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NON-EQUILIBRIUM ECONOMICS

Katalin Martinás*

[1]Department of Atomic Physics, Eötvös Loránd University,
Budapest, Hungary

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SUMMARY

A microeconomic, agent based framework to dynamic economics is formulated in a materialist approach. An axiomatic foundation of a non-equilibrium microeconomics is outlined. Economic activity is modelled as transformation and transport of commodities (materials) owned by the agents. Rate of transformations (production intensity), and the rate of transport (trade) are defined by the agents. Economic decision rules are derived from the observed economic behaviour. The non-linear equations are solved numerically for a model economy. Numerical solutions for simple model economies suggest that the some of the results of general equilibrium economics are consequences only of the equilibrium hypothesis. We show that perfect competition of selfish agents does not guarantee the stability of economic equilibrium, but cooperativity is needed, too.

KEY WORDS

equilibrium hypothesis, non-equilibrium economics, avoid the avoidable losses

CLASSIFICATION

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*Corresponding author, η: martinas@elte.hu; +36 1 2090 555 Ext 6360;
Atomfizikai tanszek, ELTE, Pazmany Peter setany 1, 1117 Budapest, Hungary.

INTRODUCTION

There is a formal and important analogy between economics and thermodynamics, namely they are phenomenological theories. We must know the rules, they govern our life. From our experiences we formulate in the form of axioms or postulates the basic behaviour. This axioms serve the basis of the mathematical version of the theory. Thermodynamics have shown that the choice of axioms is not unique, and the resulting mathematical theories maybe different, too. The distinction of equilibrium, non-equilibrium and extended thermodynamics is an example for the possibility of different construction of the axiom system. Each of them represents a different model of the reality. In standard equilibrium thermodynamics the reality is reflected as a collection of equilibrium systems, and the changes are described as "quasi-static" processes. The extended thermodynamics does not assume the equilibrium. These thermodynamic approaches are different on the metaphysical level.

Economics formulates the basis of decision rule in form of postulates. The formulation is not unique, but on metaeconomic level the basic properties are the same .A standard axiom in economic theory holds that humans are self-interested. Economists recognize, of course, that the assumption is not literally true. Many argue, however, that it is good enough for explaining most important economic phenomena.

In the neoclassical model, the essence of what the economy does is sustain (or fail to sustain) an equilibrium. The equilibrium relies crucially on the assumption of a competitive environment where buyers and sellers take the terms of trades (prices) as a given parameter of the exchange environment. Each trader decides upon a quantity that is so small compared to the total quantity traded in the market that their individual transactions have no influence on the prices. That approach assumes that individuals choose actions based on the short-sighted evaluation of their consequences based on preferences that are selfish and exogenously determined. The Walrasian approach [1] represents economic behaviour as the solution to a constrained optimization problem faced by a fully informed individual in a virtually institution-free environment. The similarities of Walrasian approach and thermodynamics are investigated and explored elsewhere [2 – 7].

Nevertheless relaxation of the Walrasian assumptions confronts us with an embarrassment of riches. In the absence of some empirical restrictions or theoretical refinements, a paradigm will remain vacuous. Few empirical predictions will be forthcoming if individuals may be self interested or not depending on the person and the situation, if some interactions are governed by contracts, others by handshakes, and others by brute force, and if there exist multiple stable equilibrium. The need for empirical grounding of assumptions is nowhere clearer than in the analysis of individual behaviour, where the process of enriching the conventional assumptions about cognition and preferences can easily descend into ad hoc explanation unless disciplined by reference to facts about what real people do. It is not enough to know that self interest is not the only motive; we need to k which other motives are important under what conditions. These restrictions are most likely to come from one of the sources that undermined the Walrasian paradigm, namely the great advances in empirical social science stemming from new techniques in econometrics, the improvement in computational capabilities and data availability, experimental techniques, and continuing progress in quantitative history. Theory, too, can provide useful restrictions on the set of plausible assumptions and outcomes. The modelling of genetic and cultural evolution, for example, can help restrict the range of plausible behavioural assumptions by distinguishing between emotions, cognitive capacities, and other influences on behaviours.

In summary the modern economic paradigm is based on the unholy trinity of Solow, the "ERG", that is "equilibrium, rationality and greed". This unholy trinity was (and is) criticized, but to neglect one of the elements ruins the present economic theory. Nevertheless the equilibrium hypothesis is natural for economists. The necessity of equilibrium follows from the comment of George Soros, who wrote [8]: "In the absence of equilibrium, the contention that free markets lead to the optimum allocation of resources loses its justification. The supposedly scientific theory that has been used to validate it turns out to be an axiomatic structure whose conclusions are contained in its assumptions and are not necessarily supported by the empirical evidence. The resemblance to Marxism, which also claimed scientific status for its tenets, is too close for comfort."

Economists are trained that the understanding of equilibrium will lead to understanding of processes. That role of equilibrium is not justified by thermodynamics, it shows just the opposite. So for non-economists the equilibrium hypothesis is an oxymoron. As a physicist Ruelle wrote [9]: "Textbooks of economics are largely concerned with equilibrium situations between economic agents with perfect foresight. The textbooks may give you the impression that the role of the legislators and government officials is to find and implement an equilibrium that is particularly favourable for the community... The examples of chaos in physics teach us, however, that certain dynamical situations do not produce equilibrium but rather a chaotic, unpredictable time evolution. Legislators and government officials are thus faced with the possibility that their decisions, intended to produce a better equilibrium, will in fact lead to wild and unpredictable fluctuations, with possibly quite disastrous effects. The complexity of today's economics encourages such chaotic behaviour, and our theoretical understanding of this domain remains very limited."

As Veseth summarized [10] Ruelle's critique is natural for outsiders, but it is irrelevant for economists. Ruelle supposes that the aim of economics is to help a good economic policy. All the economists know that the theory is about the hypothetical ERG economics. Ruelle's point, however, is extremely important for outsiders. The equilibrium hypothesis of economists necessarily eliminates the possibility of not equilibrium when there is no particular reason to do so. So the forecasts of the equilibrium and equilibrium behaviour are not results but built in assumptions.

