

INTERDISCIPLINARY DESCRIPTION OF COMPLEX SYSTEMS

Scientific Journal

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EDITORIAL

Welcome to the seventh volume of the *Interdisciplinary Description of Complex Systems*, and its first issue consisting of three regular articles.

The articles are similar, among other possible similarities, in that in all of them a formalism from theoretical physics is utilised in describing and understanding of complex phenomena in other fields. The articles', probably most manifest, difference is that each of them considers a different field.

In particular, S. Guala considers influence of taxes in wealth distribution, as a socioeconomic category. In order to analyse different possibilities of influence of taxes he projects the idealised economic system onto physical system of particles mutually interacting in a classically prescribed way. He utilises further the fact that solutions of the physical model are known, and interprets them within the context of the initial system.

Author S.A. Amelkin considers information transfer among individual agents using elements of theory of irreversible processes. He marvellously formalised information exchange process by dividing it into several well-defined and intuitively understandable categories.

Finally, D. Pećnjak asks whether free will, as defined from the libertarian point of view, is possible if chaos theory and quantum mechanics are taken explicitly into account. He argues about the existence of somewhat evolved interpretation of the free will, on the one hand linked to the existing notion free will and on the other hand aligned with the essences of quantum mechanics and chaos theory.

2 July 2009

Josip Stepanić

TAXES IN A WEALTH DISTRIBUTION MODEL BY INELASTICALLY SCATTERING OF PARTICLES

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Regular paper

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ABSTRACT

In this work we use an inelastic scattering process of particles to propose a model able to reproduce the salient features of the wealth distribution in an economy by including taxes to each trading process and redistributing that collected among the population according to a given criterion. Additionally, we show that different optimal levels of taxes may exist depending on the redistribution criterion.

KEY WORDS

wealth distribution, inelastic collisions

CLASSIFICATION

JEL: H21, H23, H30

PACS: 51.10+y, 51.30.+i

INTRODUCTION

More than a century ago Pareto [1] proposed a law of distribution of individual wealth in a society. It states that the tail of the wealth distribution follows a power-law $P(w) \sim w^{-(1+\nu)}$. Here, $P(w)$ is the amount of people possessing wealth w . The exponent ν is the Pareto exponent and generally takes values between 1 and 3 [2, 4, 5]. It is also known that for low and medium income, $P(w)$ decays exponentially or in a log-normal way [2–4]. Since the same behaviour was found for income distribution in a society [6, 7], in the following and for the sake of concreteness, we will refer to “wealth”, but “income” should be equally applicable.

As a consequence of the analysis of wealth and income distributions in different societies from available real data [6], it is well-known now that the distribution of the richest 5 % of the population has a power-law tail [2, 4, 5], while the majority (around 95 %) low-income distribution fits well to Gibbs or log-normal form [8]. There has been several attempts to model a simple economy [9–23], which involve a wealth exchange process that produces a distribution of wealth similar to that observed in real economies. Most of works are particularly interested in microscopic models of markets where the economic activity is considered as a scattering process. The models centred on savings in the trading process received special attention [6–8], which reproduce features of real wealth distributions. This type of models is analogously thought as either elastically or inelastically scattering particles. Inelastic scattering of particles was studied in the context of granular materials [24–26] by the inelastic variant of the Maxwell model [27–30].

The conclusion of these studies is that a self-similar solution of the kinetic equations exist, which is not stationary in time at individual level, but the system converges to time-independent parameters. The model introduced here studies how inelastic binary collisions may be assumed as the application of taxes. Its redistribution can reproduce the salient features of empirical distributions of wealth without regard to, in principle, any another consideration. Based on the aforementioned saving models and from the majority log-normal distribution point of view, we propose a simple granular closed-system model in which the collisions are inelastic and the loss of energy is eventually redistributed among the particles of the system according to certain state” criterion.

A parallel aim of this work is to evaluate the response of the simple model when the scope of feasible rules is extended to include taxes, specially related to income distribution, according to realistic observations.

THE MODEL

Imagine a closed economic system with total amount of money (wealth) W and total number N of agents, both constant. It is, neither production nor death/birth of agents occurs. The only economic activity is confined to trading. Agent i possess a wealth $w_i(t)$ at time t . Time changes after each trading. Any trading involves two steps: first, two randomly chosen agents i and j exchange their money in “inelastic” way such that a fraction of their exchanged wealth is lost by taxes (Figure 1):

$$\begin{aligned} w_i(t + \frac{1}{2}) &= (1 - f)b_{ij}[w_i(t) + w_j(t)], \\ w_j(t + \frac{1}{2}) &= (1 - f)(1 - b_{ij})[w_i(t) + w_j(t)], \\ w_i(t + \frac{1}{2}) + w_j(t + \frac{1}{2}) &= (1 - f)[w_i(t) + w_j(t)], \\ w_k(t + \frac{1}{2}) &= w_k(t), \quad \forall k \neq i, j. \end{aligned}$$

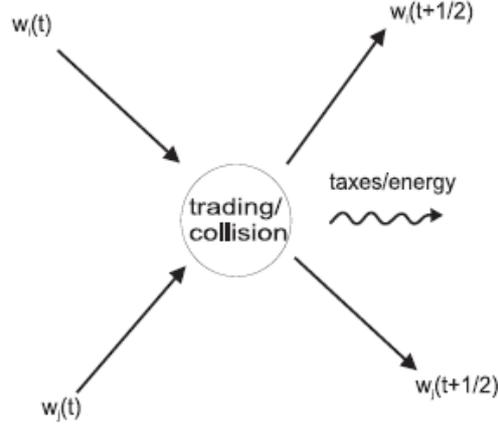


Figure 1. Schematic picture of the first step of the scattering process. Agents i and j exchange their wealth in the economy and for their exchanges pay taxes, which are redistributed among the population.

