Managing Autonomy and Control in Economic Systems

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1 The Management of Economic Systems

The Problem. Management is the process in which specified persons in an economic system guide, direct and influence people's activities and processes, with the aim of efficiently reaching predefined goals. This general notion of "management" is applicable to both microeconomic (e.g. companies) and macroeconomic (e.g. a national economy) systems, although the modalities, under which goals are formulated and managers are selected, certainly differ. Companies may aim at developing new markets based on the company owner's or director's decision, whereas a national economy defines its goals by means of a political process – but both systems rely on organizational structures (e.g. an organizational chart or a legal system) and designated persons (e.g. a team leader or the head of the central bank) in order to influence human, financial, material, intellectual or intangible resources so that the specified goals can be achieved. The embodiment of this process of management is basically a *control task*.

In modern western societies, the design of this control task has to be balanced with a core value that is deeply interweaved with our concept of state and social organization: *autonomy*, the idea of self-government and a person's or an organization's ability to make independent choices. Looking back upon the history of economic reasoning [21] and management [34], wee see that in the western world the principles of autonomy have continuously increased their influence and changed the paradigms of control. Although the embodiment of autonomy and control on both the microeconomic and the macroeconomic level certainly is controversial in the fields of political philosophy [7], national economics [35] and management theory [34], we suggest to understand *management* as the problem of finding appropriate definitions and implementations of autonomy and control, on both the microeconomic and the macroeconomic scale.

A Historical Illustration – Autonomy in Management. We briefly sketch the increased importance of autonomy in the management of economic systems on the microeconomic scale. In western societies, the industrial revolution brought about the emergence of large-scale business with its need of professional managers. Although military, church and governmental organizations provided models of management, the specific economic focus of businesses led in the late 19th century to the development of so-called *scientific management*, that focussed on worker and machine relationships. The task was to economize time, human energy, and other productive resources. The most prominent management model of that time was formulated by Frederick Taylor [28] and Henri Fayol [10]. Their model applied a *strict control regime* upon procedures and methods on each job of the production chain, which led to a tremendous increase in productivity, up to a factor four in the examples provided by Taylor. This optimization of the "human motor" [22] by means of a strict control regime was for a long time the paradigmatic view towards management in the industrialized production society.

This early concept of management was later challenged. Not only the conflict of this model with basic notions of humanity – brilliantly exhibited by Charlie Chaplin's movie "Modern Times" (1936) – was the cause for this change. Also the need of a post-industrialized "knowledge society" to exploit the creative potential of its members in order to be able to faster adopt the production processes, was incompatible with such a strict control regime. Consequently, new behavioral [23], systemic [8] and context-related management approaches were developed – to name just a few. This diversification of the theory of management can be seen as the result of balancing autonomy versus control of individual units within economic systems.

Outline of this Contribution. We intend to demonstrate the interplay of autonomy and control on both the microeconomic and the macroeconomic level, by means of two case studies. We first define our notions of "autonomy", "control" and "economic system". On the microeconomic level, we interpret *reorganizations* as a tool for setting up new control regimes upon productive teams (business units) of large companies. We analyze the influence of a reorganization upon the information-flow network of a business unit, as this network basically underlies the productive power in knowledge-based companies. On the macroeconomic level, we feel that the ability to formulate and communicate a *sufficiently simple control optimality* is a core problem in order to formulate and enforce an economic policy within democratic societies. We investigate this problem merely from a modeling perspective, by demonstrating the effect of a simple control mechanism, the properties of which have recently been fully analyzed [26], in the context of a basic model of an economic system. For both levels of economics, we will demonstrate the superiority of simple control mechanisms that allow for a maximal autonomy within the boundaries set by the control.

2 Autonomy and Control

The Nature of Autonomy. The concept of "autonomy" in the sense of self-governance was originally formulated by the antique Greek city states, aspiring independence from the Persian empire. In the age of Enlightenment, however, autonomy was seen as the ability for self-governance in combination with the commitment of responsibility [14]. In this way, autonomy became a fundamental concept of moral philosophy. Contemporary philosophers differ in their notion of autonomy, depending on whether the individual person (personal autonomy [29]), morality (moral autonomy [24]) or political systems (social autonomy [7]) are the focus of discussion. Although this context-dependency led to a rich differentiation of the concept, it is undisputed that – in the western tradition – autonomy is a basic moral and political value, affecting how individuals interact, and the rights they are provided with. Thus, the discussion on the nature of autonomy is not a mere philosophical debate, but has a large impact on how society is organized. A prominent example is medicine where the bioethical "principle of autonomy" [2] reflects a fundamental change in the relation between doctors and patients, on both the social and the legal sides.

In an economic context, several aspects reflect the importance of this *paradigm of autonomy* (see Fig. 1): On the macroeconomic level, the idea of a "free market" – i.e. the organizational principle that supply and demand of economic goods should be unregulated except for the country's competition policy – may serve as the most prominent example. Implicitly, the concept of a free market assumes that the agents of a market (individuals, organized structures like companies etc.) know best of their needs and goals, and how to satisfy and achieve them. Free trade – a principle that addresses the interaction of national economies – is a second, prominent characteristic of this paradigm. The need of a regulatory framework that protects the practical implementation of these principles – e.g. by property rights – is a third, important characteristic. We are well aware of the fact that these embodiments of the autonomy paradigm are subject to intense discussions, which basically reflects that a control problem lurks behind (see the next paragraph). Nevertheless, we consider free market and free trade in combination with a regulatory framework protecting these types of interactions as the main specifications of autonomy on the macroeconomic scale.

