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REGULAR ARTICLE

Do incentive systems spur work motivation of inventors in high tech firms? A group-based perspective

Nathalie Lazaric · Alain Raybaut

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Abstract In this paper, we explore with a model the potential tensions between the incentive system of groups of inventors and knowledge diversity in a high tech firm. We show that, when all groups are rewarded and able to interact freely with their peers, extrinsic and intrinsic motives are mutually self-reinforcing, leading to crowding in effects. As a result, the level of created knowledge increases in each group, reinforcing the diversity of the firm's knowledge base. By contrast, competitive rewards and constrained autonomy are likely to produce motivating effects in a small number of groups, limiting knowledge creation to the firm's core competencies. In this case, the firm can suffer from crowding out effects by the other groups, leading eventually to the extinction of creation in their fields and reduced diversity in the long run. The results are illustrated with empirical findings from a case study of a French high tech firm.

Keywords Work motivation · Groups of inventors · Knowledge creation · Knowledge diversity

JEL Classification O31 · O32 · L20 · D83 · J30

1 Introduction

The relationships between knowledge governance and organizational set-ups have been clearly identified in the literature (See e.g. Marengo 1992; Grandori 2001;

N. Lazaric (✉) · A. Raybaut
GREDEG, CNRS/University of Nice Sophia Antipolis, Valbonne, France
e-mail: lazaric@gredeg.cnrs.fr

A. Raybaut
e-mail: raybaut@gredeg.cnrs.fr

Cohendet and Llerena 2003; Dupouët and Yildizoglu 2006). Some authors also focused on the cognitive and motivational aspects that coordinate interactions in the firm and enable the building of its capabilities (Lazaric 2011; Witt 2011). These contributions point to a recent debate emphasizing the need for evolutionary theory to understand more deeply the micro-foundations of the firm and its organizational capabilities (Foss et al. 2012). In this perspective, an open question is to clarify the implications of the choice of an incentive system. Indeed, several recent advances raise the difficulties of calibrating and maintaining various sources of motivations that may conflict with the organizational culture, goals and existing capabilities of the firm (Gottschalg and Zollo 2007; Siemsen et al. 2007; Lindenberg and Foss 2011). However, the analysis of the effects of a sharp modification of the incentive system on the scope of the firm's knowledge base remains largely unexplored. In particular, to our knowledge, there has been no formal attempt to grasp directly this issue within an evolutionary framework. This article tries to fill this gap with a model examining the manner in which incentive systems may spur or deter inventors' motivations and eventually impact knowledge content and diversity. From this standpoint, the case of the French high tech firm, Thales, that has recently experimented different changes in the incentive systems of its inventors, provides a specific illustration of this issue (Ayerbe et al. 2012).

On this basis, our model focuses on the relationships between group-based incentive systems and the work motivation of inventors in high tech firms. Accordingly, we consider a firm composed of various groups of inventors who may be placed or not in competition for acknowledgment of their work, while the reinforcement of the firm's capabilities relies notably on the exchange of knowledge between groups.

In this framework, we consider the potential tension between the incentive system and knowledge diversity in the firm's knowledge base. Two types of motivations, extrinsic and intrinsic, are retained. We suppose that extrinsic motivations are the product of an exogenous wage and different bonus policies and that intrinsic motivation are explained by competencies, relatedness and autonomy. We show that the success or failure of an incentive system depends mainly on the type of group interactions. Our main hypothesis is that, when groups are able to interact freely with their peers, extrinsic and intrinsic motives are mutually self-reinforcing, leading to generalized crowding in effects. As a result, the level of created knowledge increases in each group, reinforcing the diversity of the firm's knowledge base. By contrast, competitive rewards and constrained autonomy are likely to produce motivating effects in a small number of groups, limiting knowledge creation to the firm's core competencies. In this case, we would argue that the firm can suffer from crowding out effects by the other groups, leading eventually to the extinction of creation in their fields and reduced diversity in the long run.

The article is organized as follows. Section 2 specifies the analytical background of our research and presents the example of Thales. Section 3 is dedicated to the model. Section 4 discusses our findings and Section 5 draws some general conclusions.

2 The analytical background

Starting with the basic concepts of intrinsic and extrinsic motivations, we argue that these dimensions should be viewed as the two faces of the same coin for understanding the relevance of an incentive system and its implications in terms of diversity of knowledge created. In this perspective, we first recall the difficulties raised by incentive systems in high tech firms, as discussed recently in the literature. Second, we focus on motivations at the group level, the specific locus of knowledge creation for inventors. Finally, we draw on the case of Thales to exemplify group-based incentives issues and their outcome for knowledge diversity.

2.1 The motivation challenge in high tech firms

A major difficulty for high tech firms is to understand why the incentives for undertaking an interesting task can undermine or reinforce intrinsic motivation of inventors and lead to crowding out or crowding in effects (Amabile 1997). Researchers in psychology and related fields have provided empirical findings showing that work motivation is difficult to monitor in the case of discretionary tasks, which by definition can hardly be compared to other activities. For instance, innovations and inventions are characterized by higher levels of uncertainty and autonomy, lower levels of control and near impossibility of monitoring individual behaviors (Hauser 1998; Sauermann and Cohen 2010; Sauermann 2008). These tasks typically are challenging since inventors mobilize intrinsic motivation in order to perform them. In organizational set ups involving these activities, it is necessary to find the right combination of intrinsic and extrinsic motives, and especially the right balance between the factors favoring positive (crowding in effect) and negative (crowding out effect) complementarity between these two types of motives (Kehr 2004).

Accordingly, Minkler (2004), in an extensive US survey, observes that intrinsic elements, such as moral motivation, peer pressure and other positive incentives, emerge as important factors explaining the moderation of individual effort. Crowding out effects can often be explained by details in the reward system and its modifications. People work hard in anticipation of substantial rewards and may reduce their effort if new, less attractive incentive arrangements are proposed. Other factors, such as competition and evaluation, may also reduce creativity, cognitive flexibility and problem solving (Amabile et al. 1990; Festré and Garrouste 2007).