with $w_i(t)$, $w_j(t)$, $w_k(t) \geq 0$ for all i, j, k and t ; f is the fraction of trading lost by taxes and b_{ij} is a random fraction ($0 \leq b_{ij} \leq 1$). Secondly, taxes are redistributed among individuals according to a certain rule (i.e., equally distributed among the population, distributed among the poorest fraction, etc.):

$$w_r(t+1) = w_r(t + \frac{1}{2}) + \begin{cases} \frac{f}{|S|} [w_i(t) + w_j(t)], & \forall r \in S, \\ 0, & \text{otherwise.} \end{cases}$$

for S being the subset of population benefited by the redistribution policy; conserving the total wealth:

$$W = \sum_i^N w_i(t).$$

From now on, we will use $P(w)$ normalized as a probability distribution function of wealth w . As we can see here, at $f = 0$ the steady-state wealth distribution of the economy becomes a Gibbs' one as reported in [31], with modal value $w_m = 0$. For $S = N$ and $f \neq 0$ (i.e., when all the agents are equally benefited by the redistribution), the equilibrium distribution becomes asymmetric unimodal with w_m of $P(w)$ shifting away from $w_m = 0$, reaching a maximum w_m and moving back to $w_m = 0$ as $f \rightarrow 1$, as shown in Figure 2.a. In this organization of the economy induced by taxes with a global egalitarian perspective is very significant the way in which the fraction of paupers decreases until certain level of taxes and most people end up close to the average wealth in the economy. In this sense, slopes of the log-normal cumulative probability $Q(w)$, defined as

$$Q(w) = \int_w^\infty P(\hat{w}) d\hat{w},$$

for the after-mode part $P(w)$ in Figure 2.b decrease as taxes increase, attaining a minimum and then increasing with taxes tending to behave as to $f = 0$. The modal value of wealth distribution seems to behave on a contrary way, according to Figure 2.a. Both figures may suggest an optimal level of taxes, in which the distribution is relatively more egalitarian. Figures 3a and 3b show modal wealth w_m of $P(w)$ and slopes of log-normal $Q(w)$ as a function of f , respectively.

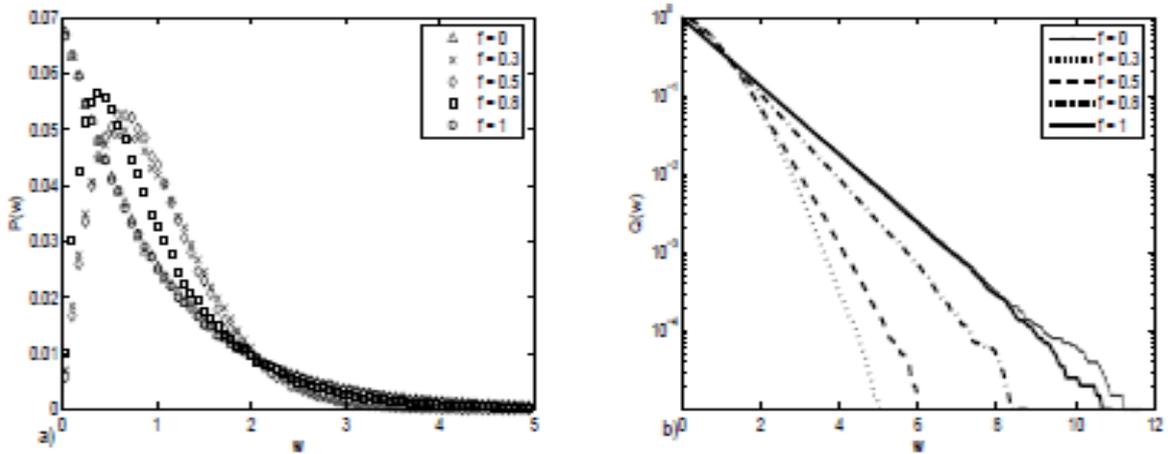


Figure 2. a) Wealth distribution $P(w)$ and b) cumulative probability $Q(w)$ for different taxes f ; $N = 1000$ and average wealth $W/N = 1$.

Besides, we consider the case in which the money collected by taxes is selectively redistributed. Figures 3c and 3d show the modal values w_m of $P(w)$ and $P(w)$, respectively, when that money is uniformly redistributed among the subset S conformed by the 20 % poorest of the population. Note from Figure 3c that $w_m \geq 1$ for $f \geq 0,3$. This fact suggests that a huge majority belong to the richest portion of the population and a few individuals belong to the poorest one, shown in Figure 3d. As a consequence, the wealth of the multitudinarius richest portion is slightly greater than the average wealth $W/N = 1$, getting closer to a socialist distribution.

