice that $B(0) = b(1)$ and therefore $B(z)z = 0$ at $z = 0$. Let us assume that

$$\lim_{z \to \infty} B(z)z = 0, \tag{8}$$

that is, for high levels of stress the relationship weakens to such a degree that buffering effect goes to zero. Then we can state the following:

Proposition 1 *There is $\overline{S}$ such that for $S_0 \in (0, \overline{S})$ the dynamic system defined by (7) has multiple (at least two) steady states.*

Proof. Function $B(z) \equiv b(a(z))$ is a composition of twice continuously differentiable functions $a(z)$ and $b(a)$, and thus is a twice continuously differentiable function itself. So is $B(z)z$. Continuity of $B(z)z$ together with condition (8) ensures that $B(z)z$ is bounded from above and it reaches its maximum value, which we denote $\overline{S}$, at some finite z^* (if there is more than one point at which $B(z)z = \overline{S}$, let z^* be any of them).

Consider $\dot{z}(z)$ defined by (7) with $S_0 \in (0, \overline{S})$. Taking into account that $B(z)z$ is continuous, $B(z)z|_{z=0} = 0$, and $B(z)z|_{z=z^*} = \overline{S}$, there is at least one value $z_1 \in (0, z^*)$ such that $B(z_1)z_1 = S_0$ and therefore $\dot{z}(z_1) = 0$.

Condition (8) implies that for any $S_m \in (0, S_0)$, there is a value $z_m(S_m)$ such that $B(z)z \leq S_m$ for any $z \geq z_m$. Since $B(z)z$ is continuous, $B(z^*)z^* =$

$\overline{S} > S_0$ and $B(z_m)z_m < S_0$ there is at least one value $z_2 \in (z^*, z_m)$ such that $B(z_2)z_2 = S_0$ and therefore $\dot{z}(z_2) = 0$ (in case of many values like that let z_2 be the largest of them).

Thus equation (7) has *at least* two steady states z_1 and z_2. ■

Also notice that the steady state with the highest level of stress, z_2, (right-most on the phase diagram) is unstable because $\dot{z}(z) > 0$ for $z > z_2$. Any disturbance would set the system on the path of increasing stress and decreasing the quality of the relationships. Beyond a certain threshold value of stress, a social relationship can no longer function as a stress-absorbing mechanism.

General case Now let there be coping, buffering and stress spillovers. The dynamics of the system defined by equation (2) includes these three factors, and gives them the characteristics discussed in section 2 above. Their relative strengths determine which steady state is realized. There is a number of the possible combinations of steady states, and in this paper we limit our analysis to one case with interesting dynamics that allows an intuitive interpretation. For that we make additional assumptions concerning functions $R(z) \equiv r(a(z))$ and $B(z) \equiv b(a(z))$.

First, we assume that agents are better off having social relationships rather than dealing with stress on their own: the positive effect of buffering exceeds negative effect of stress spillovers:

$$B(z) > R(z) \text{ for } z > 0. \tag{9}$$

Let us also assume that buffering is less sensitive to stress than is responsiveness

$$B'(z) < R'(z) \text{ for } z > 0. \tag{10}$$

Second, let us assume that the effects of having social relationships disappear as z tends to infinity (because a social relationship loses its strength as the stress level in the relationship increases):

$$\lim_{z\to\infty} R(z)z = 0, \text{ and } \lim_{z\to\infty} B(z)z = 0 \tag{11}$$

Third, we make an additional assumption about the rate at which the combination of the effects of social relationships disappear. Let $\beta(z) \equiv B(z) - R(z)$

become more elastic as stress increases:

$$\frac{d\epsilon_\beta(z)}{dz} = \left(z \frac{(B(z)-R(z))'}{B(z)-R(z)} \right)' < 0, \tag{12}$$

i.e. we require the percentage response of social relationship effect $(\Delta\beta(z)/\beta(z))$ to a percentage change in stress $(\Delta z/z)$ be a decreasing function of stress. In addition to (12) let us require the same for the marginal effect of social relationship $\beta'(z)$:

$$\frac{d\epsilon_{\beta'}(z)}{dz} = \left(z \frac{(B(z)-R(z))''}{(B(z)-R(z))'} \right)' < 0. \tag{13}$$

Under these assumptions we can state

Proposition 2 *There is $\overline{c}$ such that for any given $c \in (0, \overline{c})$ there are S_1 and S_2 such that depending on the external stress S_0, the system (2) follows one of the three qualitatively different dynamics:*

1. *$S_0 \in [0, S_1)$. There is single stable steady state z_1.*
2. *$S_0 \in (S_2, \infty)$. There is single stable steady state z_3.*
3. *$S_0 \in (S_1, S_2)$. There are three steady state $z_1 < z_2 < z_3$. Steady states z_1 and z_3 are stable, z_2 is unstable.*

Proof. See Appendix. ■

The proposition is worth few words of explanation. The system's behaviour is largely affected by the relative strength of coping versus buffering and stress spillovers: in groups of individuals with superior coping abilities ($c >> 1$) the former dominates the latter and consequently the dynamics is qualitatively similar to the case of no relationship (5) analyzed at the beginning of this section. However in more realistic case of small and intermediate values of c ($c < \overline{c}$) system's dynamics combines features of both (7) and (5).[5] Typical phase diagrams corresponding to such a case are shown in Figure 1, using the following functional forms: $a = e^{-z}$, $r(a) = a$, and $b(a) = \sqrt{a}$.

The solid grey line in Figure 1 corresponds to the reaction function $\dot{z}(z)$, and the dashed line represents the reaction function without the relationship (5) for the same values of c and S_0. For small and intermediate values of z

[5]Under assumptions of the proposition spillovers do not add any steady states.

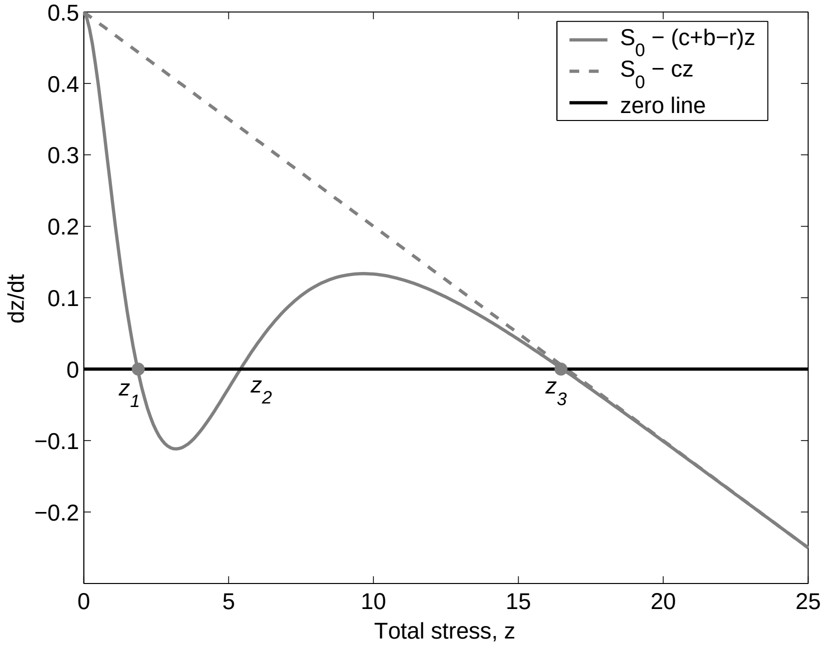

Figure 1: Phase diagrams for Equation (2). An example of phase diagram ($c = 0.03$, $S_0 = 0.5$).