The second letter in "ERG" is "R", which is for rationality. Without rationality there is mathematical theory. Rationality makes economics to a "predictive" science. If agents are rational, then theories can predict their behaviour and the predictions can be evaluated. The hypothesis can be tested against real world data. There is no real forecasting power, but after the events the explanations can be made. Without rationality it is not possible. So without rationality, economics is not a mathematical science. Bowles wrote [11]: "In adopting the rationality axiom, neoclassical economics became part of a bigger project – the program of a grand unified theory of science based on the methodology of logical positivism. The desire to make economics a science is thus embedded in the rationality axiom. As a result, there is much to lose if irrational markets exist, and especially if they exist where they may restrict the largest market process of all – globalization."

As Thaler in 2001 wrote in the American Economic Association's Journal of Economic Perspective [12]: "Economics can be distinguished from other social sciences by the belief that most (all?) behaviour can be explained by assuming that rational agents with stable well defined preferences interact in markets that (eventually) clear. An empirical result qualifies as an anomaly if it is difficult to 'rationalize' or if implausible assumptions are necessary to explain it within the paradigm."

Greed is the last element. Rationality implies that the driving force of actions is the desire to obtain the more money, the more wealth, the more material possessions. The real governing rule is the greed. In modern economic theory greed is a code word for purposeful behaviour. Historically it is a new phenomena. Greedy individuals were considered to be harmful to society as their motives often appear to disregard the welfare of others. Further, greed was the synonym of avarice. So they were considered as hopeless people, who are not able to enjoy the richness of the life, they love only the money. Greed is listed as one of the Christian seven deadly sins. Nevertheless desire to increase one's material wealth has become acceptable in Western culture. The desire to acquire wealth has been understood as indispensable for economic prosperity. Many economic rationalists agree that greed is the only consistent human motivation. No one has been able to construct a society where communal altruism dominates individual greed. Chinese philosopher Lao Tzu wrote 2500 years ago: "There is no calamity greater than lavish desires, no greater guilt than discontentment and no greater disaster than greed."

If he is right, we have created a mighty sick world for ourselves. The acceptance and need for greed follows from the misunderstanding of the role of competition. Competition is a fundamental good in utilitarian economics. Competition is a process which ensures the maximum efficiency of the economy. The competition implies greed, so greed produces preferable economic outcomes most times and under most conditions. The resulting inequalities are the price for the perfect economy. Further, they maintain that altruism does not seem to be congruent with the way human beings are constructed.

BASIC CONCEPTS

Economic activity is modelled as transformation and transport of commodities (materials) owned by the agents. Rate of transformations (production intensity), and the rate of transport (trade decisions) are defined by economic decisions made by the agents. There is a natural constraint for decisions. Balance equations for goods satisfy the law of mass conservation. The model developed here is an attempt to investigate the emergence and stability of economic equilibrium in a multi agent approach, or with other words the working of the invisible hand in a dynamical system approach. The basic assumption is that agents wish to reach a better economic state. The success depends on their skills. The desire to increase the economic well-being as a basic characteristic of economic decisions serves as a corner stone to the mathematical description of decisions. It leads to a welfare measure, Z. Welfare is a function of the goods and money possessed by the agent [13]. This function contains the economic characteristics of the agent. The first derivatives yield the economic values.

An economic agent (EA) is the smallest entity with an implicit or explicit decision-making rule. In most cases, the EA is either a firm or an individual. EAs are characterized by the scope of their activities, by their knowledge, their experiences and their belongings (goods and money). In a mathematical description, every stock can be listed, which can be effected by the economic activity of the agent, the ones, which effect the economic activity of the agent.

Commodity or good is a material or non-material object, which is denoted by $X_\mathrm{i}^\alpha(t)$ where α identifies the owner of the good. Superscript 0 represents nature, which is considered as an agent. Index i = 1, ..., n is for the different goods and t is for time. For material goods the balance equations read

$$\frac{\mathrm{d}X_\mathrm{i}^\alpha(\mathbf{r},t)}{\mathrm{d}t} = J_\mathrm{i}^\alpha(\mathbf{r},t) + S_\mathrm{i}^\alpha(\mathbf{r},t). \tag{1}$$

where $J_\mathrm{i}^\alpha(\mathbf{r}, t)$ is the flow term, usually the trade (ownership change) or transportation (location change) and $S_\mathrm{i}^\alpha(\mathbf{r}, t)$ is the source or sink term. It describes production, consumption or degradation. For money a similar equation holds. In the following subscript i = 0 represents money. The rules of the economic system (state) define the rules of money creation, that is for the source term is zero. For labour, the equation is similar, but there are two ways of modelling: namely the labour is a service, so the stock of labour is always zero. Or the labour potential is bought, and used, then labour is a commodity.

In economics the different stock changes are coupled. In trade the transfer of a good from agent α to agent β is always accompanied by the transfer of money (or an other good) from agent β to agent α. The elementary event is not a change of stock, but a change of a bundle of stocks.

Let *Price* be the money given for a unit amount of good, *p*. A trade event of quantity *y* from good i for money $p \cdot y$ between EA α and β is written as for agent α:

$$X_{\mathrm{i}}^{\alpha}(t+1) = X_{\mathrm{i}}^{\alpha}(t) + y(t), \tag{2a}$$

$$X_{0}^{\alpha}(t+1) = X_{0}^{\alpha}(t) - m, \tag{2b}$$

and for agent β

$$X_{\mathrm{i}}^{\beta}(t+1) = X_{\mathrm{i}}^{\beta}(t) - y(t), \tag{3a}$$

$$X_{0}^{\beta}(t+1) = X_{0}^{\beta}(t) + m. \tag{3b}$$

Introducing a short-hand notation of activity vector, $q^{\alpha\beta}$, where $q_{\mathrm{i}}^{\alpha\beta}$ is the quantity of the i$^{\mathrm{th}}$ good going from agent β to agent α that in the unit transaction. $y^{\alpha\beta}$, the intensity of the $\alpha\beta$ trade, and $y^{\alpha\alpha}$ is the intensity of the α^{th} agents's production. Then

$$\begin{aligned} X^{\alpha}(t+1) &= X^{\alpha}(t) + y^{\alpha\beta} \cdot q^{\alpha\beta} \\ X^{\beta}(t+1) &= X^{\beta}(t) + y^{\beta\alpha} \cdot q^{\beta\alpha} \end{aligned} \tag{4}$$

where the conservation laws demand for:

$$y^{\alpha\beta} = y^{\beta\alpha}, \tag{5}$$

and

$$q^{\alpha\beta} = -q^{\beta\alpha}. \tag{6}$$

As between two agents several type of trades are possible (the same good with other price, or different goods), a new index, j, is introduced to identify the transaction type between the agents, so $q_{\mathrm{i}}^{\alpha\beta,\,\mathrm{j}}$ tells that in the j$^{\mathrm{th}}$ type unit transaction which quantity of the i$^{\mathrm{th}}$ good goes from agent β to agent α and $y^{\alpha\beta,\,\mathrm{j}}$ is the intensity of the $\alpha\beta$, j trade. Total trade is written as:

$$X^{\alpha}(t+1) = X^{\alpha}(t) + \sum y^{\alpha\beta,\mathrm{j}} \cdot q^{\alpha\beta,\mathrm{j}}. \tag{7}$$