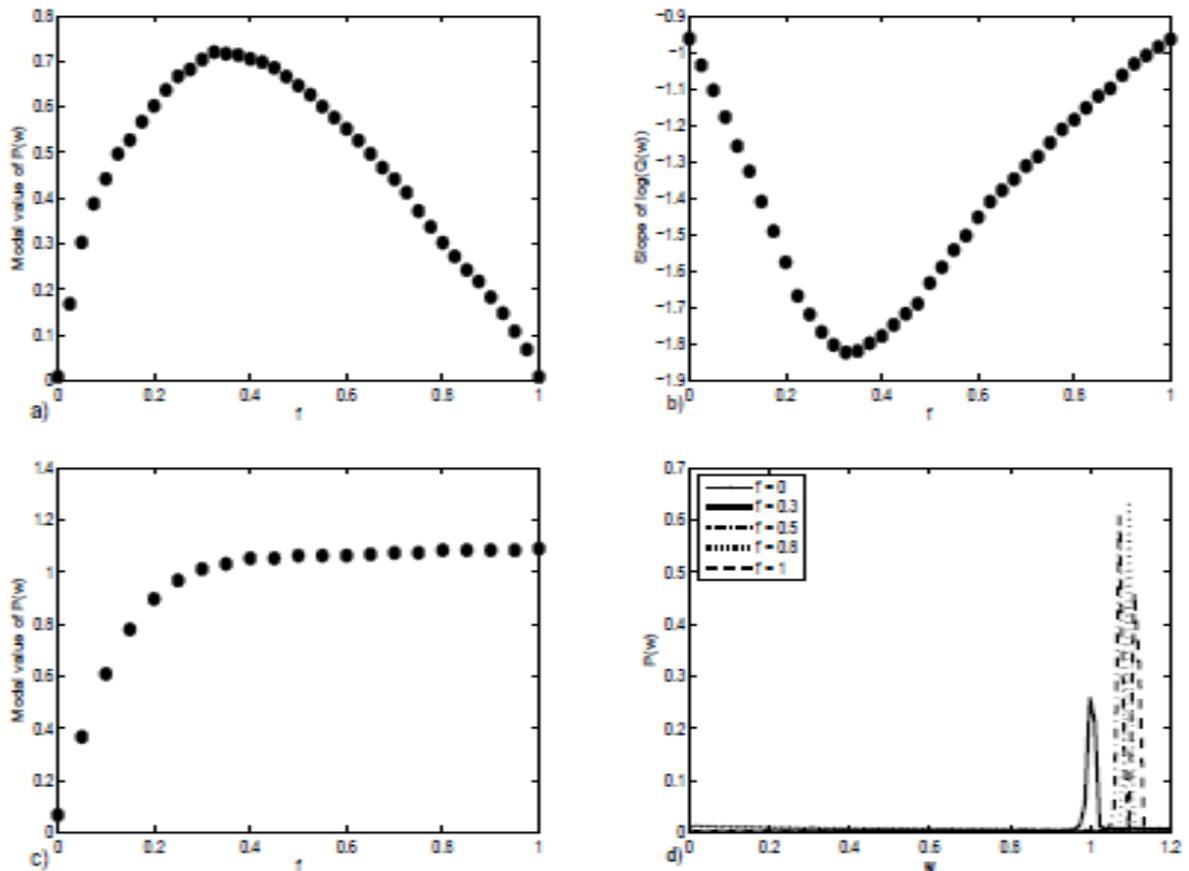


Figure 3. a) Modal values of wealth distribution $P(w)$ and b) slopes of log-normal curves of $Q(w)$ as a function of f . c) Modal values of wealth distribution $P(w)$ when taxes are redistributed among the 20 % poorest of the population and d) $P(w)$ as a function of f ; $N = 1000$, and average wealth $W/N = 1$.

CONCLUSIONS

We proposed a new rule for the simple binary trading model in the search of adding further complexities, which might appear in real economies. Besides, by this work we evaluated the robustness of that model for allowing other potentially-realistic rules, holding the same qualitative behaviour. In this case, a granular model was analyzed in which inelastic binary collisions were considered in a closed system where the after-collision lost energy is captured by the molecules in it with the aim of emulating taxes paid in each trade operation and then redistributed by the corresponding State. Observations have been made about the wealth distribution obtained fitted as a log-normal one. The optimum level of taxes $f \approx 0,325$ shows a more egalitarian economy for a model with non-selective redistribution. In the case where the redistribution is focused on the poorest individuals we observed a significant majority with wealth around the average one.

Further research in this sense should be centred in an analytical treatment of the model and in more complex instances which include simultaneously taxes into the well-known models of saving propensity, binary trading according to the possibilities of the poorest agent of both, evasion propensity according to level of taxes, etc., in order to get models from a comprising conception.

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POREZI U MODELU RASPODJELE BOGATSTVA TEMELJENOM NA NEELASTIČNOM RASPRŠENJU ČESTICA

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SAŽETAK

U ovom radu koristimo procese neelastičnog raspršenja čestica za postavljanje modela koji može reproducirati temeljna svojstva raspodjele bogatstva u ekonomiji. Pritom je svaki proces trgovine praćen porezima koji se naknadno raspodjeljuju unutar populacije prema zadanom kriteriju. Dodatno, pokazujemo kako mogu postojati različite optimalne razine poreza u ovisnosti o kriteriju raspodjele.

KLJUČNE RIJEČI

raspodjela bogatstva, neelastični sudari

FINITE-TIME APPROACH TO MICROECONOMIC AND INFORMATION EXCHANGE PROCESSES

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Regular paper

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ABSTRACT

Finite-time approach allows one to optimize regimes of processes in macrosystems when duration of the processes is restricted. Driving force of the processes is difference of intensive variables: temperatures in thermodynamics, values in economics, etc. In microeconomic systems two counterflow fluxes appear due to the only driving force. They are goods and money fluxes. Another possible case is two fluxes with the same direction. The processes of information exchange can be described by this formalism.