Given the delicate exercise of controlling the direct relationship between motivation and economic performance, some organizations try to implement enabling conditions for nurturing work motivation by providing inventors and innovators with greater autonomy to realize their own projects (Deci and Ryan 1985; Hackman and Oldham 1976). Firms may conceive various types of individual incentives, such as contingent pay for patents, or social recognition in the form of special honors, (for example, IBM Fellows who are a select group of employees working mostly autonomously) to pursue projects within their specific expertise. In some organizational set ups, conflicts can arise because the firm's employees do not benefit from the rents generated by inventions. Several Japanese firms, including Nicai Chemical, Olympus, and Ajimoto, have experienced tensions between individual and organizational goals and misalignment between the pecuniary compensations paid to inventors and the benefits reaped by the firm (Owan and Nagaoka 2011). In the discussion about scientists' motives, Stephan and Levin (1992) emphasize social benefits in addition to intrinsic and extrinsic motivation. Social benefits encompass extrinsic social benefits provided by others (social approval, peer recognition which can be institutionalized through award systems). However, social benefits can be intrinsic, i.e. the pleasure derived from good social relationships and the satisfaction derived to contributing to the well being of the individuals with whom the inventors interact (Fehr and Falk 2002). Peer recognition can take different forms. For instance, Badawy (1973) suggests that both scientists and engineers need some recognition. For scientists, recognition is linked to the broader scientific community, whereas engineers derive their recognition and motivation from within the organization. Thus, the desire for recognition may drive quite different innovative and inventive behaviors depending on the particular reference group from which the recognition is sought.

Obviously for high tech firms, the design of incentive systems to provide motivation matters. Incentives promoting intrinsic motivation may stimulate inventiveness by supporting more challenging exploratory work, while extrinsic rewards may crowd out inventiveness by pushing engineers and inventors to direct their attention to more incremental tasks (Owan and Nagaoka 2011). While the literature suggests that organizations should tap in individuals' talents by rewarding them for their contributions (Friebel and Giannetti 2009), there is a great deal of evidence showing that incentive systems in high tech firms affect the speed of problem solving (Appelyard et al. 2006) and the innovation performance of development teams (Sarin and Mahajan 2001). For this reason, some incentive systems may be significant for sustaining motivation and for promoting innovation and invention, while short term incentives may be deleterious in the long run, and especially systems that promote performance by rewarding a few individuals but failing to provide benefits to work teams and the organization as a whole (Appold 2001).

2.2 The group level

Although pure personal incentives may be successful in some specific cases, particularly when emulation at the individual level is important, teamwork is necessary for knowledge creation (Smith et al. 2005). How well individual motivations match or not with group goals has been identified as decisive for cooperative tasks and knowledge sharing (Weingart et al. 2010). Accordingly, in the context of high tech firms, the group-level is often seen as relevant for enabling intrinsic motivation. For instance, Amabile et al. (1996) focus on social and organizational factors, arguing that intrinsic motivation is supported by organizational and supervisory encouragement as well as by the diversity of ideas within work groups. Although group-based incentive systems are difficult to implement, they may motivate workers by favoring interdependencies which have a positive impact on knowledge creation and sharing (Hackman 1987; Wageman 1995). Specific organizational set-ups, consistent with group-based incentive systems, are required to promote appropriate interactions among team members, and to preserve a level of intrinsic motivation in the context of discretionary tasks (Osterloh and Frey 2000; Minkler 2004). In the field of open-source software, in small communities of developers, a range of individual motives have been identified, including the intrinsic pleasure of discovery, the social incentive of fulfilling the perceived obligations of the community, and reputation gains provided by the open source community (Lakhani and Von Hippel 2003). However, it is not clear to what extent the empirical findings in this specific context can be extended to groups in high tech firms.

This strand of the literature exemplifies the criticality of the organizational context for work motivation and for combining intrinsic and extrinsic otivation. Potential drivers of differences in incentive systems and motivation may also derive from complementary human resources practices, organizational principles and individual motives (Sauermann 2008). For this reason, top managerial decisions have a significant impact on team motivation by enabling a positive atmosphere which promotes effective collaboration. Within teams and between teams, good cohesion is necessary to build a form of organizational commitment and to create a perception of a common fate, which promotes cooperation and fosters the opportunities for social interactions and job involvement (Hoegl et al. 2004). As a consequence, deliberate attempts by managers to limit teams' autonomy may undermine their motivation and be associated with lower levels of cohesion and effort in R and D (Hoegl and Parboteeah 2006).

Autonomy between and within teams has received attention from scholars interested in motivational issues (West 2002). Nahapiet and Ghoshal (1998) claim that a cooperative atmosphere creates individual motivation among group members and sustains exchange of knowledge with group members. Group autonomy generated in some teams enables inventiveness (Smith et al. 2005; Amabile 1998) which sustains knowledge combination. Indeed, while individualism may appear to be efficient for organizations, teamwork and collective action promote knowledge creation and work motivation. Furthermore a competitive context within organizations may be deleterious for discretionary tasks, while developing intragroup safety facilitates the implementation of inventive ideas and of innovation (West 2002). In this context, the managerial strategic choices should find the right balance between autonomy and constraint of groups for promoting the inventiveness of team members and ensuring team coordination. The complexity of innovative activities and the degree of interdependence between teams involved in invention requires frequent interactions, in particular to exploit the knowledge of experts in other teams (Hoegl et al. 2004).

2.3 Group-based incentives and knowledge diversity: the example of Thales

In a recent synthesis, Lindenberg and Foss (2011) insist on the necessity for calibrating and maintaining the mixed sources of motivations in the firm. Among these difficulties for finding the right dosage between extrinsic and intrinsic motives, they mention significant problems, notably ”subgroups egoism”, passive following of the rules and the lack of intelligent effort and innovation. Thales illustrates these complications experimented during the implementation of different forms of incentive systems for inventors.

Thales was created in 2000 when Thomson-CSF was split into Thales for the defense sector and Thomson SA for the civil market (For a more detailed description of Thomson- CSF and Thales companies, see Som 2009.) Thales is now classified as an electronics company specializing in defense (50 % including air systems, land, inter-army and naval systems), aerospace (25 %, including aeronautics and space) and security (25 % including security solutions and services. More precisely, six technological fields form an integral part of Thales's core competencies: analysis, measurement and monitoring tools, telecommunications, computing, optics, electric components and audiovisuals. These six technological fields represent around 80 % of its patent-filing activity and ensure the group's strategic position as an integrator of electronic defense and security systems. Thales actually holds a portfolio of 15,000 patents covering 2,700 technological fields, maintained for an average duration of seven years (Ayerbe et al. 2012).

Thales put in place a new organization to simplify its existing practices and to develop synergies across the group. This strategy was implemented in two stages. A first period, from 2003 to 2006, is characterized by the design of a new incentive system across business units. A second period, from 2006 to the present, has seen incentive systems and HRM being reconsidered to reinforce the dual technology strategy and knowledge sharing. We describe these periods in more detail because they are relevant to work motivation.