On the microeconomic scale, the autonomy paradigm is basically reflected by personal autonomy. This includes "free will" (the power and ability of

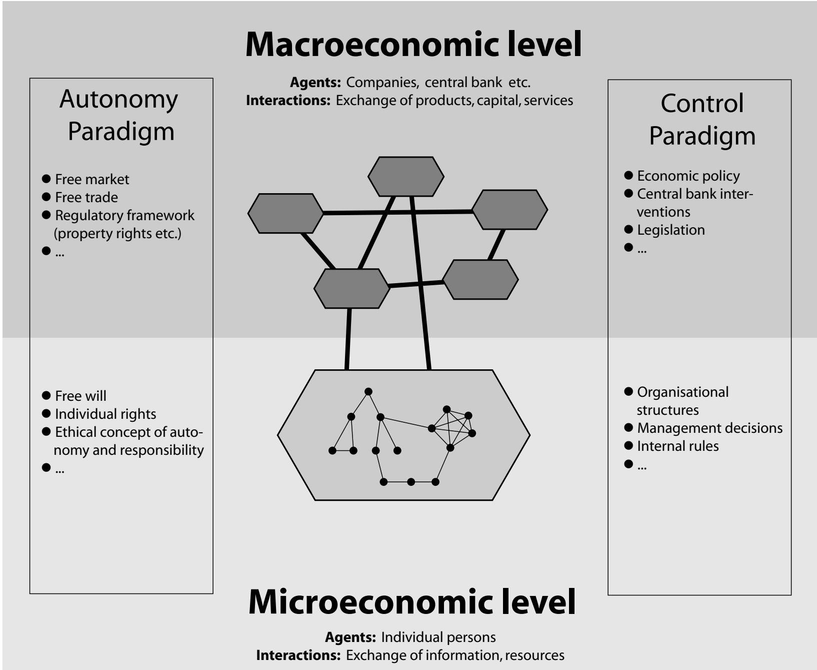

Fig. 1. Autonomy and control paradigms (not concluding lists) on both the microeconomic and the macroeconomic level of social organization

making free choices unconstrained by external agencies), the ethical concept of autonomy (the feature of the person by virtue of which he or she is morally obligated), and a set of basic personal rights (usually implemented on a constitutional level). We will not dwell into the various discussions that accompany these terms. We rather exhibit the basic ingredients that are used in economic systems to implement autonomy on the microeconomic scales (in particular by companies). This non-exhaustive list includes:

- *Interaction autonomy*: Employees are able to freely exchange information in order to solve business-related problems within the boundaries given by the organizational chart.
- *Profit-center organization*: Sub-units within a company may act autonomously in terms of client-relations, budgeting and accounting.
- *Global budgeting*: Central control is only enforced by strategic allocation of financial resources, whereas the allocation within the unit is led to local management.

New Public Management (NPM, [30]) is a prominent example of this new management philosophy. However, NPM is not unchallenged [25], where the deeper reasons for this are again related to the control problem. We thus stress that the requirement to control is the main aspect that shapes the implementation of autonomy in social systems.

The Nature of Control. We suggest to define control as the deliberate use of constraints in order to influence the dynamics of a system such that defined goals are reached. This working definition inspired by control theory [36] certainly has its pitfalls when applied to social system, but it nevertheless outlines major ingredients of the general concept of control. First, control is *deliberate*, i.e. based on some written or verbally manifested decision that includes the goal of the control, naming the system that has to be controlled and the means that are used or acceptable for control. Second, control affects the *dynamics* of a system, i.e. those system variables that have been chosen as relevant for measuring the fulfillment of the control goal. In a macroeconomic system, this could be the money supply controlled by the central bank, in a microeconomic system the output of a production unit. Third, control is implemented in the process characterizing the system dynamics by a *constraint* that requires a certain control effort, as, without the control, the "natural" dynamics would be different. However, we suggest a "liberal" understanding of constraint, which includes, for example, the choice of a certain training program in order to encourage certain goals. Fourth, in order to be able to implement a *goal-oriented* control, a certain degree of "predictive understanding" of the system is required. In economic systems, this requirement is notoriously hard to fulfill, which leads to undesired effects of control due to incomplete system knowledge. We will demonstrate that already in microeconomic systems, the understanding of the system dealt with might focus on wrong aspects leading to undesired control results. The dynamics of macroeconomic systems is even harder to predict. Therefore, we will concentrate our analysis on the application and consequences of control, applied to a model of a chaotic macroeconomics.

We will also not discuss the question of how to find a (good) control goal. In economic systems, however, it is convenient to relate this goal to an *efficient use* of relevant resources – time, capital or material – in relation to the product or service provided. At the macroeconomic level, the same basic parameters are the objects of discussion. Examples are the reduction of working hours, the foreign trade deficit problem or the efficient use of commodities due to ecological reasoning. The control tools appropriate on the two economic levels however, differ. The classic control tools on the macroeconomic level are legislations in order to guarantee certain minimal constraints for the system (e.g. minimum wages), short-term economic policies in order to address current problems (e.g. prize limiters) or monetary interventions of the central bank.