KEY WORDS

finite-time processes, information exchange, microeconomics

CLASSIFICATION

JEL: D03, D83

INTRODUCTION

Problems on extreme performance of resources exchange processes at finite time have been investigated intensively during last half of a century. Thermodynamic systems have been investigated carefully. That is especially valid for thermomechanic systems, namely heat engines, refrigerators and heat pumps. A lot of papers are published on economic approaches of these problems [1]. Analogies between economic and thermodynamic systems were discussed in papers of K. Martínás [2–4] who formulated a new optimisation approach to description of resources exchange processes. That theory enables us to consider the aforementioned problems from a point of view of a general theory of finite-time processes of resources exchange [5]. In this paper there are no discussions about analogies and differences between economic and thermodynamic systems. Based on the characteristics of finite-time economic systems we introduce another kind of resource exchange systems, namely systems of information exchange.

RESOURCES EXCHANGE IN ECONOMIC SYSTEMS

Let us consider a process of resources' sale in an economic system. That system consists of at least two economic agents, and at least two type of resources. One resource plays a role of money, thus it is called "money". Other resources are "goods". Fluxes of money and goods during the process of sale are opposite in direction.

Driving force of the process is the difference of the good's value made by the economic agents. Let us show that the only driving force induces both fluxes: the good and money ones.

In thermodynamics there are cases when the same driving force can influence several flows. If the system is near equilibrium state then intensities of flows correspond to Onsager relations $J_i = \sum_j a_{ij} \cdot x_j$, where J_i is the i -th flow, x_j is the j -th driving force, a_{ij} are Onsager coefficients, $a_{ij} = a_{ji}$.

So, existence of temperature gradient can induce both the heat and the mass flows. Similarly, difference of chemical potentials $\Delta\mu$ ($\Delta\mu/T$ is a driving force for mass exchange process) induces heat exchange between subsystems.

Therefore, difference in values of resources induces two opposite flows, one of the good and the other of the money. Assume that these flows are interconnected by Onsager relations. It means that there exists another driving force of goods and money movement in the economic system.

Because the driving forces are derivatives of wealth functions [4] then the only possible variation for another driving force is difference of economic temperatures (derivatives of wealth function with respect to money). So, we have two possibilities:

1. to postulate that difference of economic temperatures leads to economic exchange (not only money flow).
2. to postulate that only one driving force in economic system causes two opposite flows, namely good and money flows.

The second postulate is more natural because if we have n resources then difference of economic temperatures implicates simultaneous flows of all resources, which is not observed. Therefore, during the economic exchange agents tend to a state with equal values of the resource costs. The only exception is the cost of money, as there is no real economic driving force for the elimination of the difference of economic temperatures (liquidity) [4] except some "imaginary states".

SYSTEMS OF INFORMATION EXCHANGE

The existence of two flows induced by a single driving force allows us to propose further that there exists systems in which a single driving force induces a vector of flows. Intensities of components of such a vector are proportional. In economics that vector consists of two flows. Their directions are mutually opposite. In this section we consider another system in which the dimension of the vector of flows is again two, but the flows have the same direction.

That system is a system of information exchange. Let us consider a system consisting of two agents. One of them gives information flow to another.

There are three kinds of information [7]:

- (i) semantic information (knowledge),
- (ii) syntactic information,
- (iii) pragmatic information.

Let us explain these using the following example.

EXAMPLE I.

Let me introduce you the agent A. She wants to obtain an answer to a question “Is it worth to read a book R?”. She uses a computer recommendation system to get an answer [8]. She needs only one bit of information, either “yes” or “no”.

This information is a bit of knowledge which is necessary for A. To obtain that one bit she uses internet and in reality obtains 1 Mbyte of information, including the interface of the recommendation system, elements of computer design and other very convenient tools, which are however not necessary for A. So, 1 Mbyte is total (syntactic) information obtained by A. For using the recommendation A (possibly) needs to pay, so A is in economic relation and increases her wealth. That increment corresponds to a value of pragmatic information. Information as a capital including human capital is a set of knowledge and, furthermore, the “know-how” has been a subject of investigation elsewhere [9, 10]. Here we consider knowledge not as a capital, but as a good. In this sense we introduce a wealth of the agent A due to her knowledge. Dependence of that wealth on A’s knowledge is denoted as $S(I)$. Note that S depends solely on a semantic information I , because syntactic information is a common good.

This example allows us to introduce various types of information as characteristics of an agent. To formalise description of information exchange systems, let us utilise one more example.

EXAMPLE II.

Let us consider a closed system consisting of two agents A and B. A is a professor who reads a lecture to a student B. During the lecture, A transfers to B flows of both the syntactic and the semantic information with intensities g and q , respectively. A stock of information of A can be divided into the following parts [11]:

- (i) Both agents know it (I_0);
- (ii) A wants to teach B (I_1);
- (iii) A does not want to tell it to anybody because it is know-how (I_2);
- (iv) A wants to know it and tries to find that information (J).