From the creation of Thales to 2003, the incentive system inherited from Thomson CSF was in place. In this system, an inventor who participated in an individual or a collective innovation (most patents involve three or four inventors) received an automatic bonus. The number of company patents was increasing significantly, but most were related to incremental innovations and their inventors received the same rewards as inventors of totally new products or processes. This generated problems in relation to the evaluation of these inventions and their quality. This organizational set up was characterized by a very high degree of autonomy for inventors and their interactions in exploring various bodies of knowledge.

From 2003 to 2006, organizational changes were introduced. First, new managers were hired not on the basis of their academic qualifications and technical skills, but on the basis of their management capabilities, which changed the shape of the social networks in the company. Second, in order to sustain the attraction of its technical tasks, the firm introduced a dual career advancement ladder for experts and managers. Third, Thales modified its bonus scheme related to patenting.

The new incentive system provoked a rupture in traditional industrial relations. A patent committee was created to scrutinize and to select all the patents before their application by the business units. The responsibilities of the committee exceeded mere selection and included ranking of patents (the most significant for the firm in terms of strategy and economic performances) which would be eligible for bonuses. This award mechanism was aimed at promoting a limited number of technological fields defining the core competencies of the firm. Indeed, the new bonus system gave high pecuniary rewards to a few inventors, but did not reward the majority of engineers and particularly those specialized in non-core competencies. This regulation was perceived as unfair and the relations between business units deteriorated.

Furthermore, work motivation was reduced. The patent committee's decisions were considered very subjective and not transparent.[1]

The feeling of inequity among business units spread throughout the company and a climate of contestation developed towards the patent committee. Some business units refused to participate in the competition. Increased competition among the business units destroyed traditional forms of cooperation among the different groups of engineers, and this eventually became damaging to knowledge transfer and knowledge creation. This was especially noticeable among inventors working on electronic systems who were required to work across business units, because their field covered diverse bodies of the company's technological knowledge (the so called 'dual technology strategy' of Thales).

In order to develop new skills in electronics fields, Thales decided to focus on restricted core competencies to increase competitiveness and specialization in new technological trajectories, critical for the architecture of complex systems. As a consequence, the reinforcement of patent applications in a restricted range of technological classes (notably telecommunication software and instruments), considered to be core competencies, was accompanied by a stagnation in the total number of patent applications, with a sharp decline in the number of patents, notably with direct commercial application (10 % on average in 2003–2006)

In addition, new criteria for hiring people outside of traditional networks induced difficult social interactions, damaging cooperation and relationships required to foster creativity.[2] Thales's hiring of new employees outside traditional networks was too extreme a change to produce its effective outcomes. The cognitive distances were too large and the breakdown in effective communication within groups of inventors generated mistrust and ambiguity which reduced work motivation. Moreover, the potential bias in the reward system was a source of tension and generated conflicts. Thales, like many firms in this industry, tried to introduce 'safe' emulation among business units but did not take account of the risk of potential conflict with the values inherited from the prior organizational entity which had been established a decade earlier by the Thomson company which relied on the spirit of 'collective invention' and knowledge sharing, very different values from competition.

The negative outcomes on the R and D forced Thales to rethink its incentive scheme. To correct these effects and to restore knowledge transfer, Thales put an end to the race among inventors and in 2006 re-introduced a system of partial bonus sharing among business units, restoring autonomy and voluntary cooperation across business units. Thales finally found a suitable trade-off between various sources of motivations fitting to its own organizational culture. Since then, technological

[1] The policy was criticized by some business units on the basis of social network effects. In particular, there was a suspicion that engineers trained in the same French engineering schools as committee members were being favored.

[2] Engineers in the past had been recruited on the basis of known networks, including the Ecole Polytechnique (France's most prestigious engineering school). Engineers who had graduated from the Ecole Polytechnique shared a set of values based on history, myth and technical culture, and used a common language (Kessler 2005). The new intake challenged the validity of these competencies and questioned their content.

cooperation between groups has been reinforced and the firm's capabilities enlarged in core and non core competencies.[3]

3 Finding the suitable calibration for work motivation: the model

We now propose a dynamic model of the interplay between extrinsic and intrinsic motivation with different group-based incentive systems of inventors. Starting from the standpoint of the self-determination theory, we consider in this model that extrinsic motivation refers to the performance of inventive activity because of its instrumental or separable external outcomes, e.g. its monetary reward, while intrinsic motivation refers to the performance of this activity because it provides rewards in terms of the basic psychological needs for autonomy, competence and relatedness (Deci et al. 1999; Gagné and Forest 2008). In this perspective, we combine these different sources of motivation to characterize their impact on knowledge creation and diversity.

3.1 The general framework

Let us consider a firm organized around n interacting groups i involved in inventive tasks (Lazaric and Raybaut 2005, 2007). We suppose that each group is characterized by a specific skill or competency. The set $\mathcal{K} = \{1, ..., n\}$ defines the knowledge base of the firm. Let $x_i(t)$ define the level of knowledge created by group i at time t and suppose that, in each group, work motivation at time t, $m_i(t)$, is determined by an extrinsic and an intrinsic component, namely $m_i^{Ext}(t)$ and $m_i^{Int}(t)$. We have:

$$m_i(t) = m_i^{Ext}(t) + m_i^{Int}(t) \tag{1}$$

The n levels of extrinsic motives are determined by two elements, a flat exogenous wage w and a bonus b function of the performances of group i in terms of knowledge creation. We have:

$$m_i^{Ext}(t) = w + b(x_i(t), \overline{x}(t)) \tag{2}$$

where, $\overline{x}(t) = \frac{1}{n}\sum_j x_j(t)$. The bonus function b is continuous and increasing in $x_i(t)$ and $x_{i(t)} - \overline{x}(t)$, which captures the role played by peer effects.[4]

The n levels of intrinsic motivation are explained for each group by the interplay between competencies, autonomy and relatedness. We now successively specify these three components of intrinsic motivation.

To begin, let us define the competencies of i at time t by the stock of accumulated knowledge over time by i, that is by $k_i(t) = \int_{\tau=0}^{t} x_i(\tau)d\tau$. We suppose

[3] Patent applications increased by 50 % since 2008 with an average number of new inventions by researchers increasing from 350 in 2008, 359 in 2009 to 364 in 2010. The quality of these applications was also improved, with a significant growth in the number of patents with direct commercial application (See Ayerbe et al. 2012).

[4] We assume that $-w \leq b \leq w$, which implies that extrinsic motivation is non negative. In contrast, intrinsic motivation can be negative, leading to crowding out effects.

that these competencies exercise a positive effect on the intrinsic motivation of the group.