a social relationship works as a stress absorber: the solid line is far below dashed line. However as stress increases, the relationship starts to fade away and can no longer absorb stress: the reaction function approaches the no-relationship case. According to the proposition the system may have multiple steady states (two stable and one unstable). Figure 1a presents an example of such a system with three steady states: z_3 is similar to the case of no relationships (5) while z_1 and z_2 arise due to buffering function of social relationships (7).

4.2 Innovation and stress

How is this related to innovation? The intensity of innovation (other things equal) determines the value of external stress S_0. Without loss of generality we can assume that the stress level is equal to the rate of innovation: $S_0 = m$. Define a function $f(z)$:

$$f(z) = [c + R(z) - B(z)]z.$$

This function has two local extremes at z_1^* and z_3^*: $z_1^* < z_3^*$:

$$f'(z_{1,3}^*) = 0, \tag{14}$$

where z_1^* is a local maximum, and z_3^* is a local minimum of $f(z)$ (see proof of Proposition 2). Depending on the external stress the system may have three qualitatively different dynamics: for a low innovation rate m: $m < S_1 \equiv f(z_3^*)$ there is a unique low-stress steady state (stable); when the innovation rate is high: $m > S_2 \equiv f(z_1^*)$ in the long-run the system always converges to high-stress steady state (stable); under intermediate rate of innovation $S_1 \leq m \leq S_2$ low- and high- stress equilibria co-exist.

The three dynamics corresponding to the different ranges of innovation rate/external stress are shown on Figure 2.

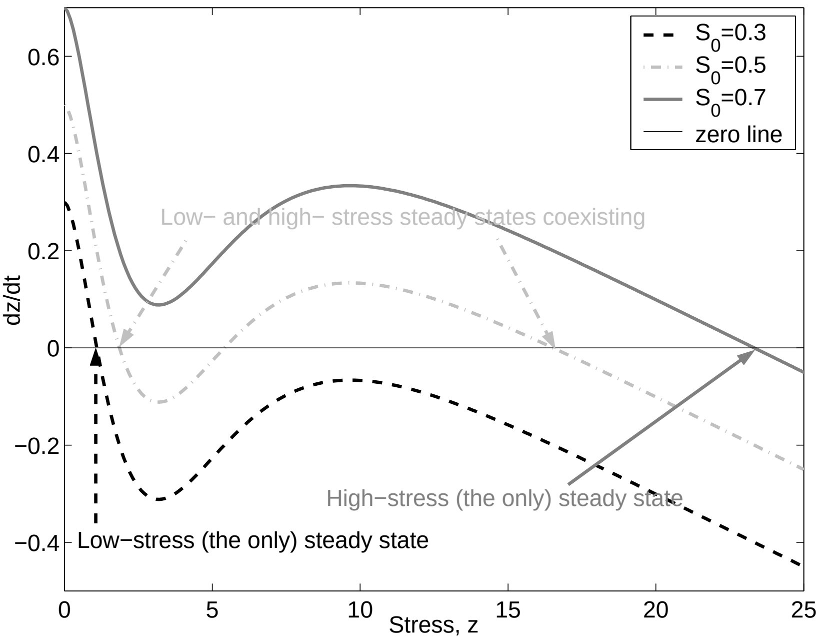

Figure 2: Phase diagrams for Equation (2). Effect of external stress.

- *Low innovation intensity (dashed line).* There is a unique steady state with relatively low stress (as compared to the situation of no relationship): the social relationship is effectively absorbing stress.

- *High innovation intensity (solid grey).* S_0 is large; there is single high-stress equilibrium. The social relationship is counterproductive and has become a stressor in itself. The relationship therefore will fade out (high z means low a). In case of a family relationship, we may think of divorce, since the partners could not cope with the ever growing stress; in case of work relationship, colleagues avoid each other, or not talk to each other. Each of the partners has to rely on individual self-control mechanisms. It is in effect similar to the case of no relationship.

- *Intermediate innovation intensity (light grey dash-dot line).* Two equilibria co-exist (the system has two stable equilibria and one unstable equilibrium. Depending on the initial conditions, we have either a low-stress equilibrium where the social relationship is absorbing the stress (as in the low innovation intensity case), or a high stress equilibrium with (almost) no social relationships (only self-control, similar to high innovation intensity).

The last situation is particularly interesting. In this case the system has "memory". Suppose that the system is in low-stress equilibrium with social relationships buffering stress. Now a major temporary shock in S_0 takes place (a major disruptive innovation episode, for example). That will shift the curve up and if the magnitude of the shock is sufficiently high, it can make the system 'jump over' the unstable steady state to the high stress equilibrium. Now, even if the external stress returns to the initial value of S_0, the system will continue to reside in a high-stress equilibrium. Thus, in this case relatively small changes in external stress S_0 may lead to drastic qualitative changes in the behavior of the system, and changes that are difficult to reverse.[6]

The effects of external stress caused by innovation on the social relationships in the group and the average level of stress are summarized in Figure 3. The diagram on the left depicts the relationship between external stress and strength of social relationships. When there is no inflow of stress, there is no stress in the system. At this point the group is tightly bound with social ties ($a = 1$). As external stress grows, the quality of social relationships deteriorates, but social support from one's partners continues to help reduce the stress. Small temporary shocks may drive average stress in the group away from steady state corresponding to the given value of external stress,

[6]In terms of dynamic systems theory our system has a "cusp" catastrophe (Saunders, 1980).

however with time the system always returns to the corresponding steady state that is located on the dashed line of Figure 3a.