It is evident that

$$\left. \frac{\partial S}{\partial I} \right|_{I \in I_0} = 0, \quad \left. \frac{\partial S}{\partial I} \right|_{I \in I_1} < 0, \quad \left. \frac{\partial S}{\partial I} \right|_{I \in I_2} > 0, \quad \left. \frac{\partial S}{\partial I} \right|_{I \in J} < 0. \quad (1)$$

Note that if A gives B one bit of knowledge, then that bit is transferred from set I_1 to set I_0 . Let us introduce value of knowledge $v = \partial S / \partial I$. Intensity of syntactic information g then depends on values of both agents. In the simplest case this intensity can be written in a linear form

$$g = -\alpha(v_B + v_A). \quad (2)$$

In our example the flow of syntactic information depends on interest of the student (value of knowledge in set J of agent B) and on qualifications of the professor (negative value of knowledge in set I_1 of agent A).

To introduce the intensity of syntactic information flow we need to find intensity of the corresponding flow of semantic information. However, prior to that we need balance equations. There is no conservation law in processes of information exchange, neither for semantic nor for syntactic information. Really, if A gives B a bit of information then the stock of A's information does not change. In any process of information exchange the total amount of information in the system will increase. But during such a process the intensity of semantic information flow decreases: B can obtain a quantity of knowledge during A's lecture, and this quantity is not larger (unfortunately, sometimes it is much smaller, even if B obtains all syntactic information from the lecture) than a quantity of information given by A.

Let us introduce redundancy of information as ratio of syntactic and semantic flows' intensities. Then, according to [12, 13], intensity of obtaining the knowledge depends on the existing level of knowledge I_0 and on the redundancy of information C_A ,

$$C_B = C_B(I_0, C_A). \quad (3)$$

If a time period for information exchange τ is not finite then for $C_A \rightarrow \infty$ agent B obtains all knowledge given by A, without losses. But the intensity of knowledge flow in that case is infinitesimal, thus we can call it a reversible process of knowledge exchange. At finite time these losses,

$$\Delta = g(v_A, v_B) \left[\frac{1}{C_A} - \frac{1}{C_B(I_0, C_A)} \right], \quad (4)$$

can be significant.

Value of Δ characterises irreversibility during information exchange. So, this value is analogy to energy dissipation in thermodynamics and to capital dissipation in economics [1]. Due to these analogies it can be called a dissipation of knowledge.

Now we have prerequisites to formalise problems of extreme performance of information exchange process. These problems are:

PROBLEM I.

The problem of maximum amount of transferred knowledge subject to a given quantity of syntactic information

$$\int_0^\tau \frac{g(v_A, v_B)}{C_B(I_0, C_A)} dt \rightarrow \max_{v_A, C_A}, \quad (5)$$

subject to

$$\int_0^{\tau} g(v_A, v_B) dt = G_0, \quad \dot{I}_0 = \frac{g(v_A, v_B)}{C_B(I_0, C_A)}, \quad I_0^0 = I_0^b. \quad (6)$$

PROBLEM II.

The problem on minimum of average knowledge dissipation subject to given average intensity of semantic information flow

$$\int_0^{\tau} g(v_A, v_B) \left[\frac{1}{C_A} - \frac{1}{C_B(I_0, C_A)} \right] dt \rightarrow \min_{v_A, C_A}, \quad (7)$$

subject to

$$\int_0^{\tau} g(v_A, v_B) dt = G_0, \quad \dot{I}_0 = \frac{g(v_A, v_B)}{C_B(I_0, C_A)}, \quad I_0(0) = I_0^b, \quad I_0(\tau) = I_0^e. \quad (8)$$

Efficiency of information exchange in this formalisation will be

$$\frac{q_B}{q_A} = 1 - \frac{\Delta}{q_A},$$

i.e. its value is determined by the value of knowledge dissipation.

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MIKROEKONOMSKI PROCESI I PROCESI IZMJENE INFORMACIJA U PRISTUPU KONAČNIH VREMENA

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SAŽETAK

Pristup konačnih vremena omogućava optimiranje režima procesa ograničenog trajanja u makrosustavima. Pokretačka sila tih procesa je razlika intenzivnih varijabli: temperature u termodinamici, vrijednosti u ekonomiji itd. U mikroekonomiji se javljaju dva suprotna toka uzrokovana samo jednom pokretačkom silom. To su tokovi robe i novca. Druga mogućnost je dva toka istog smjera. Procesi izmjene informacija mogu biti opisani tim formalizmom.

KLJUČNE RIJEČI

procesi u konačnom vremenu, izmjena informacija, mikroekonomija

COMPLEX FREEDOM*

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ABSTRACT

We have a very strong intuition and a very strong feeling that we, as human beings, generally have freedom of the will and freedom of the action. It seems that in most situations we can do this or that; namely, we can do action A or we can refrain from doing action A under the same conditions. The view which argues that this is not an illusion and that we have genuine freedom is the libertarian view. I would like to examine could that view be plausible under scientific understanding of the world. It seems that physical sciences strongly support determinism. Chaos theory and indeterminism in quantum mechanics could not save freedom because chaos is a deterministic theory and indeterminate events in quantum mechanics happen by pure chance. Pure chance is not something we want as freedom. But, perhaps, we can have freedom reconciled (although maybe in a restricted form) if actions or decisions can be described by equations which allow more than one solution and if these solutions can be interpreted as referring to different contents of the will or to different actions.

KEY WORDS

free will, determinism, libertarianism, chaos theory, complexity

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INTRODUCTION

In this article, I would like to examine some points in the philosophical debate of free will and what points from complexity or chaos theory can be, perhaps, interesting for the debate. I will simplify things a bit, but I certainly try not to make an oversimplification!