According to Deci (2008), ”autonomy means volition, a sense of choice, and full endorsement of one’s actions. It does not mean independence”. From this standpoint, autonomy and relatedness are conceived as complementary notions, contrary to a more simplistic view which would tend to oppose them. Consequently, we suppose that the degree of autonomy of a group i is captured by the capacity of the group to choose freely the structure of interactions with the other groups j, which determines its relatedness.

This desired structure of interactions is determined as follows. Define d_{ij}, for $i \neq j$ as the cognitive distance between i and j. In the rest of the paper we simply assume that $d_{ij} = |i - j|$. We suppose that this distance plays a positive role in the process of knowledge creation. The potential gain produced by the interaction is d_{ij}^{θ}, with $0 < \theta < 1$, which captures the fact that i may benefit from exchange of experience with groups j. But this distance is also costly. Assume that this cost is given by $\frac{d_{ij}^2}{2n}$. Then, i chooses to create a link with j if and only if $d_{ij}^{\theta} - \frac{d_{ij}^2}{2n} \geq 0$. Consequently, there is a critical distance $2n^{\frac{1}{2-\theta}}$ such that the structure of desired connections for i satisfies:

$$l_{ij} = \begin{cases} 1 \ \ iff \ \ d_{ij} \leq 2n^{\frac{1}{2-\theta}} \\ 0 \ \ otherwise \end{cases} \tag{3}$$

In the rest of the paper, we refer to this structure as defining a configuration with full autonomy. However, autonomy will be limited with a structure of interactions l_{ij} partially or totally imposed exogenously by the hierarchy. The interplay of the two basic needs for autonomy and relatedness is captured for each group i by $\sum_j l_{ij} r_{ij}$, where $r_{ij} = d_{ij}^{\theta} - \frac{d_{ij}^2}{2n}$.

Then, we assume that intrinsic motivation is modeled by the following relation:

$$m_i^{Int}(t) = tanh\left[k_i(t) + \sum_j l_{ij} r_{ij}\right] \tag{4}$$

Motivations $m_i(t)$ are thus completely defined by the relations (1) to (4).

To complete the model, we assume that motivation determines the rate of growth of idiosyncratic knowledge created by each group i over time. The dynamics of these rates is given by the following system of n coupled differential equations:

$$\frac{dx_i(t)}{dt} = x_i(t)(\widetilde{\lambda_i(t)} m_i(t)^{\alpha} - \delta x_i(t)) \tag{5}$$

where, $\widetilde{\lambda_i(t)}$ is the probability of knowledge creation given by a Poisson process with an arrival rate λ, $0 < \alpha \leq 1$ and δ refers to the exogenous obsolescence rate of i’s knowledge (Lazaric and Raybaut 2005).

The additive decomposition of motivation in extrinsic and intrinsic components described above may be associated with either a crowding in or a crowding out effect for group i according to the sign of $m_i^{Int}(t)$. Since $m_i^{Ext}(t) \geq 0$, a crowding in effect exists for positive intrinsic motivation. Conversely, a crowding out effect occurs with negative intrinsic motivation. We first derive in a simplified version of the model analytical results showing the existence of crowding in or crowding out effects and their respective outcomes in terms of knowledge diversity at the stationary state with different incentive systems. Then we conduct numerical simulations extending these results to the complete framework encapsulated in the dynamical system (5).

3.2 Analytical results in a simple framework

Let us assume that $k_i(t) \approx x_i(t)$, $\alpha = 1$ and $\theta = \frac{Log[n/8]}{Log[n/2]}$ with $n > 8$. In addition, let assume that for $i = 1, ...n$, $\widetilde{\lambda_i(t)} = 1$. Then the dynamical system (5) is deterministic and can be written as:

$$\frac{dx_i(t)}{dt} = x_i(t)(m_i(t) - \delta x_i(t)) \tag{6}$$

In this simplified framework, we consider successively two opposite incentive systems: a non competitive bonus rule with full autonomy of the groups and a competitive bonus rule with constrained autonomy.

***System 1**: Non competitive bonus rule with full autonomy*

In this first scenario, the incentive system is defined as follows :

- Each group receives a bonus proportional to its production in terms of the knowledge created. The bonus function is equal to $\frac{x_i(t)}{n}$.
- Autonomy is full, and thus we have:

$$l_{ij} = \begin{cases} 1 \;\; iff \;\; d_{ij} \leq 2n^{\frac{1}{2-\theta}} \\ 0 \;\; otherwise \end{cases} \tag{7}$$

Note that since $n \geq 3$ and $0 < \theta < 1$, $2n^{\frac{1}{2-\theta}} > 2$, this connection topology implies that all i are connected at least with their nearest neighbors. The following result is obtained:

Proposition 1 *Assume that $\delta > \frac{1}{n}$. Then, the model admits in this regime a stable stationary state with crowding in effects and strictly positive and almost equal creation of knowledge by each group, x_i^*. (Proof: see **Annex**)*

This proposition confirms the intuition that provided groups are rewarded and able to interact freely with their peers, extrinsic and intrinsic motives are mutually self-reinforcing, leading to generalized crowding in effects. Consequently, the levels of created knowledge eventually converge to a stationary state with positive and almost equal levels of creation in each group. Full diversity is preserved, but this configuration is also likely to favor effort dispersion as well as the development of low-quality inventions.

***System 2**: Competitive bonus rule with constrained autonomy*

In this scenario, the incentive system is characterized by two properties :

- The hierarchy decides to give discretionary rewards to only some groups. These groups receive a bonus proportional to their production in terms of knowledge created while the others receive nothing. The bonus function is given by $\frac{bx_i(t)}{n}\Theta[z_i(t)]$, where the variable $z_i(t) \in \mathbb{R}$ captures the discretionary choice of the hierarchy as regards i at time t and Θ is the Heaviside function equal to 0 for $z_i(t) \leq 0$ and to 1 for $z_i(t) > 0$ and $1 \leq b < n$ is a positive parameter.
- Autonomy is constrained. Each group i no longer has the choice to determine freely the groups j with which to interact, but the structure of interactions is imposed by the hierarchy. For reasons of simplicity, let us, from here on, consider a complete graph configuration with:

$$l_{ij} = \begin{cases} 1 \ iff \ \ i \neq j \\ 0 \ otherwise \end{cases} \tag{8}$$

  Contrary to the previous case with full autonomy, in this regime, with a complete graph configuration for all i, there exists a certain number of imposed links such that $r_{ij} < 0$, which may eventually lead for some i to $a_i = \sum_j l_{ij}r_{ij} < 0$. It is clear that it will most likely be the case for the groups more distant from the central ones in $\mathcal{K}$. The following results are obtained.