Consumption is given by the consumption vector C^{α}, so the total change of goods is

$$X^{\alpha}(t+1) = X(t) + \sum_{\beta,\mathrm{j}} Y^{\alpha\beta,\mathrm{j}} \cdot q^{\alpha\beta,\mathrm{j}} - C^{\alpha}. \tag{8}$$

Equation (8) describes time evolution of the economic system through the stock changes. The activity set $\{q^{\alpha\beta,\,\mathrm{j}}\}$ describes the "hardware" of the economic system. The institutional and technological constructions. The activity parameters $\{y^{\alpha\beta,\,\mathrm{j}}\}$ are the decisions of the agents. Constraints:

$$y^{\alpha\beta,\mathrm{j}} = y^{\beta\alpha,\mathrm{j}}$$

and the production intensity must not exceed the built in limit

$$y^{\alpha\alpha,\mathrm{j}} \le y^{\alpha\alpha,\mathrm{j}}{}_{\max}.$$

The stocks must be positive

$$X_{1}^{\alpha} \ge 0.$$

Dynamics is defined by the activity parameters y. In an agent based approach $y^{\alpha\alpha, j}$ is fixed (decided) by agent α, while $y^{\alpha\beta, j}$ is decided by agents α and β.

MATHEMATICAL MODEL OF DECISIONS

For the sake of simplicity, we assume that in a time moment t, one action is selected. All but one component of $y^{\alpha\beta, j}(t)$ are non-zero. Our ability to make trade and production decisions implies that we have the ability, to estimate whether an action is advantageous or disadvantageous for us. Every agent is characterised by an economic welfare function, and the symbol for it is $Z^{\alpha} = Z^{\alpha}(X^{\alpha})$. Sign convention is selected so that $\Delta Z^{\alpha} > 0$ for preferred state, and $\Delta Z^{\alpha} < 0$ for loss-making transactions. Z^{α}-function's partial derivatives

$$w_1^{\alpha} = \frac{\partial Z^{\alpha}\left(X^{\alpha}\right)}{\partial X_1^{\alpha}}, \tag{9}$$

are the Z^{α}-value of the good i. Similarly

$$w_0^{\alpha} = \frac{\partial Z^{\alpha}}{\partial X_0^{\alpha}}, \tag{10}$$

is the marginal Z^{α}-value of money, and

$$v_1^{\alpha} = \frac{\partial Z^{\alpha}}{\partial X_i^{\alpha}} = \frac{\partial Z^{\alpha}}{\partial X_0^{\alpha}} = \frac{\partial X_0^{\alpha}}{\partial X_{\mathrm{i}}^{\alpha}}, \tag{11}$$

is the value of the i[th] good for agent α, measured in monetary units. In real exchanges the value must be higher than the price for the buyer. The value is subjective, it is decided by the agent. Economy works because the values are different.

On the basis of the above considerations, we may write the welfare change in a general form:

$$\mathrm{d}Z^{\alpha} = w_0^{\alpha}\left(v_1^{\alpha}\mathrm{d}X_1^{\alpha} + v_2^{\alpha}\mathrm{d}X_2^{\alpha} + \mathrm{d}X_0^{\alpha}\right). \tag{12}$$

Dividing both sides by the value of money:

$$\Delta W^{\alpha} = \frac{dZ^{\alpha}}{w_0^{\alpha}} = v_1^{\alpha} dX_1^{\alpha} + v_2^{\alpha} dX_2^{\alpha} + dX_0^{\alpha}, \tag{13}$$

where the right hand side is the stock change multiplied by the monetary value plus the money change, the economic wealth change.

The form of the welfare function, Z^{α} should be determined experimentally. As the results are yet unavailable we write down some simple wealth function and look for the economic behaviour expressed by them. We expect, that

- Z^{α} is a first-order homogeneous function of stocks,
- Z^{α} is an increasing function of X_0^{α}, that is $w_0^{\alpha} > 0$,
- w_0^{α} is a decreasing function of X_0^{α}, that is the value of money decreases with increasing stock of money,
- $v_i^{\alpha} > 0$, the values of goods are positive (This is not a general rule, since there maybe harmful stocks (wastes) with negative values, and they are then decreasing function of stocks). – v_i^{α} is decreasing fuction of stock, X_i^{α}, that is $\partial v_i^{\alpha}/\partial X_i^{\alpha} < 0$ and – v_i^{α} is increasing fuction of money, X_0^{α}, that is $\partial v_i^{\alpha}/\partial X_0^{\alpha} > 0$.

The last two properties are not necessarily valid. In case of cultural goods as for instance the higher stock leads to higher value for the agent. Nevertheless, in the present work we consider only normal goods, where the last two conditions apply, too.