FREEDOM AND LIBERTARIANISM

We have a very strong intuition and a very strong feeling that we, as human beings, generally have freedom of the will and freedom of the action. It seems that in most situations we can do this or that; namely, we can do action A or we can refrain from doing action A. It seems that it is the case that it is so even in situations in which there is no reason to refrain from doing A – for example in escaping from fire – still it seems that “ontological” situation is thus that nothing inside or outside us (as agents) is such that would not allow us to refrain from doing A in that circumstances. Of course, there may be, and there are, situations in which some agents are completely determined what they will do next or what will happen. There may be cases of complete determination even if our world is such that it contains real freedom for the will and action – for example, full psychological determination (psychopathological cases or acting under alcohol or drugs, etc.) or environmental situation in which there is no possibility to “exercise freedom” because we instinctively do what we do or environmental situation in which “physical forces” are so overwhelming that agent’s will and agent’s acting is without significance and without impact (even on agent himself).

But leaving these possible situations aside, I would like to speculate about some prerequisites that must be present for us to have freedom of the will and freedom of the action in most ordinary circumstances if all these can be scientifically described. I do not endorse compatibilism, namely the view that freedom and determinism are compatible. Moreover, I think that compatibilism is untenable. (But thorough arguing for untenability of compatibilism is not the subject of present article and is not needed for present purposes.) Only viable way for genuine freedom is the libertarian view (for an excellent overview of libertarianism and its variants see Clarke [3]). Those who endorse libertarianism are incompatibilists regarding freedom and determinism – freedom cannot be reconciled with determinism. Libertarians argue exactly for what is said at the beginning: not only that we have strong intuition and feeling of freedom – because that can be an illusion – but that real “metaphysical” situation is that, in most cases, under exactly the same circumstances we can do action A or we can do action not-A (refrain from doing action A). We can use the language of possible worlds and say that if in this actual world a certain agent X does A at time t, then there is a possible world with the same laws of nature and overall history up to time t as actual world, but in which, at t, agent X does not-A (refrains from doing A). (To make things shorter at this very point, I consider deliberating, agent’s deciding and agent’s willing as types of action as well, see for example Pink [12]) How could that be possible, especially under the scientific description of nature and agents, which seems hostile to libertarianism? It seems that modern science, especially physical sciences, strongly supports determinism and deterministic view. The cases of (genuine) indeterminism are seemingly rare and tied to some special situations; and there is widespread doubt that examples of indeterminism (in physical sciences, as it will be clear a bit later taking an example) are also not of help for libertarian construction of freedom.

INCOMPATIBILITY OF FREE WILL AND DETERMINISM

First of all, let me sketch the essence of an argument for incompatibility of free will and determinism (see for example, van Inwagen [13, 14], Lamb [9]).

Universe is governed by the laws of nature. They are as they are and we cannot change them – no one has the power to make laws of nature different from what they are. Likewise, no one has the power over the past. It is not possible that someone acts now in a way that would make the past different from what in fact it was. No one has the power to act that something which is a fact of the past would not have been a fact about past [5; p.9]. The doctrine of determinism says the following: for any state or event X in the universe there is a set of previous states and events that, together with the laws of nature, inevitably entail state or event X . This kind of argument is called “The Consequence Argument” as well. It is standardly interpreted causally: Laws of nature and the set of previous states and events causally necessitate X . First clear explication of such a thought had been given by Laplace. So, by Laplaceian determinism today we simply mean that when we choose certain state of the universe at any instant of time together with the laws of nature, what happened before and what will happen after that instant of time is uniquely determined. Now it follows, according to these explications, that if freedom requires the possibility to do otherwise (than what is done in fact), namely the possibility of doing A and refraining from doing A , it is incompatible with determinism.

But, to repeat the question already posed – how could that be, because it seems that modern science strongly, if not completely, supports determinism. The cases of indeterminism are seemingly rare and tied to some special situations. But certainly even some of these indeterminisms could not be of much help for a libertarian.

DETERMINISM AND INDETERMINISM

There may be some doubts whether Laplaceian determinism firmly holds across (the whole) of modern physics and it is still unresolved matter according to Earman [4]. He analyses some very interesting examples from physics – both classical and quantum – and shows where there are cases which involve indeterminism; he also tries to show how some of them, perhaps, could be reinterpreted in a deterministic outset, though then other problems arise for those reinterpretations. These cases of indeterminism are special cases though maybe they could provide some framework how to think about how to help a libertarian view.

Of course, at the level of quantum mechanics, there are some cases of chance events which are really just pure chance (for example, the decay of a neutron in a free state). But that would not much help a libertarian: because at the level of decision making, at the level of will and the level of action and behaviour, pure chance or randomness in this sense is also something over which an agent does not have a control and influence just like an agent does not have a control and influence over the laws of nature and past states of the universe in the deterministic outset. Also, we do not frequently observe purely random behaviour. When we do, then in most cases it is the behaviour of a mentally ill person. So, randomness in action would not be a mark of freedom, but it is a mark of mental illness.