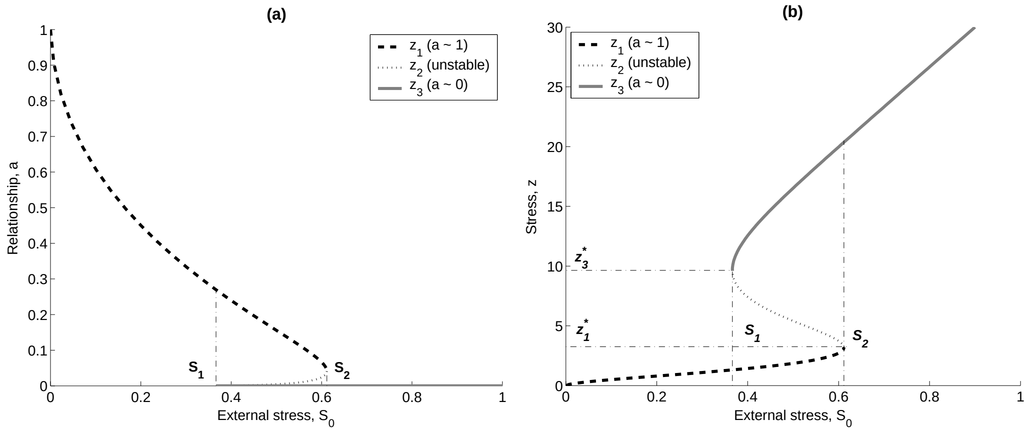

Figure 3: **Left:** Strength of social relationships as a function of external stress. **Right:** Average stress level as a function of external stress.

The first drastic change happens if the intensity of external stress reaches S_1. At this point another stable steady state, corresponding to z_3 in Figure 1, appears. This steady state is characterized by extremely weak social relationships ($a \approx 0$) — social relationships essentially vanish, at least as sources and sinks of stress. The long run behaviour of the system undergoes one more qualitative change when the intensity of external stress approaches S_2. At this point the steady state with social relationships disappears and only the steady state with no social relationships continues to exist, that is to say, the inflow of external stress with an intensity exceeding S_2 destroys the relationships between the members of the group. The corresponding evolution of the long-run level of average stress is shown in Figure 3b.[7] Between S_1 and S_2 the two steady states co-exist. In which of the steady states the system resides is determined by the evolution (history) of the system.

Historically speaking, as technological change leads to more innovation and thereby to more external stress the model suggests that increasing intensity of innovation further may lead to dramatic changes in the nature of social relationships. Indeed, suppose we start with low innovation intensity, where the economy rests in the single low stress equilibrium with social relationships acting as a stress buffering mechanism. If an increase in the

[7]The plot is provided by equation: $S_0 = f(z)$.

innovation rate raises the inflow of external stress above S_1 even temporarily, this may result in the permanent break up of social relationships in the group, and create a state in which agents have to deal with their stress on their own. Such a breakdown of social relationships corresponds to a sudden jump in the average level of long-run stress (Figure 3b). If the intensity of innovation-induced stress goes even further we risk losing the low-stress equilibrium so that in the end the stress level of the entire population is so high that social relationships disappear all together.

4.3 Innovation, stress, and economic growth

The relationship between innovation and long-term average stress level can be derived from (2). Assuming that in the long-run the system resides in a stable steady state ($\dot{z} = 0$),

$$m = f(z) \text{ for } z : f'(z) > 0,$$

(where the condition on $f'(z)$ ensures stability). Since for $m \in (S_1, S_2)$ two stable steady states coexist we need two functions $Z_1(m)$ and $Z_3(m)$ for low- and high- stress equilibria to invert equation (16):

$$Z_1 = f^{-1}(m) \text{ for } z < z_1^*, \tag{15}$$

$$Z_3 = f^{-1}(m) \text{ for } z > z_3^*, \tag{16}$$

where z_1^* and z_3^* are defined in (14).

Inserting (16) into (4) we obtain the relationship between the rate of innovation and economic growth:

$$\dot{y}_{1,3}(m) = m \cdot l(Z_{1,3}(m)), \tag{17}$$

where $\dot{y}_1$ is economic growth in a low-stress society bound by social ties, while $\dot{y}_3$ relates to population of stressed individuals 'bowling alone'.

From the point of view of our model innovation the rate has two effects on economic performance. First, there is a positive direct effect derived from the fact that innovation brings new, and more efficient methods of production. But there is also an indirect effect related to the fact that innovation increases the flow of stress as it stimulates (perceived) demand, and at the same time reduces (perceived) control over the process. According to the Yerkes-Dodson law the indirect effect can be either positive or negative, depending on the initial level of stress.

It seems reasonable to assume that the high-stress no-relationship equilibrium of our model is located above the ‘optimum stress’ of the Yerkes-Dodson law (z_L^*), on the descending part of the inverted U. In other words we assume that for an individual who is stressed to the degree that (s)he is unable to support a long-term social relationship, a further increase in stress tends to decrease his(her) productivity. Similarly we assume that low-stress equilibrium of our model is at or below ‘optimum stress’.[8] We can also assume productivity in the high-stress equilibrium to be lower than productivity in the low-stress steady state. Furthermore, we require that in the high-stress equilibrium $l(z)$ is more elastic than $f(z)$, i.e, $-\epsilon_l > \epsilon_f$.

Proposition 3 *The sign of the effect of innovation on economic growth defined by (17) depends on whether the system resides in the high- or low- stress steady state:*

$$\frac{\partial \dot{y}_1}{\partial m} > 0, \; \frac{\partial \dot{y}_3}{\partial m} < 0.$$

Proof. Differentiating (17) with respect to m gives us

$$\frac{\partial \dot{y}_{1,3}}{\partial m} = l(Z_{1,3}) + m \cdot l'(Z_{1,3}) Z'_{1,3}(m).$$

By assumption for all $z < z_1^*$: $l'(z) > 0$. Therefore

$$\frac{\partial \dot{y}_1}{\partial m} = l(Z_1) + m \cdot l'(Z_1) Z'_1(m) > 0.$$

Since for all $z > z_2^*$: $l'(z) < 0$ and $-\epsilon_l > \epsilon_f$

$$\frac{\partial \dot{y}_3}{\partial m} = l(Z_3) + m \cdot l'(Z_3) Z'_3(m) = l \cdot \left(1 + \frac{\epsilon_l}{\epsilon_f}\right) < 0.$$

■

Figure 4 illustartes the relationship between innovation and economic growth. Initially, (small m) economic growth responds rapidly to an increase in innovation rate. However, as the intensity of innovation grows further,

[8] Formally $z_1^* < z_L^* < z_3^*$, where z_1^* and z_2^* are the maximum stress in low-stress state and minimum stress in high-stress state respectively (see Figure 3b)