One of the simplest expressions satisfying all the required conditions is a logarithmic function:

$$Z^{\alpha} = \sum_{i} X_{i}^{\alpha} 1g\left(\frac{X_{0}^{\alpha}}{X_{1}^{\alpha} C_{1}^{\alpha}} \right). \tag{14}$$

where C_i^{α} are constants. The value functions will be

$$v_{i}^{\alpha} = w_{0}^{\alpha} \lg\left(\frac{X_{0}^{\alpha}}{X_{i}^{\alpha} C_{i}^{\alpha}} \right). \tag{15}$$

Wealth gain in process $\alpha\beta, j$ is:

$$\Delta W^{\alpha\beta,j} = \frac{1}{w_{0}^{\alpha}} \left[Z^{\alpha}\left(X^{\alpha} + q^{\alpha\beta,j}\right) - Z^{\alpha}\left(X^{\alpha}\right) \right]. \tag{16}$$

Let $\alpha\beta, j$ be an exchange process of the good i. The wealth change can be written for agent α as:

$$\Delta W^{\alpha} = \frac{1}{w_{0}^{\alpha}} \left(\frac{\partial Z^{\alpha}(X)}{\partial X_{i}^{\alpha}} - p_{i}^{\alpha\beta,j} \frac{\partial Z^{\alpha}\left(X^{\alpha}\right)}{\partial X_{0}^{\alpha}} \right) y^{\alpha\beta,j} = \left(v_{i}^{\alpha} - p_{i}^{\alpha\beta,j}\right) y^{\alpha\beta,j}. \tag{17}$$

The principle of wealth increase tells that the agent buys if $i_i^{\alpha} > p_i^{\alpha\beta}$, and sells if $p_i^{\alpha\beta} > v_i^{\alpha}$. Wealth gain in unit process ($y^{\alpha\beta, j} = 1$)is:

$$\Delta W_{0}^{\alpha} = \left(v_{i}^{\alpha} - p_{i}^{\alpha\beta,j}\right). \tag{18}$$

The aim of economic activity is to increase the wealth, the expected wealth increase is the driving force which pushes the actors to act. The activity is a function of force, defined by the agent. In linear approximation

$$y^{\alpha\beta,j} = L^{\alpha\beta,j} \Delta W_{0}^{\alpha\beta,j}. \tag{19}$$

where $L^{\alpha\beta, j}$ is the activity coefficient and the driving force for the process is the wealth gain of the unit process.

Price equation: Trade is a transfer of a good from an agent to an other agent, accompanied by the opposite motion of another good or money. The quantity of good and money does not change during the trade. These conservation laws define the scope of possible trade transactions. The conservation law demands for unit process that

$$y^{\alpha\beta k} = y^{\beta\alpha k}. \tag{20}$$

that is

$$L^{\alpha\beta k} \Delta W^{\alpha k} = -L^{\beta\alpha k} \Delta W^{\beta k}. \tag{21}$$

It defines the price as:

$$p_{i}^{\alpha\beta} = \frac{L_{i}^{\alpha\beta} v_{i}^{\alpha} + L_{i}^{\beta\alpha} v_{i}^{\beta}}{L_{i}^{\alpha\beta} + L_{i}^{\beta\alpha}}. \tag{22}$$

Production is a process which transforms some goods and materials into a new form, but it involves always a material flow to and from the nature. There is raw material input and waste output. The wealth gain in a unit production is

$$\Delta W^{\alpha\alpha,j} = \sum_{i} v_{i}^{\alpha}(t) q_{i}^{\alpha\alpha,j}. \tag{23}$$

In the force law assumption the expected wealth increase is the driving force, which pushes the actors to act, that is

$$y^{\alpha\alpha,j} = L^{\alpha\alpha,j} \Delta W^{\alpha\alpha,j}.$$

where $L^{\alpha\alpha, j}$ is the activity coefficient for production. The production intensity has two natural upper limits. The built in capacity, defined by the capital stocks gives a natural limit, on the other hand the scarcity of inputs also defines an upper limit. The real economy works below this boundary ($y_{max}^{\alpha\alpha, j}$).

EQUILIBRIUM IN A PURE EXCHANGE ECONOMY

In a pure exchange economy there is no production and consumption. An exchange of the i^{th} good between agent α and agent β is feasible if the values are different, $v_i^\alpha \neq v_i^\beta$. Let x_i^α be the quantity what the agent α gets for price p_i, then after the exchange the values will change, as

$$\Delta v_i^\alpha = \left(\frac{\partial v_i^\alpha}{\partial X_i^\alpha} - p_i \frac{\partial v_i^\alpha}{\partial X_0^\alpha} \right) x_i^\alpha . \tag{24}$$

A symmetric relation is valid for agent β. The net result is that the value difference decreases, and welfare of the agent increases. The process continues until the value difference diminishes. In the final, equilibrium state all the values will be the same, but the welfare (wealth) of the agents maybe different.

It is easy to show, that the equilibrium value and so the equilibrium price depends on the path, in the present model on the L parameters. The wealth gain of the agents also depends on the choice of parameter L. Details see in [14]. All equilibrium states are Pareto-optimal, but from economic point of view they are different, as the wealth distributions are different.

TIME DEPENDENT SOLUTIONS

MODEL ECONOMY

For the numerical solutions we selected a model economy, based on the text book examples of macroeconomics. Our minimum sectoral model of an economy has 3 economic agents, corresponding to sectors: agriculture, industry, and households. Agents decide the production intensity, and by the bargaining rule, they agree in the prices and traded quantities. The nature is considered infinite, the activity vectors, decision parameters do not change.

Time is discretized. One unit is called one cycle. The cycle consists of trade decisions. The agents make the trade decisions (price and quantity determination) all together. After they make independently the production intensity decision based on their stocks. In the final part the consumption happens, and if it exists, then the interest payment. From the results we plot for some cases the total production as a function of time (completed cycles) and the welfare of agents and the total welfare of economic system as a function of time.

The initial values, given to parameters and variables previously defined, are listed as:

- identification of agents – selected as industry ($\alpha = 1$), agriculture ($\alpha = 2$)and households ($\alpha = 3$),
- identification of goods: tools (i = 1), food (i = 2) and labour (i = 3),
- welfare Z-function of agents. We selected the logarithmic form for the Z-function of agent as in eq. 14. where the values of constants C^α are to be specified,
- the number of different technologies available for agent, selected as 1,
- X_i^α i^{th} stock of agent α listed in Table 1.
- $q_i^{\alpha\beta}$ activity matrix of the agents: Production activity vectors were selected as listed in Table 2.
- g is a parameter. Selection $g = 1$ describes a reproductive economy. Value $q > 1$ implies an economy where the total quantity of goods is increasing, economic growth may appear. Technological change in this aggregate level is modelled as a change in g, as an efficiency development. The same input results in more output. That is, the production activity matrix is changed.
- $q^{\alpha\beta,\,j}$: trade activity matrix. It was selected as $q_i^{\alpha\beta,\,j} = \delta_{ij}$ and $q_0^{\alpha\beta,\,j} = -p_j^{\alpha\beta}$, that is there is a separate trade process for each good. The prices are defined in the bargaining process.

Table 1: Initial Stock vectors.