The classical general relativistic physics [4; pp.34-40] also admits indeterminism in an interpretation. In a nutshell, regarding the initial value problem for source-free Einstein gravitational field equations, Earman [4; pp.35-36] says that “specifying the metric field and its normal derivative on some space-like slice Σ does not suffice to determine ... the values of the field at points of four-dimensional manifold to the future or the past of Σ . Indeed, specifying Lorentz signature metric on Σ and the entire causal past of Σ does not suffice to

determine Lorentz signature metric at points to the future.” It means that we can have completely the same past of the metric field and the same causality in it, but that, from some point, the future is not the same in an evolution of the manifold.

For another example, not tied to Earman, here I shall mention the work of the so-called Bruxelles-Austin group led by Prigogine on far-from-equilibrium systems. They look at the complex systems as a whole and take a new approach to describe them. Fundamental to their description and explanation is distribution. So, the structure of the distribution of complexes of particles from which a system is build is something elementary important and not the classical description and explanation of single particle with its trajectory, momentum and direction. As, for example, says Robert Bishop [1; p.121] – these kind of theories and explanations which are concerned primarily on distribution functions open possibilities for genuine indeterminacy, namely, that macroscopic far-from equilibrium systems are irreducibly indeterministic. If so, that would mean that some indeterminism is inherent in complex macroscopic systems.

CHAOS IS OF NO HELP FOR LIBERTARIAN CONSTRUCTION OF FREEDOM

I think that it is pretty much obvious that chaos theory could not help libertarians in explaining their notion of freedom. Chaos theory is in fact a deterministic theory [6, 10, 16] and could nicely fit into Laplaceian vision of determinism. However, there are several very interesting properties of ingredients of chaos theory. Among others, the theory incorporates many non-linear equations and there is so-called sensitive dependence. A system is sensitively dependent on initial conditions if very slight, indeed, very tiny, difference in initial conditions leads to great differences in later development. “In fact, in some dynamical systems it is normal for two almost identical states to be followed, after a sufficient time lapse, by two states bearing no more resemblance than two states chosen at random from long sequence” writes Lorenz [10; p.8]. So, a system of non-linear equations can produce huge differences between initially almost identical dynamical systems (for a particular example, see Wolf [17]). This means that the principle which says that from similar conditions and similar causes we should arrive to similar effects is no longer universally valid. The other property which follows is that chaotic dynamical systems are very complicated systems: though some of them can be governed even by simple equations, their appearance is very complicated. Because of that complicated appearance, they may even look random. But they are not random: they just look random and they are just very complex and complicated.

One thing that must not mislead us is that at the practical level, there could be many cases of poor predictability or predictability could be completely impossible. This is due only to sensitive dependence in chaotic or complex systems. It is not a mark of freedom. When investigating and measuring real systems, we are bounded how precise we can measure important values. So if we can, for example, be precise in measurement to fifth decimal, but two similar systems show sensitive dependence only to the sixth or further decimal, we would be in no position to predict what will happen to those systems and how much would they differ, perhaps even after just a few steps. But this situation arises only due to our limitations or the limitations of our instruments. It is not that, in reality, the systems in question are not completely deterministic systems.

So, for genuine freedom, it seems that we must steer between randomness and complete determination. Let’s see what could be done.

FREEDOM AND NON-SOLVABLE EQUATIONS

In an article with the title “Free Will Remains a Mystery”, van Inwagen [15] argues, among other things, precisely for that – free will is a mystery! Namely, he is an incompatibilist regarding free will and determinism, but also he thinks that free will is something that exists and that we have it. In his words: “But if free will is incompatible with determinism, we are faced with a mystery, for free will undeniably exists, and it also seems to be incompatible with indeterminism” [15; p.158]. Robert Kane [7; p.12] comments: “Van Inwagen believes that no one to date has been able to give an intelligible account of incompatibilist freedom; and he has doubts about the possibility of doing so. Yet because he also thinks the Consequence Argument is undeniably sound, he argues that we must continue to believe in an undetermined will even if we do not know how to give an intelligible account of it.” If such a mysterian view is right, namely that we cannot explain how we have (if we have) free will, how can that view be reflected upon, regarding scientific view of the world?

First of all, maybe we have fundamental freedom of will and of action and indeed it is not explicable in any theory that can be available to human beings. We, with our cognitive capabilities are, to borrow the phrase from Colin McGinn [11] used in another context, “cognitively closed” for such an explanation. Simply, as chameleon is cognitively closed for a physical theory of colours and light that we, humans, have, perhaps we cannot come to formulate and understand what lies in the foundations of free will and free action and to explain them. On the other hand, perhaps we shall be able to formulate a very precise and complex(ity) theory of our deliberating and acting on the results of that deliberating. Such a theory, if it will be a mathematically formulated physical theory, will perhaps contain all, some or at least one of the equations which will be in such a form that they have no solution. Let me cite Edward Lorenz [10; p.13], though from other context, in support of this speculation: “Very often, when the flow is defined by a set of differential equations, we lack suitable means for solving them – some differential equations are intrinsically unsolvable. In this event, even though the difference equations of the associated mapping must exist as relationships we cannot find out what they look like. For some real-world systems we even lack the knowledge needed to formulate the differential equations; can we honestly expect to write any equations that realistically describe surging waves, with all their bubbles and spray, being driven by a gusty wind against a rocky shore?”

We can interpret this in two ways: in an epistemic sense and in a metaphysical sense. Epistemic interpretation would suggest that we are limited in the possibility of knowing how something happens – but that what happens happens in a (complex) determined way. So that is not a rescue for a libertarian account of freedom and free will. The other interpretation, a metaphysical one, seems to be more promising. This would suggest that there is not a determinate process inherent in reality that would be computationally solvable. The lack of suitable means of solving the equations may perhaps mean that there is no inherent process in reality which happens in a completely determined way (but not perhaps completely randomly).