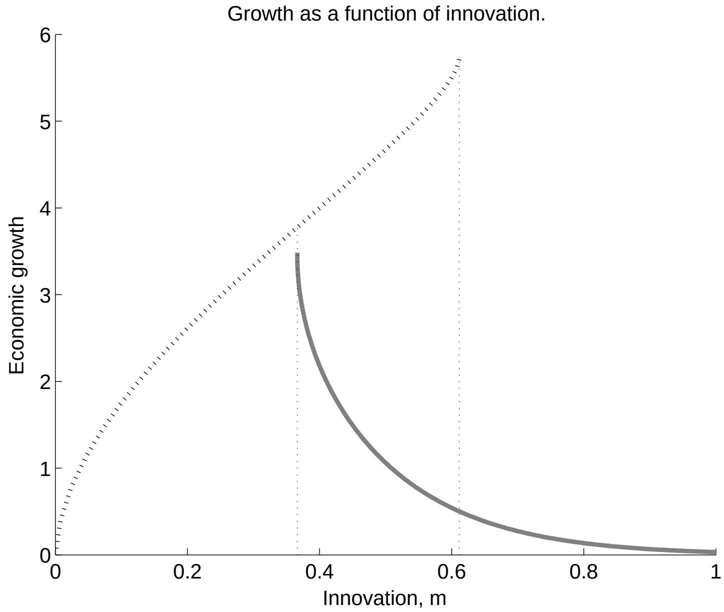

Figure 4: Economic growth as a function of innovation rate.

the dark side of the innovation related to its role as a stressor on workers overwhelms the positive effect of innovation and productivity suddenly drops. Any further increase in the innovation rate reduces economic growth. Co-existence of equilibria in the middle range of innovation rate makes an economy unstable with respect to small fluctuations in the flow of external stress (generally speaking not necessarily related to innovation) — small shocks may drag the system out of the low-stress equilibrium and set it on the declining branch of $\dot{y}(m)$. To return the system to the low-stress equilibrium we have to decrease the innovation rate much lower (so that only the low-stress equilibrium exists).

In other words, not only do we find multiple steady states, we also find hysteresis. Within a certain range of external stress flow S_0, thus within a certain range of rates of innovation, there is a double value function. If external stress S_0 increases, the steady state value of z will increase. Above a critical value of S_0, z tips over to the high steady state value; this has the character of a phase-change. If after crossing this threshold, S_0 is reduced again (through reducing the innovation rate for example), z will remain on the high value segment of the stress curve. This means that at the same level of flow of external stress S_0, there can be different levels of steady state stress z, depending on the history of S_0 (whether S_0 was reached by going from a low to a higher S_0 or by going from a high to a lower S_0). What it means in practice is that if innovation rates become too high, thereby creating high rates of stress flow, a reduction to the (previously maintained) intermediate level of innovation and hence external stress, (because because the high stress levels are viewed as socially undesirable), we will nevertheless retain a much higher stress than before. In order to lower stress levels, we will have to lower the innovation rate considerably below the original rate which was initially associated with acceptable stress levels. This will clearly have consequences for the speed of innovation (which will be lower) and for the increase of productivity (which will also be lower). This hysteresis can imply a significant economic loss.

The explanation for the hysteresis lies in the fact that above a certain level of external stress, relationships start to become stressors and will start to break down. If after relationships have broken down, the level of external stress is brought back to intermediate levels again, the buffering effects of relationships are no longer present. The cycle is vicious. The absence of the buffering effect of relationships makes it more difficult to restore relationships (increase responsiveness). This keeps stress that is in a sense internal to the relationship, high. Thus only for much lower levels of external stress will responsiveness recover, and return relationships to their stress-reducing role.

This implies that it is economically costly to have innovation rates that are extremely high, even if only temporarily. The price is that due to the breakdown of relationships people are less able to reduce their stress levels and therefore are less able to deal with higher intermediate rates of innovation than they were before.

Innovation increases productivity, so a higher rate of innovation should speed up the increase or productivity. However, the higher the rate of innovation, the higher the flow of stress. Since stress is related to productivity as an inverted U, the level of stress resulting from the rate of innovation is important for understanding the real effects of innovation on productivity. At a critical rate of innovation, a phase-change takes place, the steady state of stress switching from the low to the high steady state. Due to the Yerkes-Dodson law, this can induce a decline in productivity, including productivity of those producing innovations. And this, of course, passes through to economic growth. In the most extreme case, high rates of innovation actually lead to lower rates of productivity growth. Even a temporary burst of high innovation, if it passes over the critical value, can induce a relatively long period of lower growth, due to the effects of hysteresis.

4.4 Comparative statics

In this section we are interested in the consequences of changing certain variables. This will give some perspective on possible interventions and their effects.

Coping skills

One variable that can be changed is coping. Over time people generally learn better ways of coping, by selecting more effective, more context- and problem-sensitive coping strategies (Greve and Strobl 2000). Indeed, it is possible to increase coping skills actively, for example through coaching or training. On the other hand, accumulation of stress over time may negatively affect one's self-control reducing abilities to cope with stress. Coping skills are captured by our variable c. In the absence of a relationship, if c is increased, a person can reduce his stress level at a higher rate, and long-term levels of stress go down. Given a certain stream of new innovations, he will arrive faster at a steady state stress level, and that steady state stress level is positively related to c.

We see a similar effect when we look at people engaged in social relationships, however in this case a change in coping abilities may have much more dramatic effect. An example of such a situation is shown in Figure 5. Suppose the coping ability is $c = 0.027$. As one can see at the present level of external stress a relationship cannot be sustained and the long-term stress level is about the same as where there is no relationship ($z_c(c = 0.027)$). However if through training coping skills are enhanced to $c = 0.029$ then the long-term stress level can be reduced not only to $z_c(c = 0.029)$, but to z_1 as now social relationships may effectively buffer external stress. Thus increasing coping skills results in a lower steady state of stress, especially in the presence of a relationship. Conversely a deterioration in self-control may have additional adverse impact in the presence of social relationships if it leads to a breakdown of the relationships, as beneficial effects of buffering go away together with the social relationships.

Monnier et al. (2000) demonstrated that interventions that focus on developing prosocial coping skills, such as negotiating compromises between

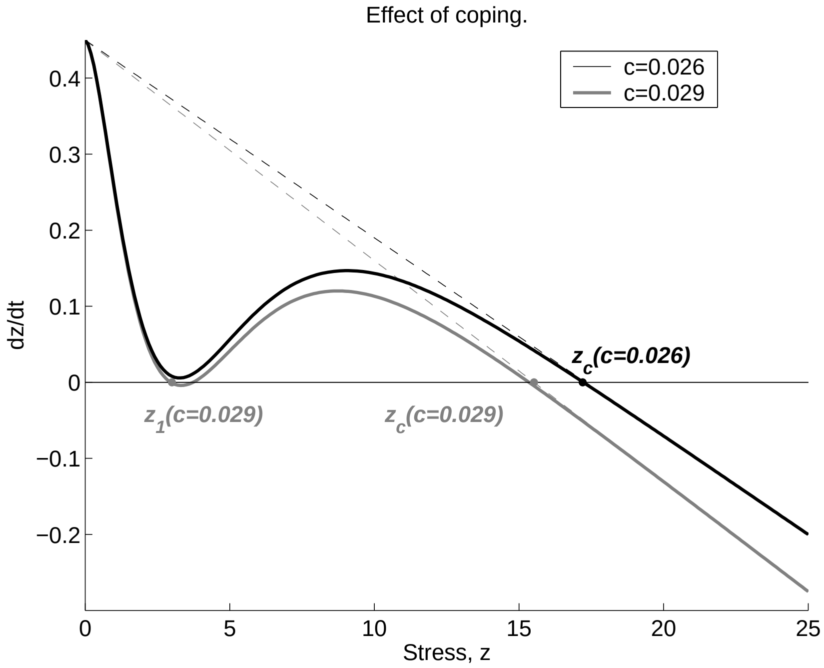

Figure 5: Economic growth as a function of innovation rate.