	Money	Food	Tools	Labour
Agriculture	1000	22,98	18,51	14,07
Industry	1000	22,05	19,34	14,16
Households	1000	21,97	18,86	14,73

Table 2: Production activity vectors $q^{\alpha\alpha}$.

	Food	Tools	Labour
Agriculture	*g*	-0,14	-0,08
Industry	-0,40	*g*	-0,36
Households	-1,83	-1	*g*

- C_i^{α}, the consumption vector of the agents, which were selected as:

$$C_1^{\alpha\alpha} = C_{10}^{\alpha} \text{ if } y^{\alpha\alpha} < 1. \tag{25}$$

$$C_1^{\alpha\alpha} = C_{10}^{\alpha\alpha} \cdot y^{\alpha\alpha} \text{ if } y^{\alpha\alpha} > 1. \tag{26}$$

  Selection of the *C* terms: Agriculture (0,25; 0; 0), Industry (0; 0,06; 0) and Households (0; 0; 0.04),

- $L_i^{\alpha\beta}$ activity coefficient of the agents The *L* parameter for all trades is assumed to be unity, viz. $L = 1$. Each agent trades with every other agent. The production parameters are: $L_1 = 0{,}352$, $L_2 = 0{,}288$ and $L_3 = 0{,}352$.

REPRODUCTIVE ECONOMY

The above model economy is an equilibrium economy. The initial state is reproduced. A slight modification of the initial stocks reveals two important properties of the system. The price equilibrium appears shortly, so for a short time the equilibrium seems to be stable, nevertheless wealth difference appears and increases with time. The rich will be richer, the poor become poorer, until the poor looses everything. We considered economic death of the agent when the stocks are less then a critical level. It is the collapse of the economic system. The initial stocks were modified randomly with the rule:

$$X_1^{\alpha} = X_1^{\alpha} \cdot \frac{3-a}{2}$$

where *a* is a random number in the [0, 1] interval. In Figure 1 the total production of the economy is plotted as a function of time, where total production is the sum of the production intensity of the individual agents.

The system apparently finds the equilibrium after the first 20 cycles. There is a relatively stable production, or economic equilibrium for the first 4500 cycles. This equilibrium is not a perfect equilibrium. Wealth differences, shown in Fig. 2, continuously increase, until the instability of the economic system is reached[1].

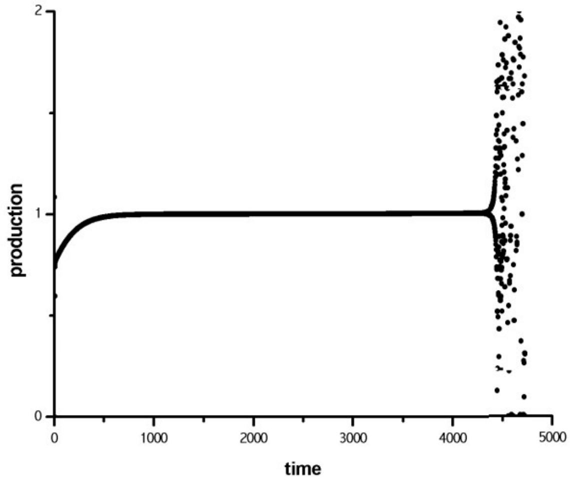

Figure 1. Production as a function of time for near equilibrium initial stocks.

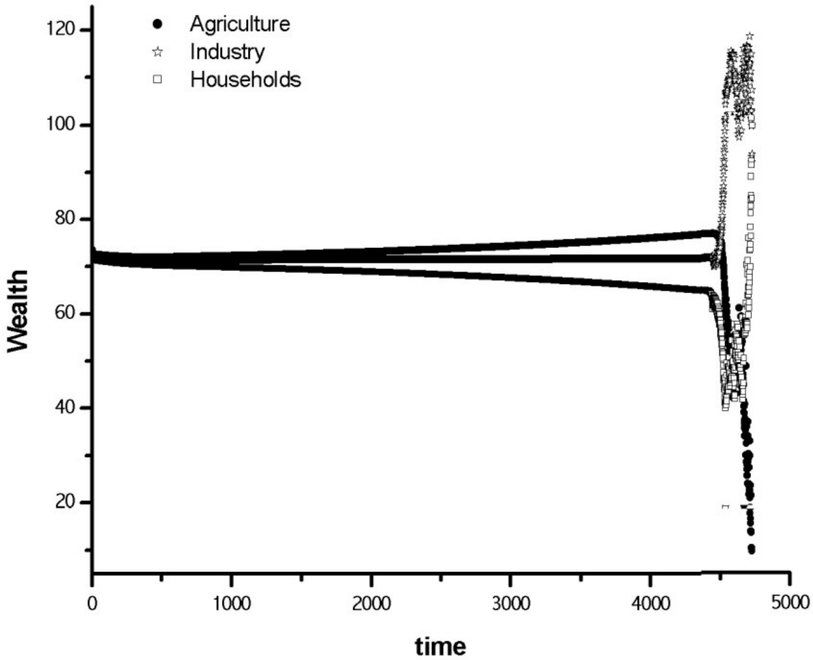

Figure 2. Wealth of agents as a function of time.

GROWTH

The production activity with net gain is necessary for the increase of production activity, but it is not sufficient, as the previous results show. Money has to be increased, too, as otherwise the economic driving forces decrease. As a first approach to the problem, the interest was introduced. Every agent gets an interest payment for their money sock in each cycle. So the money is increased as

$$X_0^\alpha(t+1) = X_0^\alpha(t)\left(1+\frac{r}{1000}\right). \tag{27}$$

The results show that *r* defines the growth rate, while *g* defines the stability range of quasi-equilibrium growth. In the next figures we show the results for different interest rates at $g = 2$.

Constant money

Constant money, that is $r = 0$ leads to a chaotic reproductive economy. Fig. 3 shows that total production starts at 14, but after 50 cycles the average production decreases to approximately 0,5. The economy founds the working path as a nearly reproductive economy. The production seems to show a chaotic behaviour until the collapse, which appears at 48 000 cycles.