On the microeconomic level, control can be much more sophisticated, which actually powers a tremendous industry of management consultants. This discussion we will basically avoid; we only sketch the main aspects of embodied control. The first control tool of managers is to *constraint the interaction* of employees through a specified organization chart. This important aspect is the main focus of our first case study in the next section. The second control tool is the amount of allowed resources like capital, material, space, or time of collaborators (*input control*). The third tool is real-time control (*process control*) – either by detailed rule-sets (in the tradition of Taylor's scientific management) or by several means of supervision (which could be perverted into a kind of "big brother" control). Finally, control can be implemented by measuring specific results of the sub-unit (*output control*) and followed by a re-arrangement of processes, resources etc., within the unit. In practical life, control by management is usually implemented as a mixture of all four instances of control.

Microeconomic Systems – Business Units. Large companies perform *business processes* within specified organizational units – business units – in order to create products or services that are supplied to the market. The business processes are mapped to the units such that the organizational structure of the business unit optimizes production. The adaptation of the organizational structure of companies through reorganizations is a widely used control tool used by management. The measure to evaluate the effectiveness of a reorganization is efficiency in terms of the time needed to perform business processes [31]. Customarily, the *organizational structure* of the business unit is grasped by the organization chart, where several different forms can be distinguished (e.g. line organization or matrix organization [17]). The coaction of the steps associated with a business process is described by the *operational structure* – e.g. in the form of a flow chart. As a business unit usually performs more than one business process, it is the task of the manager to find a organizational structure that can be mapped in an optimal way to the different operational structures. Thus, we define a *reorganization* as the adaptation of the organizational structure to a new set of operational structures.

Reorganizations result in new constraints for the interaction of the employees of a business unit. In knowledge-based companies, these interactions basically consists of information transfer – text, e-mail, program-code etc. – that form the edges of a *social network* [33]. The structure of this network is crucially dependent of the interaction autonomy the employees have. The structure is also informal in the sense that the personality of the individuals involved lead to implicit optimizations of the operational structure that may not be recognized by members of the senior management. This makes reorganizations a challenging task, as they may influence the social network of business units in an unforeseen way [27]. For example, a person A could have important knowledge in order that person B can perform a specific step of a business process, leading to information exchange (i.e. an edge) between A and B. A reorganization could transfer B to another unit with a less satisfying work, such that B refuses to further collaborate informally with A (as it is "no more his or her business"). In our case study, we will demonstrate how this effect can be quantified in terms of "robustness" of the network and how it leads to unforeseen, negative results due to a wrong control approach.

Macroeconomic Systems – Economic Cycles. Economic booms and bouts affect modern societies strongly, with a direct impact on individuals biographies. In western economies, cycles have been an ubiquitous and undesired observation. Among the most remarkable,Kitchin cycles emerged [16]. These macroscopic variables are the target of control when the economic system is object of investigation. Until the 1970s, as the legacy of John Maynard Keynes [15], cycles were regarded as primarily due to variations in demand (company investments and household consumption). As a consequence, economic analysis focused on monetary and fiscal measures to offset demand shocks. During the 1970s, it became obvious that stabilization policies based on this theory failed. Shocks on the supply side, in the form of rising oil prices and declining productivity growth, emerged as equally crucial for the generation of cycles. In a paper published in 1982, Finn Kydland and Edward Prescott [18] offered new approaches to the control of macroeconomic developments. One of their conclusions was that the control should be kept constant throughout a cycle, in order to minimize negative effects.

Cycles and crises may be inherent to the principles on which our economics is based. However, if they could be predicted and their origin understood, they might be engineered to take a softer course. An extreme form of this control approach was taken in the centrally planned economies in the former socialist countries. This approach failed, as it was not able to aggregate sufficient and reliable information about supply capacities and demand needs, which is necessary for efficient control. Furthermore, in the western tradition, the strong and ubiquitous control approach of socialistic economies is not compatible with our basic notion of autonomy on the personal as well as on the social level. In order to deal with the control problem of macroeconomic systems in western democratic societies, it is necessary to be able to communicate a sufficiently simple optimality policy. For obtaining it, the understanding of the response to control in simple economical models may provide important guidelines. As the number of variables that govern a macroeconomic system is vast, one is confronted with a hard prediction problem. We suggest, that the prediction problem of macroeconomics is related to the one in chaotic processes, where strategies for overcoming it have been developed. Although the question of to what extent real economies are classified as chaotic can readily be disputed, low-dimensional chaotic models yield insight into the mechanisms that govern the response of economics to control policies.

3 Control in Toy Models

3.1 Microeconomic Level: Reorganization and Robustness

Definitions We use the social network paradigm in order to understand the effect of reorganizations. Thus, we describe a *business unit* as a network, where the nodes represent employees and the edges represent information transfer. The main concepts are defined as follows:

- *Business process* P: A sequence $\{p_1 \ldots p_n\}$ of n processing steps associated with a specific product.
- *Business unit* $B(k)$: A social network of k nodes associated with a class $\{P\}$ of business processes. The part of $B(k)$ that performs processing step p_i is called *process unit* B_{p_i}.
- *Process operating expense* $E_P = \sum_i e(p_i)$: The sum of the times $e(p_i)$, associated which each p_i, needed to perform P.
- *Process runtime* T_P: The total time from initiation to completion of P.
- *Robustness* $R(l)$: Defined as $R(l) = 1 - I_P(l)$, where $I_P(l)$ is the probability of process interruption in dependence of the relative fraction of node outage of a business unit B (l/k, where l is the number of nodes that turned out).

Note that we distinguish E_P and T_P, because employees can be absent (due to illness etc.), possibly leading to an interruption of P if no redundance is implemented in the network. T_P is an estimate of the efficiency of P. We have $T_P \geq E_P$, as a temporary outage of a B_{p_i} increases T_P.