one's own needs and those of others may produce more fruitful, long-term results. Interventions that seek to increase active coping skills without regard to the social implications of these behaviors may produce individual symptom reduction but may also cause harm to social relationships, in part, because of this differential impact of coping behaviors. Thus, careful attention to development of prosocial coping behaviors and the reduction of purely individualistic coping behaviors appears important for interventions to be effective (Lyons et al. 1998, Manne and Glassman 2000).

Buffering

Another variable that can be changed is the quality of the relationship, for example through developing better social skills, or by providing more insight into the dynamics of relationships through more reflection or through relationship therapy. This enters the model through buffering: $b(a)$. Since $b(a)$ is a product of a compound variable including social skills and reflection, then increasing social skills and reflection will shift $b(a)$ upward, increasing the potential beneficial effects of having a relationship. Holding spillover levels

$(r(a))$ constant, the net result of being in a relationship will be more positive and will remain positive longer, at higher levels of stress, than before. This implies that both the low and the high steady state of stress level z are located at lower levels of stress.

Relationships

Both buffering and responsiveness have to do with the quality of the relationship, and how individuals relate to each other. This issue is beginning to receive attention in psychology, in particular in the context of spousal relationships, with research on interventions that involve more than the individual expressing symptoms.

Benazon and Coyne (2000) argue that spouse burden may potentially be an important point of intervention. Instead of focusing exclusively on the reduction of patient depression and improvement of patient interpersonal functioning, attention could profitably be directed to the distress and burden experienced by spouses. Spouse burden is potentially modifiable with a renegotiation of roles within the dyad. Practical implications include assessment and treatment strategies that include interpersonal processes as a focus (e.g., interpersonal psychotherapy for depression), and couples, family, or group therapeutic strategies that "inoculate" depressives' significant others against the effects of contagious depression (Joiner 1994).

The relationship between spouses' well-being has important implications for clinical interventions. For enhancement of the quality of life in individuals, interventions that target both members of a spousal pair may be most effective, as one partner's well-being may spill over to that of the other (Bookwala and Schultz 1996). Hammer et al. (2005) find significant longitudinal crossover effects of positive spillover on spouses' experience of depression. This suggests that considering spouse effects on well-being outcomes over time is important. The findings of Westman et al. (2004) suggest that such interventions should focus on the reduction of social undermining, as it is found to be a powerful mediator of the adverse impact of economic hardship on marital satisfaction. They suggest that efforts to reduce the stress and strain of employees should also target their spouses. The findings demonstrated that a distressed wife is likely to generate a process of social undermining that will have an adverse effect on the husband, and then later, through the husband, on herself. It appears that if a distressed spouse is not part of the solution, he or she is likely to become a big part of the problem. Thus, what is needed according to Westman et al. (2004) are programs that train and counsel couples in developing skills for reducing negative interactions and enhancing their relationships. The primary objective of such programs is prevention and ongoing improved functioning, achieved by focusing on techniques designed to help couples manage negative affect and handle conflict situations constructively (Markman, et al.1994). The findings of Monnier et al. (2000) highlight the idea that people function within the context of others and cannot determine their well-being alone as if being Robinson Crusoe, but are to some extent dependent on others for their well-being. Adopting a communal perspective when approaching both individual and family treatment may be beneficial to treatment recipients. Thus, recognition of coping crossover is important and, if addressed, may lead to enhanced individual and relationship well-being. This understanding can be applied also to interventions programs designed for nonintimate relationships (e.g. coworker to coworker) (Monnier et al. 2000). At most stress levels except for high stress levels, relationships help a person to reduce his stress faster, thereby resulting in a lower steady state of stress. This means that at least within a certain range of stress, a person without a relationship can deal with less innovation (external stress) when at the same stress level as a person with a relationship. If we assume that stress represents disutility, and if we assume more innovation in principle is a good thing, being in a relationship is in principle economically desirable.

5 Conclusions

In this paper we have presented a simple model of induced stress. While an agent is exposed to stress from his environment, including innovations in it, the stress level he ultimately experiences is mediated by aspects of a relationship between himself and another agent. Associating stress with the Yerkes-Dodson inverted-U permits us to take this micro-model of stress contagion as a basis for understanding how innovation and growth interact with mental capital. The limited ability of any agent to cope with stress, combined with spillovers from one agent to another imply that it is possible to get too much of a good thing — very high levels of innovation, if not accompanied by increases in agents' abilities to cope with their own stress, or buffer each others' stress, may be counter-productive in terms of productivity growth. In addition, the counter-productivity has an unfortunate hysteretic aspect. If innovation rates become so high that the society is tipped into the high-stress equilibrium, a simple re-establishment of the previous, lower rate will not necessarily re-establish the lower stress levels. Some over-correction may be necessary, which can be costly. The point has not been to argue that including stress or mental capital shows that high rates of innovation are bad, but rather that including them points out the complexity of the interaction between innovation, agents, stress, productivity growth, and ultimately welfare.

References

[1] Alterman, Richard and Zito-Wolf, Roland (1993) Agents Habitats and Routine Behavior, International Joint Conference on Artificial Intelligence, pp. 305-310.

[2] Barsade, S. G. (2002). The ripple effect: Emotional contagion and its influence on group behavior. Administrative Science Quarterly, 47, 644-675.

[3] Beehr, T. A., Johnson, L. B. and Nieva, R. (1995). Occupational stress: Coping of police and their spouses. Journal of Organizational Psychology, 16, 3-25.

[4] Beehr, T.A., Farmer, S.J. and Glazer, S. (2003) The enigma of social support and occupational stress: Source congruence and gender role effects. Journal of Occupational Health Psychology, Vol 8(3), Jul 2003. pp. 220-231.

[5] Benazon, N.R. and J.C. Coyne (2000) Living with a depressed spouse, Journal of Family Psychology Vol. 14 (1) March 2000, pp. 71-79.

[6] Bolger, N., DeLongis, A., Kessler, R. and Wethington, E. (1989). The contagion of stress across multiple roles. Journal of Marriage and the Family, 51, 175-183.

[7] Bolger, N, and Eckenrode, J. (1991) Social relationships, personality, and anxiety during a major stressful event. Journal of Personality and Social Psychology, Vol 61(3), Sep 1991. pp. 440-449.