FREEDOM AND RATIONALITY

I would like to say something about the connection of rationality and freedom as well. Here, I would not go into assessing what people actually do and how they actually behave – we know, of course, that people are too much irrational in practical everyday life – but I would like to examine what rationality would require how to choose and how to behave.

Rationality also can be an obstacle for freedom. However complex may be our intertwining of our preferences and however complex we must think about them, for most situations in

which we can find ourselves, there is one and only one solution which is the best solution for that situation. Rationality would dictate that we take the solution which is the best and take a course of action which it prescribes. There may be situations in which more than one action would be equally rational for us to take, so it would not matter which one of that equal actions is undertaken (from the viewpoint of rationality). But, in most cases, there is only one solution available as the best solution. So, according to rationality, there would not be genuine choosing – only one course of action is possible as the most rational and, if we want to maximize our rationality and be completely rational beings there will be no freedom for us. But, of course, anyone who would like to argue for libertarianism, would not like to lose rationality. Libertarian would like to have a situation that we (can) act rationally, but that we do so freely. So, rationality (or maximization of rationality) somehow has to be reconciled with freedom. I have no offhand solution for this problem (but Thomas Pink [12; pp.44-54] offers a plausible solution) but I would like to say the following: Perhaps we should distinguish abstract theory of rationality on one side and how that rationality is realized in human beings as, for example, a complex interaction of components of a system of beliefs, desires, preferences and representations of the situations in which subject finds himself. This system is mentally and physically realized as dispositions and/or states and processes in the brain. The physical description (if something as that would be ever available) should be then in some form which does not yield a unique solution which would be a definite determination of the undertaking of the most rational action of the agent. That description should allow for different possible outcomes in this situation. In other words, the physical situation of the agent should be so that it allows for different actions and not only the most rational. So, we shall perhaps have descriptions and explanations at two levels: at more abstract level – the rational (intentional) level there would be only one solution which would be the most rational for the agent and at the more basic level – let's provisionally say physical level – we shall have a situation of the realization of that rationality as part of a complete (physical) situation of the agent which does not uniquely determine and causally necessitate undertaking the most rational even though an agent does the most rational action.

CONCLUSION

So, bearing in mind what is said above, where should freedom be between determinism and chance? I'll try to sketch just a general frame and I admit that there are many ifs in my conclusion!

First, perhaps, we should narrow the scope of possible actions under the same set of circumstances. It would mean that not everything is possible to will and to do under the same set of (antecedent) circumstances. But it would also mean that not only one inevitable action is possible but a certain range of them. So, both at the level of rational (intentional) explanation and “physical” explanation we should have descriptions which do not (causally) necessitate. Rational reasons provide what is best or most rational for an agent to do but they do not causally necessitate that agent would inevitably do what it prescribes; and rational explanation in virtue of these reasons does explain why agent does according to it if agent really takes that course of action which is prescribed by what is most rational to do. But it does not explain agent's actions as inevitable and completely determined by previous states and laws of nature. So, perhaps “physical” situation of an agent should also be such that it does not necessitate the outcome what agent will do.

There are equations or systems of (differential) equations which have multiple solutions (more than one solution). If we could interpret these different (numerical) solutions that they refer to different contents of the will or to different actions, then it could mean that different actions are compatible with the same situation which obtains before taking a certain action.

So, an agent would be in situation with open possibilities, though it could be a restricted range of possibilities. But, in that range there would be a genuine openness (which action to take and whichever action is then taken, it would not be one that inevitably followed). But that what is chosen and which action is undertaken would not be random on the other hand, because it would be compatible with some intentional (broad) rational explanation, even in the cases where the action undertaken is not the most rational, and it would be compatible with specified previous states and a physical description of a situation; and whatever else is in that range what equations allow, is, by that very fact, compatible with previous states and a physical description of a situation.

Of course, details of such an approach, if possible at all, are yet to be worked out, but it seems that it provides a general framework how libertarian and scientific worldviews could be reconciled.

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SAŽETAK

Naša intuicija i osjećaji da mi, kao ljudska bića, općenito imamo slobodu volje i djelovanja. U mnogim situacijama djeluje kao da možemo napraviti jedno ili drugo, tj. možemo provesti djelovanje A, ili se možemo suzdržati od provedbe djelovanja A pod istim uvjetima. Libertarianizam je pogled prema kojemu to nije privid, nego izvorna sloboda. U radu ispitujem može li taj pogled biti moguć pri znanstvenom razumijevanju svijeta. Djeluje kao da fizikalne znanosti snažno podržavaju determinizam. Teorija kaosa i indeterminizam u kvantnoj mehanici ne mogu održati slobodu jer je teorija kaosa deterministička teorija, dok se nedeterminirani događaji u kvantnoj mehanici odvijaju nasumično. Nasumičnost nije nešto što želimo kao slobodu. Ali, možda, možemo ponovo uključiti slobodu (iako možda u reduciranom obliku) ako djelovanja ili odluke mogu biti opisane jednadžbama koje omogućavaju višestruka rješenja te ako ta rješenja možemo interpretirati kao da se odnose na različite sadržaje volje ili različitih djelovanja.

KLJUČNE RIJEČI

slobodna volja, determinizam, libertarianizam, teorija kaosa, kompleksnost

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