Defining Robustness. Robustness refers to the ability of a network to avoid malfunctioning when a fraction of its constituents is damaged [4]. One differs between *static robustness*, the influence of deleting nodes without redistribution of information flow, and *dynamical robustness*, which takes the latter into account. In our case study, dynamic robustness basically reflects the degree of interaction autonomy the employees have. Thus, it is related to the informal networks that are formed in the business unit within the boundaries given by the organizational chart. Dynamical robustness is usually warranted only *within* a process unit B_{p_i} that is formed by a sub-set of employees of the business unit. We therefore calculate the robustness of our business unit as the static robustness of the network of process units. This probability is calculated using the hypergeometric distribution (see appendix).

Robustness alone does not account for the *relevance* of process interruption for process runtime. For example, longer downtime of a node may have cumulative effects on runtime. To model this effect in a simple way, we weight the probability of process interruption by a factor that accounts for the additional time that prolongs process runtime. By changing this weighting factor we can analyze the parameter space spanned by this factor and the relative fraction of node outage.

To demonstrate our approach, we investigate a reorganization in a toy example (Fig. 2). Here, the management intends to concentrate a business unit $B(k)$ on its core business, by reducing the number of business processes P from three to two and by releasing one employee in each B_{p_i}. We assume that $e(p_i)$ for a specific P is reduced from 3 to 2, as the number of p_i that have to be processed in parallel by each B_{p_i} decreased, which reduces friction losses. Thus E_P decreases from 9 to 6. However, when the decrease of robustness of the social network (Fig. 2.c) is taken into account, depending on the weight of process interruption, the reorganized $B(k)$ may be less efficient than before (Fig. 2.d). In the bright region of parameter space, the organizational structure

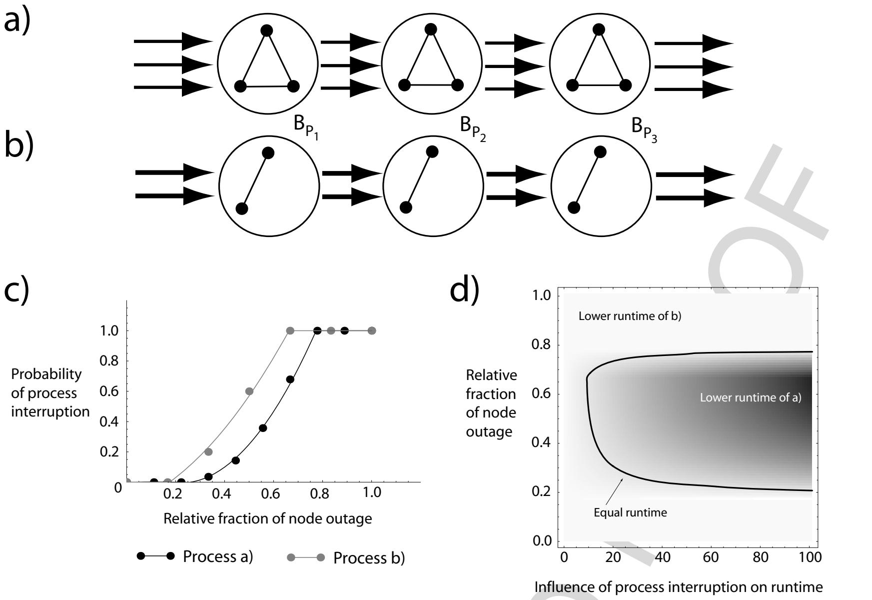

Fig. 2. **a**) Three business processes P incorporated in a business unit B consisting of three process units B_{P_i} of three employees each. **b**) B after reorganization: the number of business processes has been reduced from three to two and in each B_{P_i} an employee has been released. **c**) Robustness before and after reorganization for a single P. The increase of interruption probability (= decrease of R) is approximated by quadratic fit-functions. **d**) Process runtime in dependence of the weight of process interruption and the relative fraction of node outage (the darker region identifies the parameter space where P in the organizational structure of a) is processed faster compared to the structure of b)

b) is more efficient in performing a business process P, whereas in the darker region, the structure a) is superior to b).

3.2 Macroeconomic Level: Controlling the Dynamics

Logistic Economy. When exponential growth is possible, real economies have little problem. But when the limits of the economic systems are reached, their prediction becomes difficult. From the mathematical point of view, this is due to the nonlinearities that are required to keep the system within the boundaries. Economies naturally tend towards the recruitment of all available resources – which can be interpreted as a unrestricted exhaustion of the autonomy paradigm. This drives the macroeconomy towards the boundaries and fosters a natural tendency of the system to evolve towards maximally developed nonlinearities. We can describe economics in a simplified and abstract way in terms of a parameter indicating the degree of globalization of resources (nonlinearity parameter a), a dynamical parameter x expressing a generalized consumption, and a noise parameter r modeling short-term fluctuations, which are often of local or external origin. Thus, the evolution of this simple model of economics takes place on three timescales: a slow one which modifies parameter a, an intermediate term variable x that is assumed to be deterministic, and momentary perturbations that are included in x in the form of noise. The underlying deterministic system is defined by the property that for states far from full exploitation of the resources, the consumption can grow almost linearly. Close to maximal exploitation, the next consumption is required to be small, to let the system recover. Over a large parameter range of small a (local economics), this behavior, however, is avoided and a state of quasi-constant consumption emerges. A most simple and generic setting for modeling this dynamics is provided by the iterated logistic map (see Fig. 3), whose mathematical properties are explained in the appendix.