Lemma *It exists in $\mathcal{K} = \{1, ...n\}$ an interval $\mathcal{C}$ centered on $\frac{n}{2}$ such that $a_i = \sum_j l_{ij}r_{ij} > 0$ for $i \in \mathcal{C}$ and $a_i \leq 0$ for $i \notin \mathcal{C}$. This interval $\mathcal{C}$ defines the core competency set in the knowledge base of the firm, $\mathcal{K}$.*

(Proof : see **Annex**)

Proposition 2 *Assume that $\delta > \frac{b}{n}$ and $0 \leq w < \widehat{w} < 1$. Then, the model admits a stable stationary state with crowding in effects and stationary values $x_i^* > 0$ for $i \in \mathcal{C}$ and crowding out effects with $x_i^* = 0$ for $i \notin \mathcal{C}$.*

(Proof: see **Annex**)

These findings indicate that an incentive system with competition and constrained autonomy increases the work motivation of a limited number of groups, concentrating the efforts in knowledge creation only on the core competencies of the firm. However, this result is obtained at the expense of all the other groups, with crowding out effects eventually leading to total extinction of creation in their fields, and, as a consequence, a reduction of variety in the firm's knowledge base in the long run.

3.3 Numerical results in the complete framework

To complete the preceding findings, we investigate numerically the complete framework. We consider here three examples of incentive systems: the non competitive bonus rule with full autonomy and the competitive bonus rule with constrained autonomy defined above, and a mixed system with competitive bonus rule and full autonomy.

In the three cases, the initial conditions are randomly selected from a uniform distribution on [0; 2]. The results are averaged respectively over 150 independent realizations. In the three cases, the parameters are as follows:

n	α	θ	w	δ	λ	b
27	$\frac{3}{4}$	$\frac{1}{4}$	1	.5	$\frac{1}{n}$	3

This specification is obviously arbitrary, but the qualitative features of the three scenario discussed below may be not drastically modified for different ranges of parameters satisfying the assumptions made in Sections 3.1 and 3.2 above.

3.3.1 Non competitive bonus rule with full autonomy

In this first scenario, the following results are obtained (Figs. 1, 2 and 3):

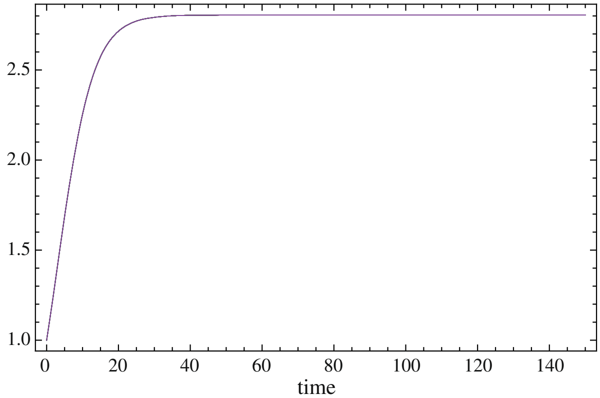

Fig. 1 Dynamics of the n levels of created knowledge x_i

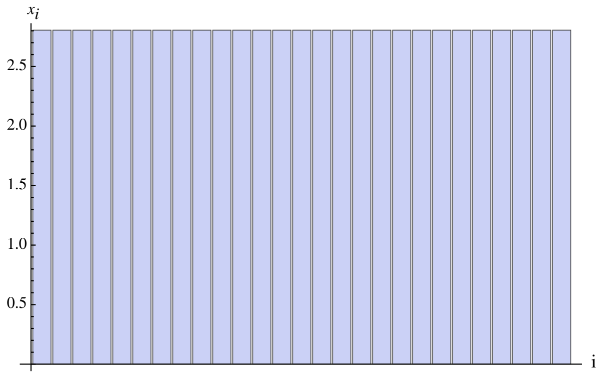

Fig. 2 The x axis displays the n groups $i = 1...27$ and the y axis the levels of created knowledge x_i at the stationary state

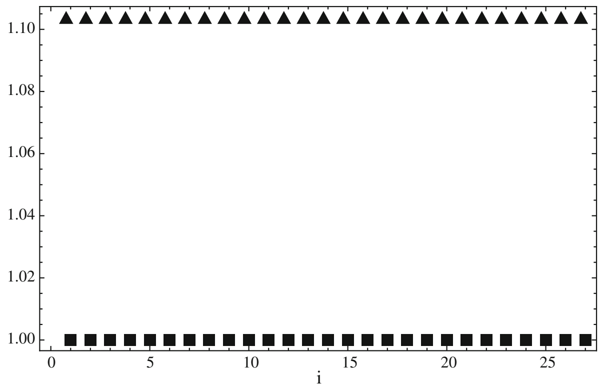

Fig. 3 The x axis displays the n groups $i = 1...27$ and the y axis their respective levels of extrinsic (*triangles*) and intrinsic (*squares*) motivation at the stationary state

This non competitive scenario with full autonomy produces two main results. From the motivational point of view, no crowding out effect occurs, intrinsic and extrinsic forms of motivation are positive and are mutually self-reinforcing, producing a crowding in effect for all groups. Knowledge creation is boosted, and the model eventually converges to a stationary state with almost equal participation in terms of knowledge creation. These numerical findings confirm the results of Proposition 1 obtained in a simplified framework.

3.3.2 *Competitive bonus rule with constrained autonomy*

In this system, the following results are obtained (Figs. 4, 5 and 6):

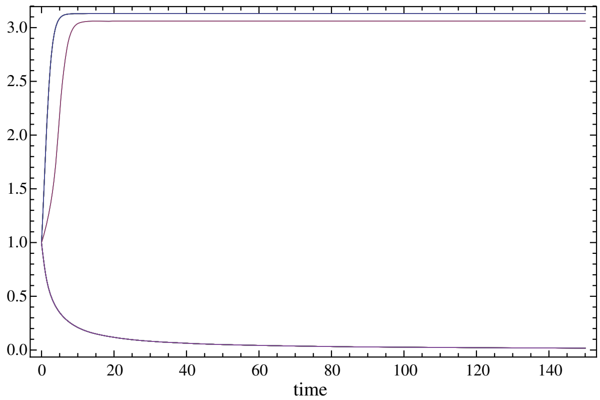

Fig. 4 Dynamics of the n levels of created knowledge x_i

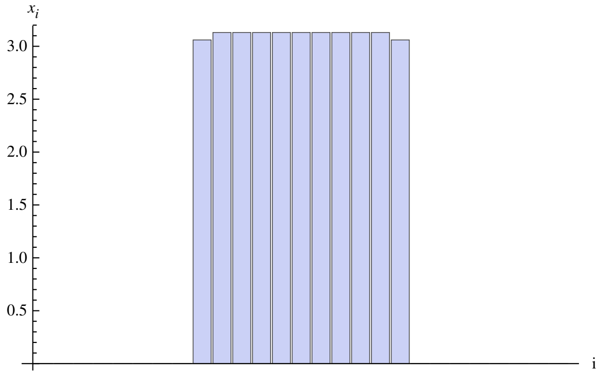

Fig. 5 The x axis displays the n groups $i = 1...27$ and the y axis the levels of created knowledge x_i at the stationary state