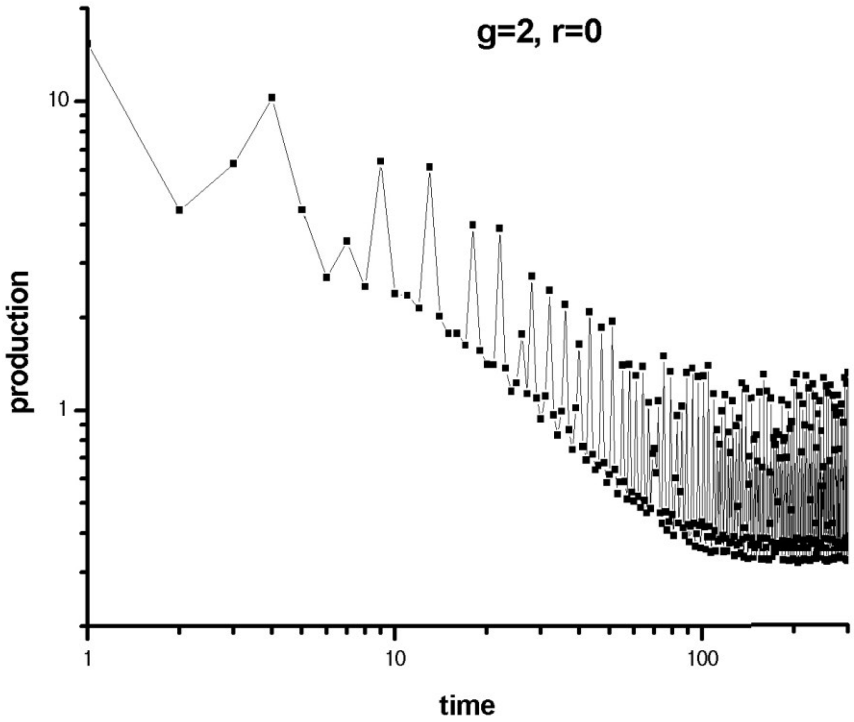

Figure 3. Production as a function of time for $g = 2$ with constant money ($r = 0$)

The production for the whole time interval is shown in Fig 4.

The technical change did not improve the total welfare. As it is shown in Fig 5. the total welfare is decreasing in time. It is interesting to note, that just before the collapse a relatively huge (but instable) welfare growth appears.

Very low interest rate, *r* = 0,005

This small interest rate increases the life time of economy to 62 000. Further, the disappearance of the chaos appears. At between 37 000 and 40 500 an almost perfect oscillations replaces a chaos. At 53 500 a new ordering appears, but the collapse finishes the economy at 62 000, Fig 6.

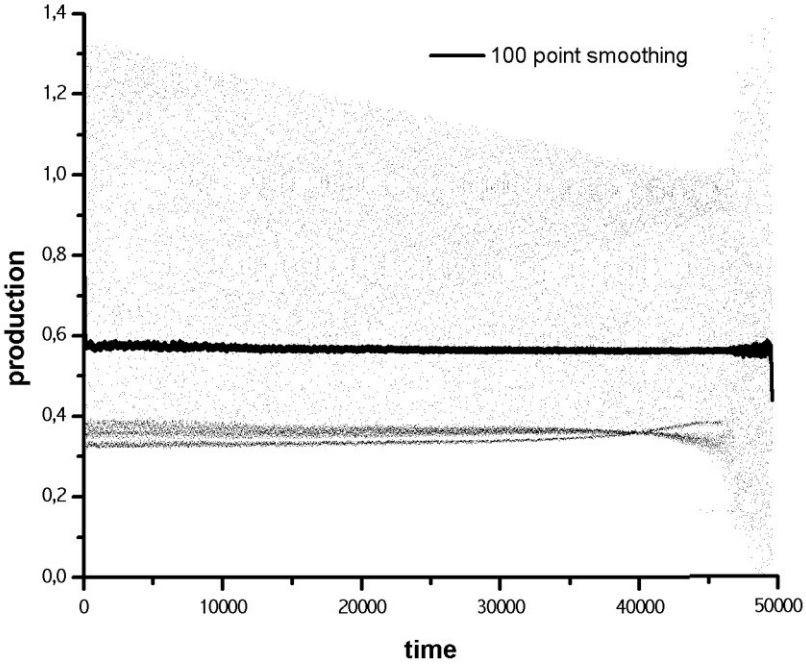

Figure 4. Production as a function of time for g = 2 with constant money (r = 0).

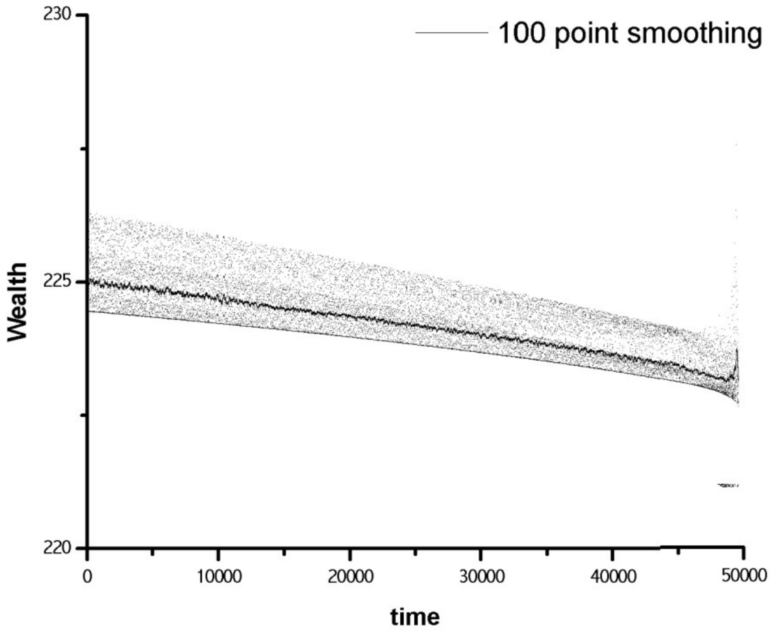

Figure 5. Wealth as a function of time for g = 2 with constant money (r = 0).