A simple illustration of this type of economics is whaling in the Northern Atlantic Ocean. If the whaling fleet is small (captured by $a \ll 1$), the annual catch x_n will be small and affect the whale population little, so x_n will stay at a quasi-fixed point. An increase of a will raise the average catch $\bar{x}$. Larger ships will start venturing to the whole of the Atlantic Ocean. At

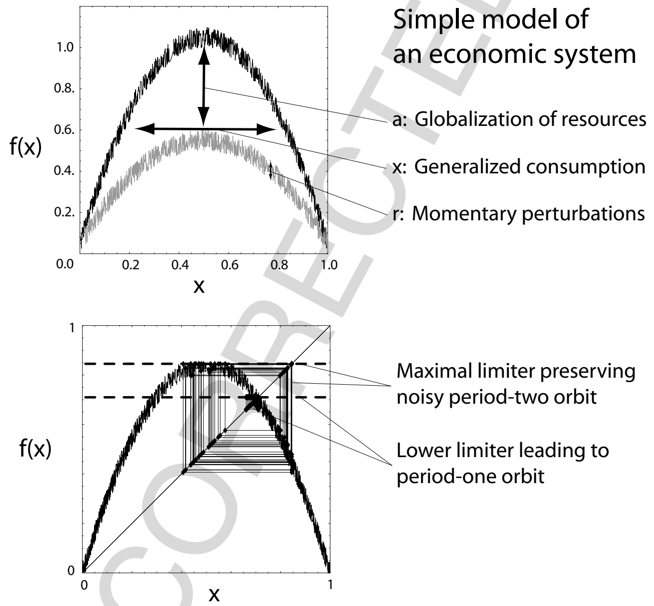

Fig. 3. a) Illustrating the three parameters of a logistic economy (for mathematical details please consult the appendix). **b**) Hard limiter control for the noisy logistic map. Placement of the limiter around the maximum of the map preserves the natural noisy period-two orbit (*black*). For lower placement, a modified period-one behavior is obtained (*grey*)

the point when we start to exploit a considerable part of the whole system ($a \to 4$), the fixed-point behavior naturally ceases to hold. After a situation of almost complete exploitation ($x_n \approx a/4$), the system needs an extended time to recover. Novel technologies may annihilate the constraints that originally defined the confinement to the unit interval. The universality underlying the above-discussed route to ever more complex dynamical behavior, however, implies that under the new constraints, the whole process will repeat, leading to a cascade of such processes.

Controlling Chaos. The logistic map is a generic example of a chaotical system. From a dynamical system's point-of-view, chaos is composed of an infinite number of unstable periodic orbits of diverging periodicities. In order to exploit this reservoir of characteristic system behavior, methods to stabilize (or control) such orbits using only small control signals have been developed and applied mostly in electronic system. These practical applications often require that the orbits are quickly targeted and stabilized. For the classical Ott-Grebogi-Yorke [20] and for feedback control, this is a problem. Recently, Corron and coworkers [9] introduced a new control approach (termed control by simple limiters) and suggested that it could overcome the limitations of the previous methods. The general procedure can be summarized as follows: An external load is added to the system, which limits the phase space that can be explored. As a result, orbits with points in the forbidden area are eliminated. The authors also observed that modified systems tend to replace previously chaotic with periodic behavior. The mathematical properties of this type of chaos control has recently been fully described (see appendix for more details).

A variety of economic models are based on the logistic approach, as it generically implements the dynamic effects of shortage of goods – thus catching the core problem of economy [3]. Therefore, our approach intends to analyze the effect of simple limiter control upon such models. In economic terms, simple limiter control is realized for example by prize limiters (minimum or maximum price levels). Such an economic policy is indeed simple and must not necessarily contradict the paradigm of autonomy. Benefits and pitfalls of this type of control are discussed in the next section.

4 Empirical and Modeling Results

4.1 Inefficiency of Hierarchic Business Information Networks

Characteristics of the Microeconomic Case Study. We investigated the IT division of a Swiss telecommunication company that develops products for telecommunication and insurance companies [5]. The division had 1400 employees before, and 1250 employees after reorganization. We focused on an business unit within this division that performed four classes of P: project management, application development, operations and maintenance of IT services. Before reorganization, $B(k)$ (23 employees) was organized as profit center and acted autonomously on the marked in terms of client relations, budgeting and accounting (mean turnover: 16.5 Mio. CHF, profit: 2 Mio. CHF). This large degree of autonomy of the unit led to a small-world social network [32] with a low characteristic path length $L = 2.05$ and a high clustering coefficient $C = 0.92$. The business unit contained three hierarchical levels and two persons supporting the unit managers in administrative needs (Fig. 4.a).