[8] Bookwala, J. and R. Schultz (1996) Spousal similarity in subjective well-being: the cardiovascular health study, Psychology and Aging Vol.11 (4) Decembert 1996, pp. 582-590.

[9] Burchell, B.; Lapido D. and Wilkinson F. (2001) Job insecurity and work intensification, Routledge: London.

[10] Cohen, S. and Wills, T.A. (1985) Stress, social support, and the buffering hypothesis, Psychological Bulletin, Vol 98(2), September, pp. 310-357.

[11] Coie, John D.; Cillessen, Antonius H. N.; Dodge, Kenneth A. (1999) It takes two to fight: A test of relational factors and a method for assessing aggressive dyads. Developmental Psychology, Vol. 35(5), Sep 1999. pp. 1179-1188.

[12] Conger, R. D., Rueter, M. A. and Elder, G. H. (1999). Couple resilience to economic pressure. Journal of Personality and Social Psychology, Vol. 76(1), 54-71.

[13] Cox, T. (1978). Stress. London: MacMillan Education.

[14] Davila, J.; Bradbury, T.N.; Cohan, C.L. and Tochluk, S. (1997) Marital functioning and depressive symptoms: Evidence for a stress generation model, Journal of Personality and Social Psychology, Vol 73, pp. 849-861.

[15] Davila, J., Karney, B.R. and Hall, T.W. (2003) Depressive Symptoms and Marital Satisfaction: Within-Subject Associations and the Moderating Effects of Gender and Neuroticism. Journal of Family Psychology, Vol 17(4), Dec 2003. pp. 557-570.

[16] Dodge, Kenneth A. (1990) Developmental psychopathology in children of depressed mothers. Developmental Psychology, Vol 26(1), Jan 1990. pp. 3-6.

[17] Florian, V.; Mikulincer, M.; Hirschberger, G. (2002) The anxiety-buffering function of close relationships: Evidence that relationship commitment acts as a terror management mechanism, Journal of Personality and Social Psychology, Vol 82(4), April. pp. 527-542

[18] Ginn, J., Sandell, J. (1997) Balancing home and employment: stress reported by social services staff, Work, Employment and Society, Vol. 11 No.3, pp.413-34

[19] Glomb, T.M.; Kammeyer-Mueller, J.D. and Rotundo, M. (2004) Emotional Labour Demands and Compensating Wage Differentials, Journal of Applied Psychology Vol 89(4), August, pp. 700-714.

[20] Glowinkowski, S.P., Cooper, C.L. (1985) Current issues in organizational stress research, Bulletin of The British Psychological Society, Vol. 38 pp.212-16.

[21] Green, F. and S. McIntosh (2001) The intensification of work in Europe. Labour Economics, Vol 8(2), May, pp. 291-308.

[22] Greve, W. and R. Strobl (2004) Social and individual coping with threats: Outlines of an interdisciplinary approach, Review of General Psychology Vol. 8(3), 194-207.

[23] Gump, B.B and J.A. Kuliks (1997) Stress, affiliation and emotional contagion, Journal of Personality and Social Psychology Vol. 72 (2) February 1997, pp. 305-319.

[24] Hammer, L.B, J.C. Cullen, M.B. Neal, R.R. Sinclari and M.V. Shafiro (2005) The longitudinal effects of work-family conflict and positive spillover on depressive symptoms among dual-earner couples, Journal of Occupational Health Psychology, Vol. 10 (2) April 2005, pp 138-154.

[25] Hatfield, E., Cacioppo, J. T. and Rapson, R. L. (1994). Emotional contagion. Cambridge, England: Cambridge University Press.

[26] Hobfoll, S. (1988). The Ecology of Stress. Washington D. C.: Hemisphere

[27] Hobfoll, S. E. (1989). Conservation of resources: A new attempt at conceptualizing stress. American Psychologist, 44, 513-524.

[28] Hochschild, A.R. (1983) The managed heart: Commercialization of Human Feeling, University of California Press: Berkeley CA..

[29] Holmes, T.H. and Rahe, R.H. (1967). The social readjustment rating scale. Journal of Psychosomatic Research, Vol 11(2), pp. 213-218.

[30] Hubbard, Julie A.; Dodge, Kenneth A.; Cillessen, Antonius H. N. (2001) The dyadic nature of social information processing in boys' reactive and proactive aggression. Journal of Personality and Social Psychology, Vol 80(2), Feb 2001. pp. 268-280.

[31] Joiner, T. E. (1994). Contagious depression: Existence, specificity to depressed symptoms, and the role of reassurance-seeking. Journal of Personality and Social Psychology, 67, 287-296.

[32] Karasek, R. (1979). Job demands, job decision latitude and mental strain: Implications for job redesign. Administrative Science Quarterly, 24, 285-306.

[33] Kiyokawa, Y.; Kikusui, T.; Takeuchi, Y. (2004) Partner's Stress Status Influences Social Buffering Effects in Rats. Behavioral Neuroscience, Vol 118(4), Aug 2004. pp. 798-804.

[34] Langlois, R.N. (1992) Transaction-cost economics in real time. Industrial and Corporate Change 1(1), pp. 99127.

[35] Lepore, S.J. (1992) Social conflict, social support, and psychological distress: Evidence of cross-domain buffering effects. Journal of Personality and Social Psychology, Vol 63(5), November. pp. 857-867

[36] Liston, C.; Miller, M.M.; Goldwater, J.J.; Radley, A.B.; Hof, P.R.; Morrison, J.H. and B.S. McEwan (2006) Repeated Stress Induces Dendritic Spine Loss in the Rat Medial Prefrontal Cortex, J. Neurosci, Vol. 26, pp. 7870-7874.

[37] Lyons, Renee F., Kristin D. Mickelson, Michael J.L. Sullivan and James C. Coyne (1998) Coping as a Communal Process, Journal of Social and Personal Relationships, Vol. 15, No. 5, 579-605 (1998)

[38] Manne, Sharon; Glassman, Marc (2000) Perceived control, coping efficacy, and avoidance coping as mediators between spousal unsupportive behaviors and psychological distress. Health Psychology, Vol 19(2), Mar 2000. pp. 155-164.

[39] Mantler, J.; Matejicek A. and Matheson, K. (2005) Coping with Employment Uncertainty: A Comparion of Employed and Unemployed Workers, Journal of Ocdupational Health Psychology, Vol. 10(3), July 2005, pp. 200-209.

[40] March, J.G. and Olsen, J.P. (1989) Rediscovering Institutions: The Organizational Basis of Politics. New York: Free Press.

[41] Markman, H. J., Renick, M. J., Floyd, F. and Stanley, S. M. (1994). Preventing marital distress through effective communication and conflict management: A four- and five-year follow-up. Journal of Consulting and Clinical Psychology, 61, 70-77.