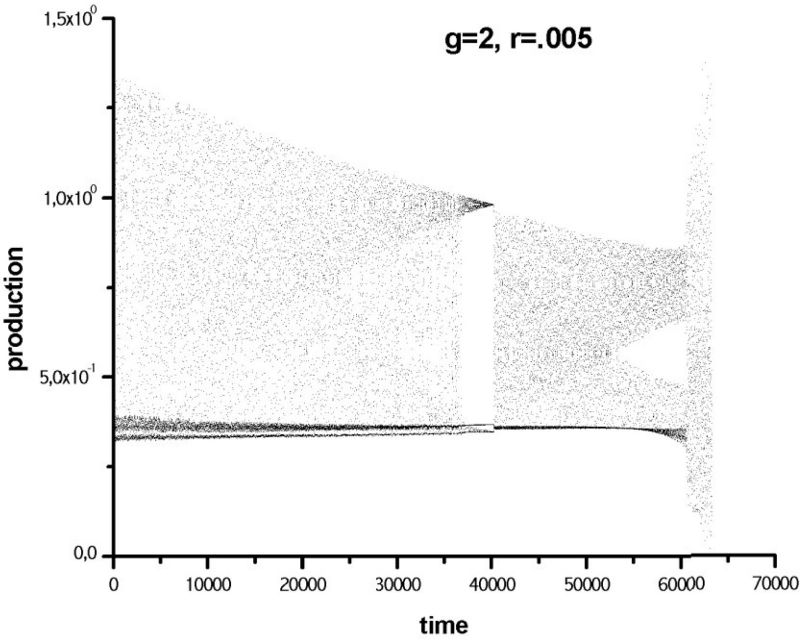

Figure 6. Production as a function of time for $r = 0$.

The Fig. 7 shows the smoothed results.

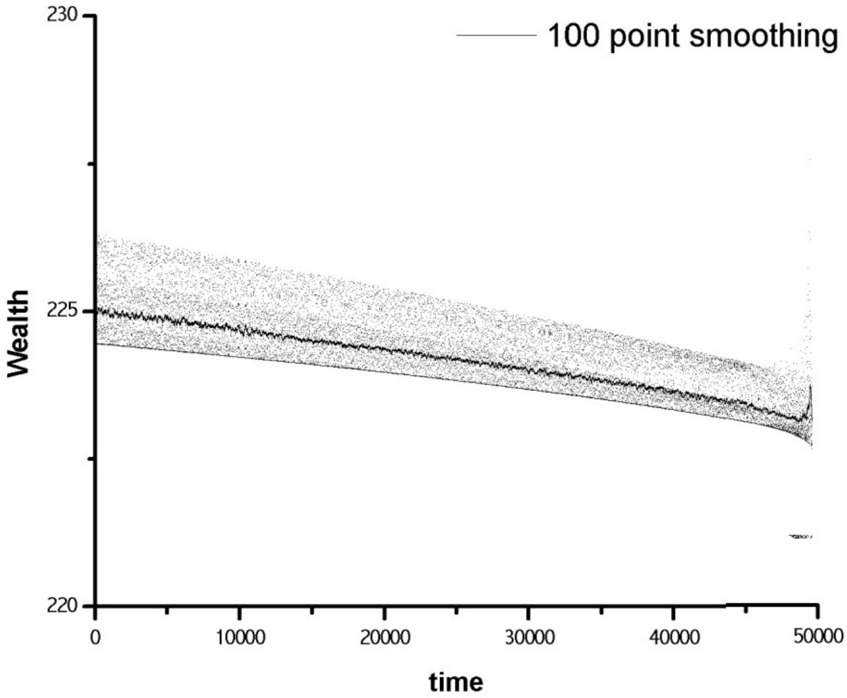

Figure 7. Production as a function of time for $r = 0{,}005$.

Low interest rate *r* = 0,013

The economy finds the equilibrium growth path if the interest rate is higher than a critical value (depending on *g*). The time needed to achieve the equilibrium path decreases with the interest rate. Nevertheless this equilibrium growth has a finite lifespan, which is decreasing with increasing interest rate. For each g belongs an *r*, where the equilibrium growth seems to have an infinite lifetime. In the following figures some results are plotted.

The critical interest rate is in the 0,0015 – 0,0025 range. First we show the result for *r* =0,0013 in Fig. 8, its detail in Fig. 9, and then the result for *r* = 0,0025 in Fig. 10.

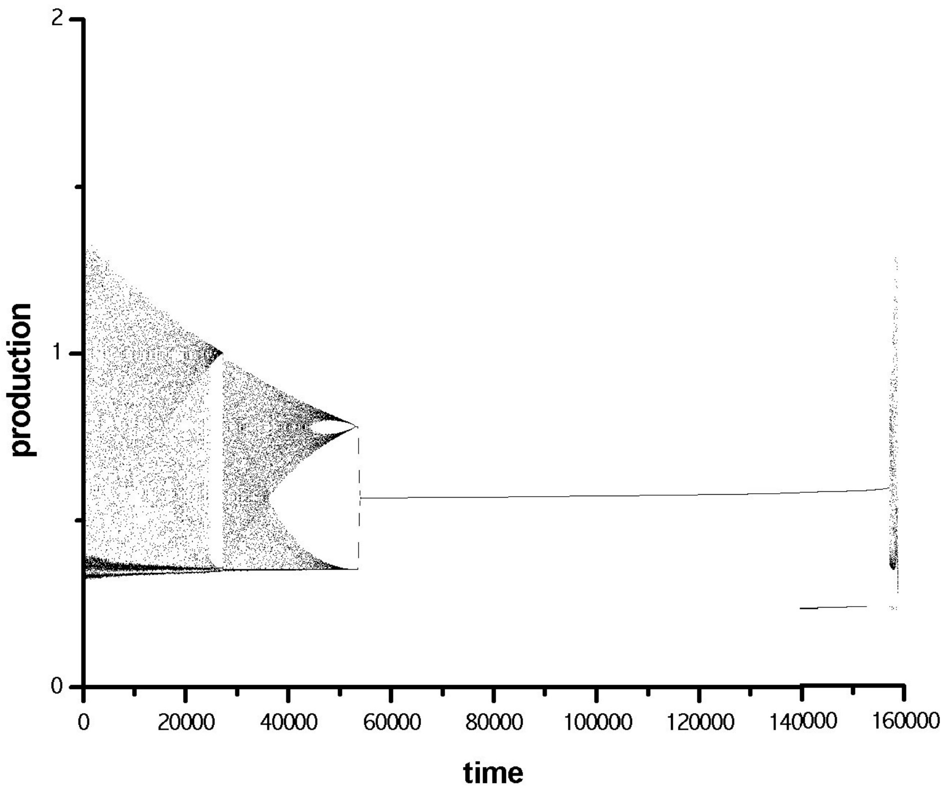

Figure 8. Production as a function of time, *r* = 0,0013.