In 2002/2003, the whole division was subject of a reorganization. The reorganization intended to separate the different P more clearly and to map them on more precisely defined B_{p_i} in order to increase efficiency in terms of E and T_P. Furthermore, the reorganization aimed to increase the control on the beforehand autonomously acting business units, as competition between the units within the division sometimes led to the situation, that external customers obtained different tenders for the same product and could choose for the best solution within the division. Thus, after the reorganization, the information flow within the business unit was much stronger restricted, leading to a hierarchical network characterized by a characteristic path length that was more than doubled ($L = 4.72$) and a strongly reduced clustering coefficient ($C = 0.07$) (Fig. 4.b). Furthermore, more unit managers and additional

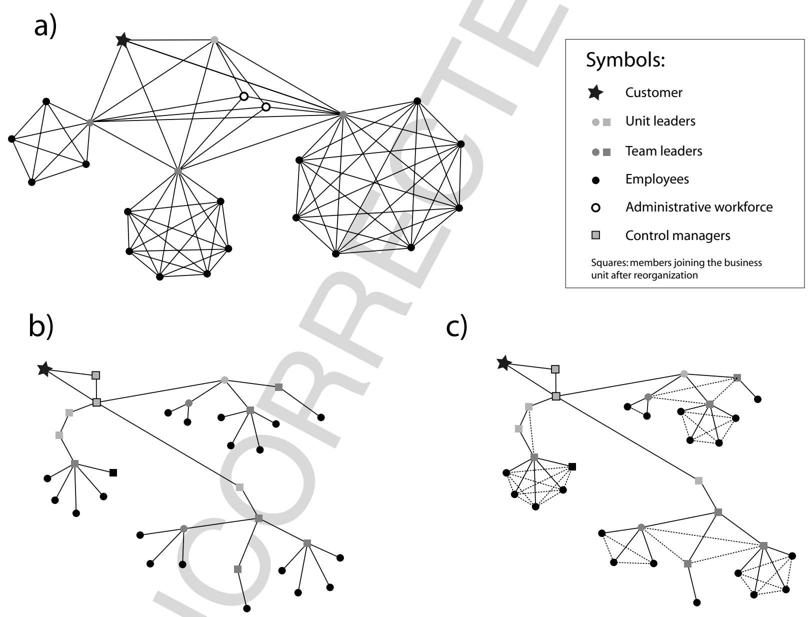

Fig. 4. Information flow network of a business unit before **(a)** and after **(b/c)** reorganization. Quadratic nodes in b) and c) indicate new members joining the business unit after reorganization. Dashed lines in c) indicate informal information transfer emerging within the teams

control managers taking care of customer relation were included, such that the business unit contained 34 employees after reorganization (the administrators have been released). After some time, informal information transfer emerged within the teams, leading to an increase of the clustering coefficient ($C = 0.73$), but not strongly affecting the characteristic path length ($L = 4.33$) (Fig. 4.c).

Day-to-day experiences of the employees of $B(k)$ aroused the suspicion that T_P increased significantly after reorganization. This phenomenon was investigated for several classes of P performed by the unit by determining E and T_P empirically [5]. Although both parameters could not be measured precisely due to comparability issues, valuable estimations could be gained. In the following, we focus on project management processes, where the most trusted results have been obtained.

Explaining Inefficiency as a Result of Decreased Robustness. Project management processes are performed within the business unit according to general procedures. In the IT company we investigated, the procedure emerged out of the so-called Hermes-method – a standard procedure that has been implemented in the late 1970s in the large public enterprizes of Switzerland [13]. This widely distributed standard has been used by the business unit before and after reorganization, so that basic comparability is given. One task of the unit was to develop tender offers for large IT projects. Whereas realization and implementation of such projects largely depend on their individual character, the tender phase was much more uniform, allowing to compare process operating expense and process runtime before and after reorganization (the details of the measurement process are outlined in Ref. [5]).

We find that, in the mean, E_P slightly decreased after reorganization, whereas T_P considerably increased (Table 1) – confirming the general impression of the employees. This observation becomes explicable when determining the change in robustness of the social network (Fig. 5). Before reorganization, basically two B_{p_i} with in total 11 employees were involved in the process. After reorganization, the project management process was separated into a system engineering branch and an application development branch, where five B_{p_i} with in total 16 employees were involved. As Fig. 5 demonstrates, the project management process after reorganization is much less robust compared to the process before reorganization. Interestingly, even the larger number of employees involved in the process after reorganization (16 instead of 11) does

Table 1. Mean process operating expense E and process runtime T_P before and after reorganization for the project management process

	E_P	T_P
Before reorganization	88 hours	19 days
After reorganization	86 hours	35 days

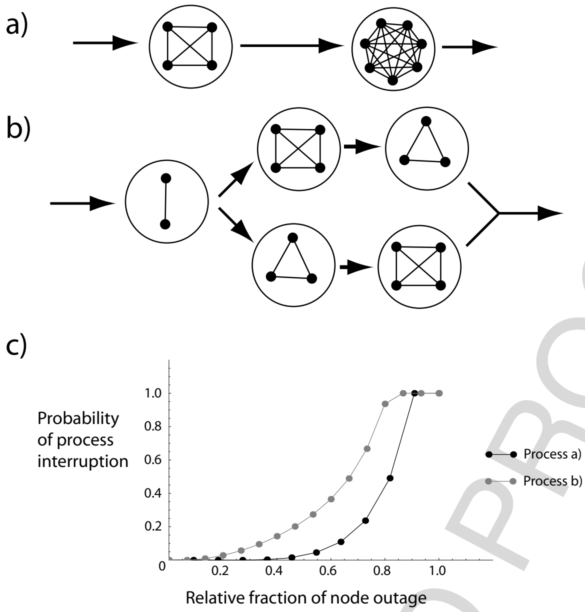

Fig. 5. Project management process before (**a**) and after (**b**) reorganization of the business unit performing a project management process. (**c**) Decreased robustness of the network after reorganization (*grey*) that elucidates the empirically measured decrease in process runtime

not increase the robustness – independent whether the relative fraction of node outage or the absolut number of turned out nodes is taken as reference.