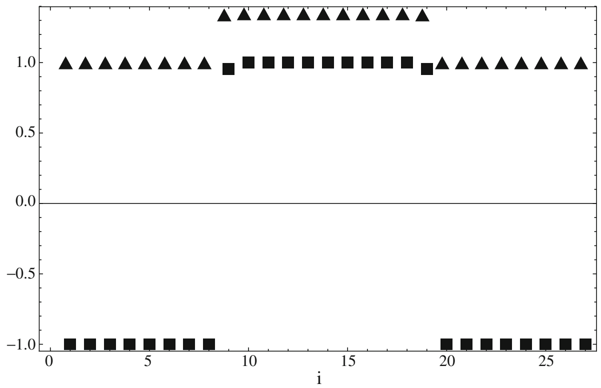

Fig. 6 The x axis displays the n groups $i = 1...27$ and the y axis their respective levels of extrinsic (*triangles*) and intrinsic (*squares*) motivation at the stationary state

These numerical findings illustrate the results of Proposition 2. In particular, they indicate that the results can be obtained without the as if assumptions on the parameters. In this competitive scenario with constrained autonomy, we obtain crowding out effects for the groups of inventors endowed with non core competencies. Conversely, groups with core competencies present a crowding in effect. Contrary to the first scenario, this incentive system limits the dispersion of knowledge creation, concentrating the efforts on a limited number of technologies, the core competencies of the firm. However, it can be argued that the effects of this system are not totally positive because of the decoupling between intrinsic and extrinsic motives for the non-core competencies groups. The crowding out effects for the non-core competencies groups eventually lead to total extinction of creation in these fields with the risk of depletion of the firm's capabilities in the long run.

3.3.3 Competitive bonus rule with full autonomy

We consider here a mixed system combining the competitive bonus rule of the preceding case with full autonomy of the first scenario. The following results are obtained (Figs. 7, 8, and 9):

In this mixed system with competitive bonus rule and full autonomy, intrinsic motivation remains positive for all groups with this system. Competitive monetary rewards enable intrinsic motivation because they are not perceived by inventors as a sole instrument of control, but as the acknowledgment of the group effort.Knowledge is created principally in core competencies. However, unlike scenario 2, a smaller but positive level of knowledge creation still exists in non core competencies at the stationary state, preserving enough diversity in the firm's knowledge base in the long run. These findings suggest that the main issue is not so much peer pressure and

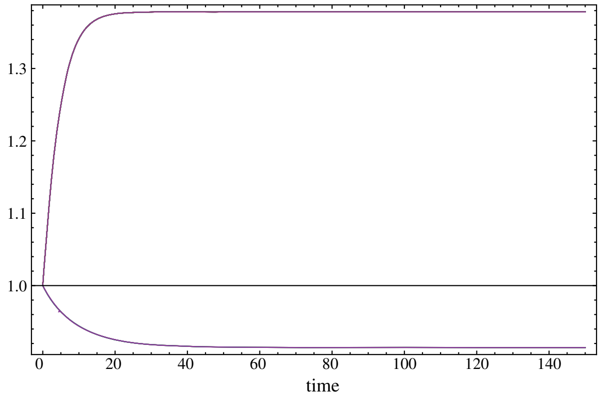

Fig. 7 Dynamics of the n levels of created knowledge x_i

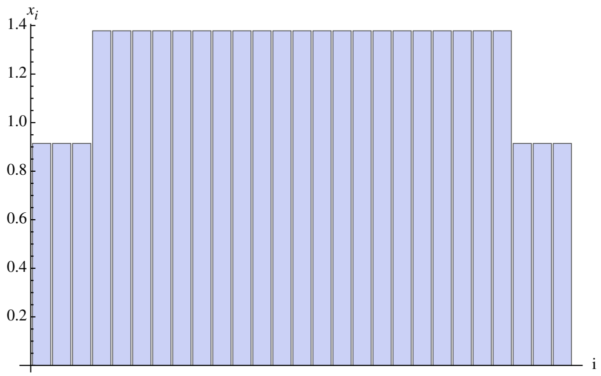

Fig. 8 The x axis displays the n groups $i = 1 \ldots 27$ and the y axis the levels of created knowledge x_i at the stationary state

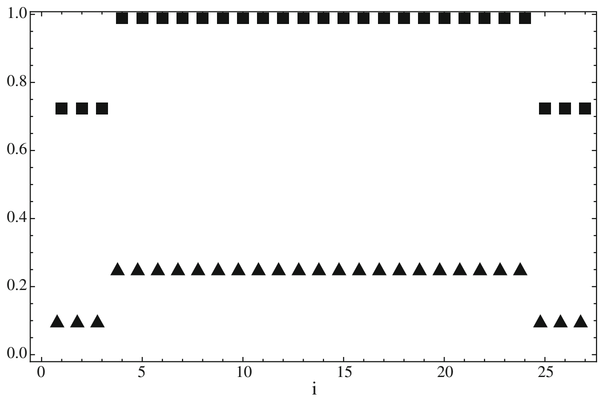

Fig. 9 The x axis displays the n groups $i = 1...27$ and the y axis their respective levels of extrinsic (*triangles*) and intrinsic (*squares*) motivations at the stationary state

competitive reward policies, but the implementation of a suitable calibration for work motivation.

4 Discussion of the results

Our findings indicate the manner in which an incentive systems may produce quite different outcomes according to groups' capacity and the organizational culture that prevails before its implementation. In this sense, history matters and has a direct impact on knowledge diversity and firms' capabilities (Winter 2012). In the initial configuration considered above with full autonomy, a bonus was automatically given to each inventor participating in an individual or a collective invention with potential problems related to patent quality (scenario 1). At first glance, the introduction of competitive rewards and constrained autonomy considered in the second case succeeds in limiting the dispersion of knowledge creation to a small number of technologies, the core competencies of the firm (scenario 2). However, this result is obtained with crowding out effects for the rest of the groups endowed with other competencies. These crowding out effects actually reveal a tension between these groups and the firm's goals and create latent inter-group conflicts, impeding knowledge diversity and explorative capacity in the long run.