[42] McEwan, B.S. and Sapolsky R.M. (1995) Stress and cognitive funcition. Curr Opin Neurobiol, Vol 5(2), April, pp. 205-216.

[43] Monat, A.; Averill, J.R. and Lazarus R.S. (1972) Anticipatory stress and coping reactions under various condition of uncertainty, Journal of Pesonality and Social Psuchology, Vol 24(2), November, pp. 237-253.

[44] Monnier, Jeannine; Cameron, Rebecca P. and Hobfall, Stevan E. (2000) Direct and crossover effects of prosocial and antisocial coping behaviors. Journal of Family Psychology, Vol 14(4), Dec 2000. pp. 570-584.

[45] Morris, J.A. and Feldman, D.C. (1996) The dimensions, antecedents and consequences of emotional labour, Academy of Management Review, Vol 21(4), pp. 986-1010.

[46] Neiss, R. (1988). Reconceptualizing arousal: Psychological states in motor performance. Psychological Bulletin, 103, 345-366.

[47] Nelson, R. R., and Winter, S. G. (1982). An evolutionary theory of economic change. Cambridge, Mass.: Belknap Press of Harvard University Press.

[48] Procidano. M.E., and Smith, W.W. (1997). Assessing perceived social support: The importance of context. In G.R. Pierce, I.G. Sarason, N. Sarason, and B. Lakey (Eds.). Sourcebook of theory and research on social support and personality (pp. 93-106). New York: Plenum.

[49] Rabkin, J.G. and E.L. Struening (1976) Live events, stress and illness, Science 3, Vol. 194(4269), December, pp. 1013-1020.

[50] Radley, J.J.; Rocher, A.B.; Miller M.; Janssen, W.G.M.; Liston, C.; Hof, P.R.; McEwan, B.S. and J.H. Morrison (2006) NO TITLE Cereb Cortex, Vol. 16, pp. 313-320.

[51] Rafferty, Alannah E.; Griffin, Mark A. (2006) Perceptions of Organizational Change: A Stress and Coping Perspective. Journal of Applied Psychology, Vol 91(5), Sep 2006. pp. 1154-1162.

[52] Repetti, R.L.; Wood, J. (1997) Effects of daily stress at work on mothers' interactions with preschoolers. Journal of Family Psychology, Vol 11(1), Mar 1997. pp. 90-108.

[53] Repetti, R. L. (1989). Effects of daily workload on subsequent behavior during marital interactions: The roles of social withdrawal and spouse support. Journal of Personality and Social Psychology, 57, 651-659.

[54] Sapolsky, Robert M. (1996) Why stress is bad for your brain, Science, Vol. 273(5276), 9 August, pp. 749-750.

[55] Saunders, P.T. (1980) An Introduction to Catastrophe Theory. Cambridge University Press, Cambridge, England.

[56] Scase, R. and Goffee, R. (1989) Reluctant Managers. Unwin and Hyman

[57] Selye, H. (1956). The stress of life. New York: McGraw-Hill.

[58] Silverstein, M., X. Chen and K. Heller. (1996) Too Much Of a Good Thing? Intergenerational Social Support and the Psychological Well-Being of Aging Parents. Journal of Marriage and the Family. 58: 970-982.

[59] Simon, Herbert A. (1947) Administrative Behavior. New York: Macmillan.

[60] Simon, Herbert A. (1955) A Behavioral Model of Rational Choice, Quarterly Journal of Economics, 69, 99118.

[61] Simon, H. A. (1977). Models of discovery. Dordecht: D. Riedel.

[62] Sinclair-Desgagne, B.; Soubeyran, A. (2000) A Theory of Routines as Mindsavers, CIRANO Scientific Series 2000s-52.

[63] Smith, B. W., and Zautra, A. J. (2001). Interpersonal sensitivity and reactivity to spousal conflict in healthy older women. Personality and Individual Differences 31: 915923.

[64] Stephens, Mary Ann Parris; Franks, Melissa M.; Atienza, Audie A. (1997) Where two roles intersect: Spillover between parent care and employment. Psychology and Aging, Vol. 12(1), Mar 1997. pp. 30-37.

[65] Sullins, E. S. (1991). Emotional contagion revisited: Effects of social comparison and expressive style on mood convergence. Personality and Social Psychology Bulletin, 17, 166-174.

[66] Vinokur, A.D., Price R.H. and Caplan R.D. (1996) Hard times and hurtful partners: how financial strain affects depression and relationship satisfaction of unemployed persons and their spouses, Journal of Personality and Social Psychology. July, Vol 71(1), pp.166-79.

[67] Westman, M. and Etzion, D. (1995). Crossover of stress, strain and resources from one spouse to another. Journal of Organizational Behavior, 16, 169-181.

[68] Westman, M. (2001). Stress and strain crossover, Human Relations, 54, 557-591.

[69] Westman, M. A.D. Vinokur, V.L. Hamilton and I. Roziner (2004) Crossover of marital dissatisfaction during military downsizing among Russian army officers and their spouses, Journal of Applied Psychology Vol. 89 (5) October 2004, pp. 769-779.

[70] Wheeler, L. (1966). Toward a theory of behavioral contagion. Psychological Review, 73, 179-192.

[71] Yerkes, Robert M. and John D. Dodson (1908) The Relation of Strength of Stimulus to Rapidity of Habit-Formation. Journal of Comparative Neurology and Psychology, 18, 459-482).

Appendix

Proof of Proposition 2. The dynamics of the system is greatly affected by properties of $\beta(z)$. Therefore before we start with the proof of the proposition let us examine some properties of this function.

First, notice that $\beta(z)$ and its derivative are continuous functions of z. Indeed, function $\beta(z)$ defined as

$$\beta(z) = b(a(z)) - (n-1)r(a(z)),$$

where $b(a)$, $r(a)$, and $a(z)$ are twice continuously differentiable, is twice continuously differentiable function itself. Furthermore, conditions (9) and (10) imply that $\beta(z)$ is strictly positive monotonously decreasing function of z.

Second, the elasticities of $\beta(z)$ and $\beta'(z)$ are continuous monotonous functions of z. The elasticity of $\beta(z)$ defined as

$$\epsilon_\beta(z) = \frac{z\beta'(z)}{\beta(z)}$$

is a ratio of continuous functions with the denominator different from zero (strictly positive), and hence is a continuous function of z. By assumption (12) $\epsilon_\beta(z)$ is monotonously decreasing. Similarly $\epsilon'_\beta(z)$ as a ratio of continuous functions with non-zero denominator ($\beta'(z) < 0$ by assumption (10)) is continouous, and by assumption (12) it is also monotonously decreasing. Also, notice that $\epsilon_\beta(0) = 0$ (as $b'(1)$, $r'(1)$, and $a'(0)$ are finite and $\beta(0)$ is non-zero).