4.2 Efficiency of Hard Limiter Control

Effects of Simple Control. We investigate the effect of controlling the simple model of economics introduced in the previous section by placing a limiting value on x that the system is not allowed to cross (hard limiter control). In Fig. 6, three time series generated from this model are displayed. For the first series, the system was tuned so as to generate a noisy, superstable period-four orbit. For the second series, a limiter at the highest cycle point was inserted, whereas in the third series the control was on the unstable period-one orbit. It is easily seen that the period-one orbit yields the highest average value. In an analysis that is mathematically more involved, it can also been shown that implementing the limiter at maximal system response is generally a suboptimal solution [6]. We found that the system average is generally optimized by controlling a period-one cycle. In the presence of a substantial amount of noise, only low-order cycles can be controlled.

The *efficiency* of this control approach emerges in two aspects: First, hard limiter control yield higher averages of the generalized consumption x. Second,

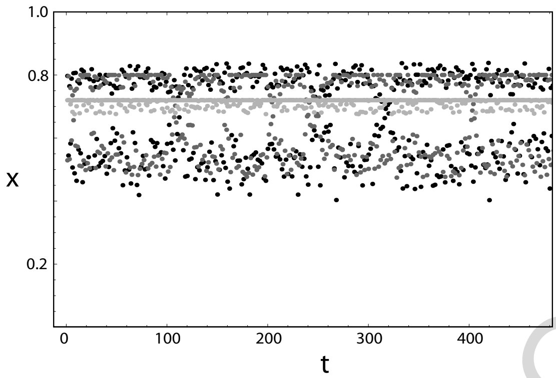

Fig. 6. Time series of a superstable period-four orbit: uncontrolled (*black*), controlled in the maximal cycle point (*dark grey*), and controlled in the unstable period-one orbit (*light grey*). The period-one orbit yields the highest average of x (t: number of iterations)

by means of the applied control, the system predictability increases (i.e. control leads from chaotic to periodic, or from higher periodic to lower periodic orbits). Both aspects are interrelated, as the "simplest" system dynamics (period-one cycle) also yields the highest average. Latter, however, must not necessarily be of positive value from a point of view of political economics. Hea and Westerhoff applied this type of limiter control to a model of commodity market, basically reproducing our result [12]. Both the implementation of a bottom price level (to support producers) or a top price level (to protect consumers) can reduce market price volatility – thus increases the predictability of the system. But as the variable x represents prices in their context, a maximum price limit increases the average price, which can be considered as a unwanted side-effect.

5 Summary and Outlook

We characterized management as the task to balance the autonomy of the constituents of an economic system and the control of the dynamics of the system in order to reach predefined goals. Our case studies provide inside of benefits and pitfalls of this understanding of management on both the microeconomic and the macroeconomic level. The first case study can be characterized as the analysis of a *failure* of management through implementing a new control structure in a business unit by means of a reorganization. We have shown that robustness, determined in terms of how business processes are affected by an outage of nodes in the information flow network, can be a critical parameter that tends to counteract the intended gain in efficiency by reorganizations. The example demonstrates that reorganizations focussing on efficiency by optimizing the division of labor and by increasing the control has the effect that the information flow network looses the small-world property. This property result from the interaction autonomy of the employees within the business unit, which obviously had a beneficial effect on the efficiency of how the processes within the unit have been performed, although the system looked rather complex from an external point of view. In our real-world example, these negative effects have been recognized by the senior management and the reorganization has basically been retracted.

But how should this control problem be solved? One possibility would have been to change the perspective towards the result of internal competition within the division, i.e. by benefitting the successful profit centers and by focusing on those units that were less productive. Alternatively, the concept of a "hard limiter", suggested by the macroeconomic case study, could have been implemented – for example by defining that tender offers are not allowed to surpass a certain minimal amount. This would indeed be a simple control policy, not touching interaction autonomy within the units.

In macroeconomies, the autonomy paradigm leads to a tremendous complexity in number and types of interactions between the agents. Although it has been found that for either very underdeveloped or mature economies, stable fixed-point behavior is predominant [1], at an intermediate level, complex economics emerges that can induce chaotic dynamics – e.g. leading to large fluctuations of entrepreneurs wealth W_n [19]. There, a control task for economic policy could emerge. Our model suggests, that hard limiter control in the form a tax on assets with a sufficiently fast progression could be applied, forcing W_n to remain below a maximal value, $W_{\max}$. With sufficient care, control on a period-one system could be achieved, and excessive economic variations due to chaotic dynamics could be prevented. Political realizability will often require the use of "softer" limiters (in the sense that $W_n > W_{\max}$ is not strictly prohibited), but the main features of hard limiter control will be valid even in these cases.

We emphasize that control mechanisms of limiter type are indeed common in economics. This control, however, inherently generates superstable system behavior, whether the underlying behavior be periodic or chaotic. Political activism may suggest a frequent change of the position of the limiter to be a suitable strategy in order to compensate for the amplified or newly created cyclic behavior. This strategy, however, will only result in ever more erratic system behavior. Our analysis shows that it is advantageous to keep the limiter fixed, adjusting it only over timescales where the system parameter a changes noticeably. In this way, reliable cycles of small periodicity should emerge. Among these cycles, the period-one cycle appears to be the optimal one, from most economic points of view. To recruit this state, a strong initial intervention is necessary and the control should be permanent. Otherwise, a strong relaxation onto the suboptimal natural behavior sets in. In discussions of real economics, these effects will be natural arguments against the proposed control. To overcome such arguments, a sufficiently simple control policy must be formulated in democratic societies.