First, constrained autonomy induces an exogenous change in the traditional forms of interactions between groups favorable to the development of the requisite variety in skills for enabling creativity. In the presence of new interactions, cognitive distances may be insufficiently well digested to generate positive outcomes in terms of intrinsic motivation and to provide new combinations of knowledge (Pelled et al. 1999). If organizations want to encourage the development of new links among groups of inventors as a remedy to an increasing development of incremental innovations, the regeneration should be conceived in harmony with the existing networks and corporate culture (Audia and Goncalo 2007). In addition, group composition matters not only for sustaining motivation and creativity but also for maintaining some diversity of skills. In this context, groups composed of employees with distinct professional backgrounds will be more inventive because they will bring diverse perspectives to problem solving. Diverse skills and overlapping knowledge domains are more likely to engender groups that are creative compared to groups with similar professional backgrounds (West 2002). In this field, recruitment of new members in high tech firms may encourage communication and interactions for the development of new products (Ancona and Caldwell 1992; Frey et al. 2011). However, there is a trade-off between creating and maintaining sufficient diversity inside and between groups, "without threatening their shared view of their task and their ability to communicate and work effectively together" (West 2002: 364), since "there must be sufficient overlap of group members mental models for them to communicate effectively" (ibid). Indeed, the development of new interactions is critical for preserving explorative capacity, a process well documented by Audia and Goncalo (2007), but cognitive distance between inventors must not be too large to inhibit effective interplay among knowledge frames. In line with the trade-off discussed by Nooteboom (2000), it could be argued that knowledge should be sufficiently but not radically distant to facilitate its absorption by various groups of inventors. In the case of complex industries characterized by highly interdependent components and some degree of sequentiality among innovations such as in the case of Thales, this trade-off is particularly critical for the development of fruitful interactions among groups of inventors (Bessen and Maskin 2009).

Second, the emphasis on individual creativity, competition between groups of inventors and the climate of mistrust engendered accentuate the perception of a lack of "organizational safety " between groups. In scenario 2, the deteriorating "organizational climate" (Smith et al. 2005) and the strategy of introducing competition among inventors has deleterious impact on intrinsic work motivation of most of the groups endowed with non-core competencies (see Figs. 7 and 8).

Moreover, as noticed by O'Leary and Mortensen (2010), incentive systems have critical effects on the perception of "in-group" and "out-group" feelings inside the firm with the reinforcement of feelings of inequalities between groups that may nurture tensions and activate latent conflicts. In effect some groups in core competencies may perceive themselves as more influential and tend to exercise their own authority to the detriment of the others, generating "a spiraling effect in which all members behave competitively in an effort to protect their own interests" (O'Leary and Mortensen 2010: 121). In line with the argumentation developed by Lindenberg and Foss (2011) on joint production motivation, we may also insist on the necessity to calibrate properly motivation goals for avoiding "subgroup egoism" problems, such as those encountered by Thales.

In this perspective, the third scenario retained in the model defines the more pertinent configuration for successfully introducing some change in an incentive system in spite of persistent effects of the initial organizational culture. A competitive spirit has been introduced in harmony with the existing networks, preserving total autonomy between groups, notably their ability to create freely new combinations of knowledge. Indeed, this mixed configuration relies on a kind of "friendly competition [which] ... encourages comparison of outcomes but do not peg expected rewards [in our understanding intrinsic motivation] to that comparison" (Lindenberg and Foss 2011: 516). In the case of a corporate culture, characterized by a strong tradition of collective invention (such as in Thales with the traces of the prior Thomson entity), this latter configuration makes compatible the introduction of new organizational goals with intrinsic motives of core and non core groups, while preserving the scope of technological capabilities of the firm in the long run.

5 Conclusion

This contribution examines different ways of calibrating work motivation, focusing on their impact on knowledge diversity. The model considers three configurations where crowding out or crowding in effects are likely to occur, depending on the distribution of links and the structure of group interactions. The first scenario represents an idealistic view of the firm where each group is interacting with a high degree of autonomy and relatedness. Intrinsic and extrinsic sources of motivation are self-reinforced in all groups of the firm. The second scenario introduces restricted relatedness and autonomy with competition between groups. As expected, intrinsic motivation decreases in groups endowed with non core competencies producing crowding out effects in these groups. Despite a subsequent production of knowledge in groups endowed with core competencies, cohesion between groups is largely deteriorated with potential negative outcomes for knowledge diversity in the long run. Besides these two extreme configurations, a third scenario illustrates numerically a mixed system with competitive bonus and high autonomy. Knowledge diversity and intrinsic motivation are preserved, allowing groups to cooperate in core and non core competencies. Negative effects of competition between groups, notably subgroups egoism, are thus avoided, maintaining the technological capabilities of the firm in core and non core competencies.

Our findings show the way in which a new incentive system can conflict with intrinsic work motivation, notably because of the corporate imprinting. Instead of spurring work motivation, it may produce crowding out effects with a decline in motivations of some groups. Thus the incentives system should be in accordance with the preexisting culture to preserve knowledge diversity, emulating core competencies while benefiting potential creativity in non-core competencies. In firms characterized by a strong corporate culture, a mixed configuration, as suggested in scenario three, mitigates the negative effects of conflicts between groups, organizational goals and values of its employees. As exemplified by the case of Thales, where everything changed during the last decade, our contribution outlines the risks changing drastically incentive systems to spur motivation. Indeed, drastic changes and new organizational principles may not be fully absorbed, understood nor espoused by employees. Work motivation may suffer from these radical changes that damage the development of intra group safety as well as the integration of new skills, deteriorating links between inventors and their creativity.

Nevertheless, calibrating work motivation for inventors remains an uneasy task as social motives of inventors may not be fully acknowledged. When introducing new incentive systems, firms have to look back to their founding values and the organization story to find some compromises while preserving the scope of technological capabilities necessary for their survival. More generally, the long run effects of an incentive system should also be considered to avoid potential organizational inconsistencies. Indeed, firm governance may be prone to favor the exploitation of some existing core competencies by acknowledging the performances of the groups active in these fields and neglecting the others. Consequently, the explorative capacity of the firm may be undermined, whereas diversity of technological capabilities should be constantly maintained and rejuvenated for preparing future inventions. In this perspective, future research should question the interplay between individual motives and group cohesion, particularly in the context of new interactions and interdependent tasks characteristic of high tech industries.