On the curve 3 distinct regime can be distinguished. In the first (0 < i < 50 000), the emergence of order. The technological factor means that we start our economy out of equilibrium. The interaction of agents (through the trade) leads to this very slow equilibration. The first period is magnified in Figure 9. It resembles to a chaotic path.

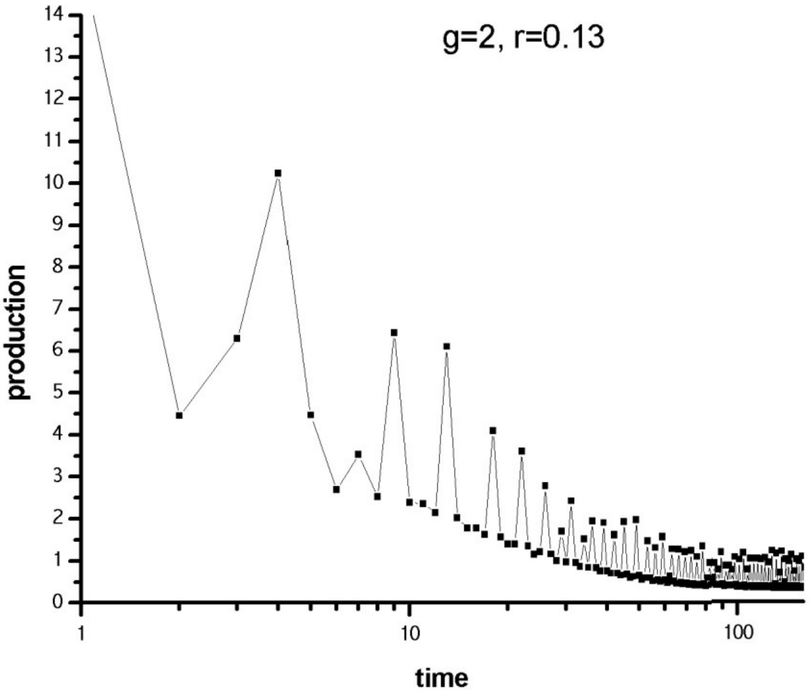

Figure 9. Production as a function of time, r = 0,013.

Stable Growth

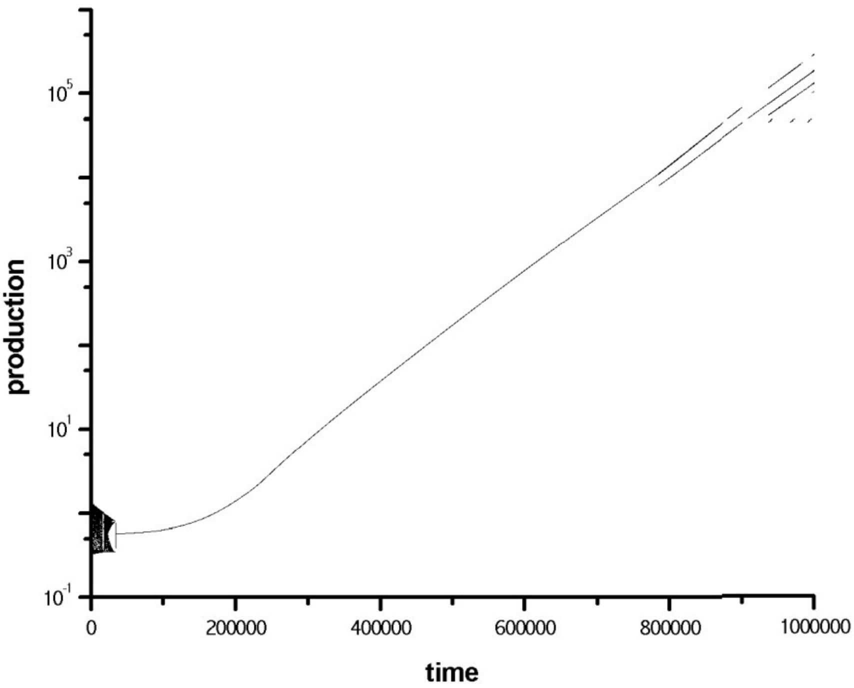

Figure 10. Production as a function of time, r = 0,025.

CONCLUSIONS

The modern economic paradigm is based on the unholy trinity of Solow, the "ERG", that is "equilibrium, rationality and greed". This unholy trinity has been criticized, but here we outlined a non-equilibrium foundation of economic theory, where the maximization (rationality) is replaced by the "Avoid the avoidable losses" rule, the greed assumption is not needed and the equilibrium is the question of dynamics.

The results of numerical solutions show that this rule is sufficient to ensure the emergence of market prices and the stable working of an economy, nevertheless for longer run the system is unstable, because of the emergence of wealth differences.

ACKNOWLEDGMENT

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REMARK

[1]It is worthwhile mentioning that the stability of equilibirum can be ensured by a "social law". Introducing a social wealth redistribution, namely the richest give some money to the poorest, gives a longevity to the system.

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NERAVNOTEŽNA EKONOMIJA

K. Martinás

Odsjek za atomsku fiziku, ELTE
Budimpešta, Madžarska

SAŽETAK

Mikroekonomski okvir dinamičke ekonomije, temeljen na učesnicima, postavljen je u materijalističkom pristupu. Naznačeno je aksiomatsko utemeljenje neravnotežne mikroekonomije. Ekonomska aktivnost je modelirana kao transformacija i transport dobara (materije) koje posjeduju učesnici. Stope transformacije (intenzitet proizvodnje) i transporta (trgovine) definirane su putem učesnika. Ekonomska pravila odlučivanja izvedena su iz opaženog ekonomskog ponašanja. Nelinearne jednadžbe su za modelnu ekonomiju rješene numerički. Numerička rješenja za jednostavni model ekonomije upućuju na zaključak kako su neki od rezultata iz opće ravnotežne ekonomije posljedice samo hipoteze ravnoteže. U članku se pokazuje kako potpuna kompeticija sebičnih učesnika ne garantira stabilnost ekonomske ravnoteže, nego je potrebna i kooperativnost.

KLJUČNE RIJEČI

hipoteza ravnoteže, neravnotežna ekonomija, izbjeći gubitke koje se može izbjeći