Unfortunately, the "control trend" in most western societies goes into a different direction, as an increasing body of legislation in combination with a decreasing ability to enforce these rules is observed [25] – a control strategy that we consider as being the contrary of hard limiter control. In this way, a regulatory system interfering in a hardly predictable way on many levels of social organization emerges, that affects beneficiary effects of the autonomy paradigm. Our empirical investigations of a microeconomical problem as well as the theoretical analysis of a macroeconomical model suggest, that a control regime in order to manage the behavior of economic systems should be simple but enforceable. Or course, the central problem of how to find the appropriate goals of management is not addressed by this argument. But as soon as those are defined, simple control mechanisms that allow maximal autonomy within the control's boundaries should be implemented.

Appendix

Calculating the Robustness of Networks

We define the robustness of a business unit as the static robustness of the network of process units. We consider each process unit (r members) in a business unit (k members) separately. We have to calculate the probability that from a number l of nodes that fail in the network those x nodes fail that interrupt the process by means of the hypergeometric distribution. As $x = r$ in our case (i.e. the complete process unit has to fail), the effect of a single B_{p_i} on the probability of process interruption caused by an outage of l nodes is calculated as

$$I_{B_{p_i}}(l) = \frac{\binom{r}{x}\binom{k-r}{l-x}}{\binom{k}{l}} \overset{x=r}{=} \frac{\binom{k-r}{l-r}}{\binom{k}{l}} \tag{1}$$

$I_{B_{p_i}}(l)$ is calculated for all l up to a value where at least one B_{p_i} fails definitely (i.e. the probability of process interruption is one – this depends on the network topology) and for all B_{p_i}. Basically, $I_P(l) = \sum_n I_{B_{p_i}}(l)$ applies – but one has to take into account that specific constellations of node-outage may possibly be counted twice (this, again, depends on the network topology). These cases have to be identified and incorporated when calculating $I_P(l)$. In this way one obtains – for each given $l = 1 \ldots n$ – the probability of process interruption $I_P(l)$ and thus the robustness $R(l)$. Due to the dependence of R on the network topology, no general analytic formula for $R(l)$ can be provided.

Mathematics of Hard Limiter Control

Our economic model contains a parameter indicating the degree of globalization of resources (nonlinearity parameter a), a dynamical parameter x expressing a generalized consumption, and a noise parameter r modeling short-term fluctuations. Whereas in the case of small a such perturbations are stabilized by the system itself, for larger a they lead to ever more long-lived erratic excursions. To incorporate these fluctuations within our model, we perturb x with multiplicative noise, for simplicity chosen uniformly distributed over a finite interval. The size of the noise sampling interval denoted by $\bar{r}$, is a measure for the amount of noise. The most simple and generic setting for modeling this dynamics is provided by the iterated logistic map.

$$f : [0, 1] \to [0, 1] : \quad x_{n+1} = ax_n(1 - x_n) + r \tag{2}$$

The self-organization towards an ever-growing exploitation of the phase space [0, 1] is reflected in a slow increase of the order parameter a towards $a = 4$. At $a = 4$, it can easily be seen how the nonlinearity keeps the "orbits" x_n away from the boundary: starting with small values, x_n increases almost linearly (with factor a). As soon as x_n approaches the upper phase-space boundary (at $x_n = a/4 = 1$), this is counterbalanced by the factor $1 - x_n$. If a is increased further, large-scale erratic behavior sets in, as the process is no longer confined to the previously invariant unit interval. After a potentially chaotic transient, the system settles into a new area of stability, where the same scenario takes place anew, starting at rescaled small a. We believe that in particular the effects of technical shocks may be adequately described in this framework. On its way towards the globalization of resources ($a \to 4$), the system undergoes a continued period-doubling bifurcation route, where a stable period-one solution is transformed, over a cascade of stable orbits of increasing orders 2^n (where $n = 2, 3, 4 \ldots$), into a chaotic solution (the Feigenbaum period-doubling cascade [11]). Our model is characteristic for the whole class of systems that are subject to such a process of self-organization.

By introducing a limiter, orbits that sojourn in the forbidden area are eliminated. Modified in this way, the system tends to replace previously chaotic with periodic behavior. By gradually restricting the phase space, it is possible to transfer initially chaotic into ever simpler periodic motion. When the modified system is tuned in such a way that the control mechanism is only marginally effective, the controlled orbit runs in the close neighborhood of an orbit of the uncontrolled system. This control approach was successfully applied in different experimental settings. The properties of the control method are fully described by the one-parameter one-dimensional flat-top map family, implying that orbits are stabilized in exponential time, independent of the periodicity and without the need for targeting. Fine-tuning of the control is limited by superexponential scaling in the control space, where orbits of the uncontrolled system are obtained for a set of zero Lebesgue measure. In higher dimensions, simple limiter control is a highly efficient control method, provided that the proper limiter form and placement are chosen [26].

In applications, the time required to arrive in a close neighborhood of the target orbit is an important characteristic of the control method. With the classical methods, unstable periodic orbits can only be controlled when the system is already in the vicinity of the target orbit. Hard limiter control renders targeting algorithms obsolete, as the control-time problem is equivalent to a strange repeller-escape (control is achieved as soon as the orbit lands on the flat top). As a consequence, the convergence onto the selected orbit is exponential. These properties of 1D hard limiter control systems fully describe the effects generated by the limiter control. Due to the control, only periodic behavior is possible.

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