Annex

Proof of Proposition 1 The dynamical system writes for $i = 1, ...n$:

$$\frac{dx_i(t)}{dt} = x_i(t)\left(w + tanh[x_i(t) + a_i] + \left(\frac{1}{n} - \delta\right)x_i(t)\right) \tag{9}$$

where $a_i = \sum_j l_{ij} r_{ij}$.

i) First, the connection topology implies that if $i \neq j$ are connected, then $r_{ij} > 0$. Consequently,$a_i = \sum_j l_{ij} r_{ij} > 0$. Thus, $tanh[x_i(t) + a_i] > 0$, which rules out for all i and all t crowding out effects.
ii) Second, for each $i = 1, ...n$, a strictly positive stationary solution x_i^* is a solution of $g(x_i) = 0$, where g is a continuous differentiable function in $x_i \in \mathbb{R}$ given by $g(x_i) = w + tanh[x_i + a_i] + \left(\frac{1}{n} - \delta\right)x_i$. Assume that $\delta > \frac{1}{n}$. We have $g(0) = w + tanh[a_i] > 0$ and $g(+\infty) = -\infty$. In addition, for non negative x_i and $a_i > 0$ we have $g''(x_i) = -2tanh[x_i + a_i]sech^2[x_i + a_i] < 0$. Thus, a unique strictly positive stationary value x_i^*, solution of $g(x_i) = 0$ exists for each i. In addition, since w is unique, the properties of $tanh$ imply that these solutions are almost similar for all i.
iii) Third, the only element of coupling in this system is given by the a_i, and is independent of the state variables. Thus, $g''(x_i^*) < 0$ for $i = 1, ...n$ gives a stability criterion of the stationary solution.

□

Proof of Lemma Let $\theta = \frac{Log[n/8]}{Log[n/2]}$ with $n > 8$. Then, $\forall i, \forall j \in \mathcal{K} = \{1, ..., n\}$, $r_{ij} = d_{ij}^{\theta} - \frac{d_{ij}^2}{2n} \geq 0$ for $d_{ij} \leq \frac{n}{2}$, (respectively < 0 for $d_{ij} > \frac{n}{2}$), where $d_{ij} = |i - j|$. Consequently, with a complete graph configuration, it exists in $\mathcal{K}$ an interval $\mathcal{C}$ centered on $i = \frac{n}{2}$, such that $a_i = \sum_j l_{ij} r_{ij} > 0$ for $i \in \mathcal{K}$ and $a_i \leq 0$ for $i \notin \mathcal{C}$.

Fig. 10 below shows this result for $9 \leq n \leq 100$. □

Proof of Proposition 2

1) Let us first suppose that $a_i > 0$ and $z_i \leq 0$. The dynamical system can be written as :

$$\frac{dx_i(t)}{dt} = x_i(t)(w + tanh[x_i(t) + a_i] - \delta x_i(t)) \tag{10}$$

where $a_i = \sum_j l_{ij} r_{ij}$.

i) First, we have $tanh[x_i(t) + a_i] > 0$ and therefore crowding in effects for theses i.

ii) Second, for these i, a strictly positive stationary solution x_i^* is a solution of $g(x_i) = 0$, where g is a continuous differentiable function in $x_i \in \mathbb{R}$ given by $g(x_i) = w + tanh[x_i + a_i] - \delta x_i$. We have $g(0) = w + tanh[a_i] > 0$ and $g(+\infty) = -\infty$. In addition, for non negative x_i with $a_i > 0$ we have $g''(x_i) = -2tanh[x_i + a_i]sech^2[x_i + a_i] < 0$. Thus, a unique strictly positive stationary value x_i^*, solution of $g(x_i) = 0$ exists for such i. In addition, since w is unique, the properties of $tanh$ imply that these solutions are almost similar for all i.

iii) Third, the coupling in this system is still given by the a_i, and is independent of the state variables. Thus, $g''(x_i^*) < 0$ these i gives a stability criterion of the solution.

2) Let us now suppose that $a_i > 0$ and $z_i > 0$. The dynamical system can be written as :

$$\frac{dx_i(t)}{dt} = x_i(t)\left(w + tanh[x_i(t) + a_i] - \left(\frac{b}{n} - \delta\right) x_i(t)\right) \tag{11}$$

By the same token, it can be shown that a stable stationary solution $x_i^* > 0$ exists for such i with $\frac{b}{n} < \delta$.

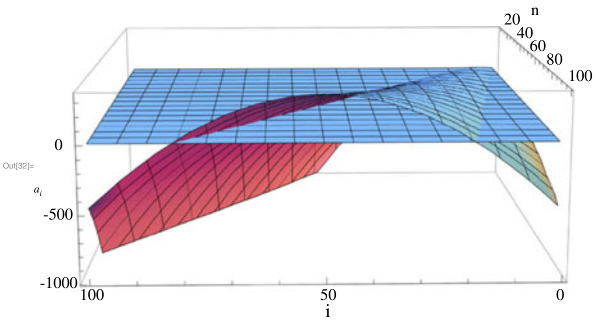

Fig. 10 a_i plotted for $9 \leq n \leq 100$. The x axis displays the i, the y axis n and the z axis the corresponding a_i

3) Let us now suppose that $a_i < 0$ and $z_i \leq 0$. The dynamical system can be written as :

$$\frac{dx_i(t)}{dt} = x_i(t)(w + tanh[x_i(t) + a_i] - \delta x_i(t)) \tag{12}$$

i) First, $tanh[x_i(t) + a_i] < 0$ since $|a_i| > x_i(t)$; therefore, crowding out effects obtain for theses i.

ii) Second, let $\widehat{w} = \min_i |tanh[a_i]|$. Then, with the assumption $w < \widehat{w}$, we have $w + tanh[x_i(t) + a_i] - \delta x_i(t) < 0$ for $x_i(t) > 0$. Consequently, the unique stationary solution is $x_i* = 0$.

iii) The stability criterion in 0 is verified, since $w + tanh[a_i] < 0$.

4) Finally, let suppose that $a_i < 0$ and $z_i > 0$. The dynamical system can be written as:

$$\frac{dx_i(t)}{dt} = x_i(t)\left(w + tanh[x_i(t) + a_i] - \left(\frac{b}{n} - \delta\right)x_i(t)\right) \tag{13}$$

It can be shown by the same token as in 3) above that a stable stationary solution $x_i^* = 0$ exists for such i, assuming in addition $\frac{b}{n} < \delta$. □

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