Next let us prove that there is a unique level of stress where $\beta(z)$ has unit elasicity, i.e. there is unique z^* such that $\epsilon_\beta(z^*) = -1$. Consider function $\varphi(z)$ defined as

$$\varphi(z) = -\beta(z)z.$$

Since $\beta(z)$ is strictly positive and bounded, $\varphi(0) = 0$ and $\varphi(z) < 0$ for $z > 0$. Furthermore according to (11) $\lim_{z\to\infty} \varphi(z) = 0$, i.e. $\varphi(z)$ approaches to zero from below as z tends to infinity. Hence there must be $x > 0$ such that $\varphi'(x) > 0$. Take first derivative of $\varphi(z)$ at $z = x$

$$\varphi'(x) = -\beta(x) - x\beta'(x) = -\beta(x)(1 + \epsilon_\beta(x)) > 0.$$

Provided that $\beta(z)$ is always positive, we conclude that $\epsilon_\beta(x) < -1$.

Now, taking into account that $\epsilon_\beta(z)$ is continuous and monotonically decreasing, $\epsilon_\beta(0) > -1$, and $\epsilon_\beta(x) < -1$ there exists a unique $z^* \in (0, x)$ such that $\epsilon_\beta(z^*) = -1$. Notice that $\varphi(z)$ has unique minimum at $z = z^*$.

Following similar lines we can prove that there is a unique $z^{**} > z^*$ such that

$$\epsilon'_\beta(z^{**}) = -2.$$

Indeed, as we have shown above $\varphi(z)$ is a unimodal function with local (and global) minimum at z^*. It approaches to zero from below as z tends to infinity. Thus there is $x > z^*$ such that $\varphi''(x) < 0$. The second derivative of $\varphi(x)$ at $z = x$ is

$$\varphi''(x) = -2\beta'(x) - x\beta''(x) = -\beta'(x)(2 + \epsilon_{\beta'}(x)) < 0. \tag{18}$$

Given that $\beta'(z) < 0$ the inequality is equivqlent to $\epsilon_{\beta'}(x) < -2$.

Write down the second order condition for $\varphi(z)$ at local minimum $z = z^*$:

$$\varphi''(z^*) = -\beta'(z^*)(2 + \epsilon_{\beta'}(z^*)) < 0. \tag{19}$$

In this inequality $\beta'(z^*) < 0$, therefore $\epsilon_{\beta'}(z^*) > -2$.

Since $\epsilon_{\beta'}(z)$ is continuous and monotonous, it follows that there exist a unique $z^{**} \in (z^*, x)$ such that $\epsilon_{\beta'}(z^{**}) = -2$.

Now we are ready to analyze the phase diagram corresponding to dynamics defind by (2). First and second derivatives of $\dot{z}(z)$ are

$$\frac{d\dot{z}}{dz} = -c - \beta(z)(1 + \epsilon_{\beta}(z)) \tag{20}$$

and

$$\frac{d^2\dot{z}}{dz^2} = -\beta'(z)(2 + \epsilon_{\beta'}(z)). \tag{21}$$

Since there is unique z^{**}: $\epsilon_{\beta'}(z^{**}) = -2$, $\dot{z}(z)$ has unique inflection point at $z = z^{**}$, and this a point of maximum for $\dot{z}'(z)$, i.e.

$$\frac{d\dot{z}}{dz}(z^{**}) = \max_{z} \frac{d\dot{z}}{dz}(z).$$

Notice that if $\dot{z}'(z^{**}) > 0$ then $\dot{z}(z)$ has two local extremes: local minimum at z_1^* ($z_1^* < z^{**}$) and local maximum at z_3^* ($z_3^* > z^{**}$). The phase diagram in such a case is similar to those shown at Figure 1: $\dot{z}'(z) > 0$ for $z \in (z_1^* < z_3^*)$, and $\dot{z}'(z) < 0$ for $z \in (0, z_1^*) \cup (z_3^*, \infty)$

If $\dot{z}'(z^{**}) < 0$ then $\dot{z}(z)$ is monotonicaly decreasing for all z.

Let us define $\bar{c}$ as

$$\bar{c} = -\beta(z)(1 + \epsilon_{\beta}(z**)).$$

Then the condition for having extremes can be written as

$$c < \bar{c}.$$

Let us assume that this condition holds. Define S_1 and S_2 as

$$S_1 = cz_3^* + b(a(z_3^*))z_3^* - (n-1)r(a(z_3^*))z_3^*,$$
$$S_2 = cz_1^* + b(a(z_1^*))z_1^* - (n-1)r(a(z_1^*))z_1^*.$$

Consider (2) with $S_0 < S_1$. Then we have $\dot{z}(0) = S_0 > 0$, $\dot{z}(z_1^*) = S_0 - S_2 <$

$S_0 - S_1 < 0$. By continuity of $\dot{z}(z)$ there is $z_1 \in (0, z_1^*)$ such that $\dot{z}(z_1^*) = 0$. This steady state is unique and stable since $\dot{z}'(z) < 0$ for $z \in (0, z_1^*)$. There are no other steady states because $\dot{z}(z) < S_0 - S_1 < 0$ for all $z \in (z_1^*, \infty)$. This corresponds to **case 1** of the proposition.

Now let $S_0 > S_2$. Notice that (a) $\dot{z}(z_3^*) = S_0 - S_1 > S_0 - S_2 > 0$, and (b) $\dot{z}(z) < 0$ for any $z > z_c = S_0/c$ (z_c corresponds to 'no relationship' case). By continuity of $\dot{z}(z)$ there is $z_3 \in (z_3^*, z_c)$ such that $\dot{z}(z_1^*) = 0$. Since $\dot{z}'(z) < 0$ for $z > z_3^*$ steady state z_3 is stable and unique. This is **case 2** of the proposition.

Finally, take $S_0 \in (S_1, S_2)$. First, we have $\dot{z}(0) = S_0 > 0$, $\dot{z}(z_1^*) = S_0 - S_2 < 0$, and $\dot{z}'(z) < 0$ for $z_1 \in (0, z_1^*)$. Thus there is a stable state z_1: $\dot{z}(z_1^*) = 0$ and it there are no other steady states on $(0, z_1^*)$. Second, there is unique steady state z_2 on (z_1^*, z_3^*) because $\dot{z}(z)$ is monotonically increasing, $\dot{z}(z_1^*) = S_0 - S_2 < 0$, and $\dot{z}(z_3^*) = S_0 - S_1 > 0$. However z_2 is unstable because $\dot{z}'(z) > 0$. Third, given that $\dot{z}(z_3^*) = S_0 - S_2 > 0$, $\dot{z}(z) < 0$ for $z > z_c$, and $\dot{z}'(z) < 0$ for $z > z_3^*$ there is unique stable steady state on (z_3^*, ∞). **Case 3** of the proposition is proven.

■

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