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Information Technology, Telecommunication and Economic Stability

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Abstract: *Physical and mathematical examples show that the increase of effectiveness of a system performance might lead to instability of operation. The question whether the development of Information and Communication Technologies (ICT) can lead to instability of economic systems will be examined. The final conclusion is yes, we cannot exclude that unlimited development of Information Technologies (IT) and telecommunication might induce structural instability. Slowing down technological development is out of question, other economic means could be applied, that add artificial friction to the systems in order to reserve stability. A potential instrument might be the application of transactional taxes.*

Keywords: *Economy, stability, equilibrium, Tobin-tax.*

1. The role of information technology and telecommunication in the economy

Information Technologies (IT) is one of the most important factors of the operation and development of the contemporary economy. One can hardly find an area in manufacturing, service, finance, or any other business, where stopping all Information and Communication Technologies (ICT) operations by switching off the network will not disrupt all activities immediately.

Development of ICT provided the basis for new business models that could not be even dreamed of in business forecasts 15-20 years ago. New businesses were created in hardware, software and telecommunication industry, but even more important are the businesses based on fast communication and IT services, e.g. e-Commerce, e-Government.

Amazon, eBay, Skype, Google established new business, communication and marketing models, built on contemporary ICT technologies. These businesses could not be established even half a decade before their launch. They are built on personalized customer service of tens of millions of people and very simple and user-friendly communication with the customers. They also focus on the full exploitation of the marketing and sales potential of the latest ICT technology.

The significant role of ICT in the economy, society and private life has been dealt with in a vast amount of studies; it is not our goal to add just one more analysis. Instead, we shall analyze the question how the development of ICT possibly affects the stability of economic systems. We shall demonstrate that ICT can destabilize the system and in order to regain stability it is recommended to throw some sand onto the gears in form of some transactional taxation.

The following example from the era of industrial revolution will demonstrate that development of the engineering technology in some cases might lead to instability.

2. A classic case – Watt's centrifugal governor

The centrifugal (flyball) governor for stem engines was designed and employed by James Watt in 1788 to regulate the speed of stem engines. He used the idea of a flyball governor previously applied for windmills. The governor became the icon of the process control since then. [10, 14, 3]. The role of the governor was the regulation of the speed of the stem engine at changing load. The governor is a mechanical device that automatically controls the throttle that allows more or less steam to the engine cylinder depending on the external load. When an increase in external load slows down the rotation of the engine, the device opens the throttle and more steam is allowed to the engine and the process is stabilized in a relatively short time [14].

Tens of thousands of governors employed in a great number of steam engines performed flawlessly almost a hundred years. However, after the fifties of the 19th century the regulators in general became unreliable, they started to oscillate or showed a chaotic behavior, they did not regulate the engines any more. Engineers started to find out what happened, and the problem was solved by M a x w e l l [7] in 1867 and V i s h n e g r a d s k y [17] in 1876. Vishnegradsky examined the stability of the regulator's stable states using a system of differential equations, a dynamic model of the regulator's movement. According to Vishnegradsky (see [10]) the sufficient condition of the stability of the equilibrium speed of the dynamic system is

$$s = \frac{I*b*v}{m} > 1, \tag{1}$$

where I is the moment of inertia of the flywheel, b – friction of the regulator, m – mass of the regulator's balls, v – inhomogeneity of the system (a derivative of the angular velocity of the engine's flywheel divided by the load).

In the second half of the 19th century the perfection of the manufacturing technology resulted in decrease of the friction. Several applications of the steam engines required higher performance and speed and also faster feedback reaction. Those requirements were met by decreasing the flywheel mass and increasing the regulator balls mass. According to the Vishnegradsky condition (1), all three factors act against stability. It is quite interesting that the increase of the speed of a negative feedback is one of the destabilizing factors. After Vishnegradsky's explanation engineers increased the friction, increased the inhomogeneity and slowed down the feedback process, and restored stability. It was necessary to throw sand on the gears.

3. Stability

So far we have used the concept of instability without any exact definition. Now we shall give a semi-intuitive definition of stability of dynamical systems without mathematical precision. The stability concept is used in connection with dynamical systems in two different cases:

1) stability of an equilibrium state of the system,
2) structural stability of the system itself.

Further on we shall use discrete iterative models instead of differential equations, as they are sufficient to demonstrate all stability phenomena in question [4].

The trajectory of the k-dimensional vector x_0 in a multidimensional space is defined by the iteration $x_n=f(x_{n-1})$, $n=1,...,\infty$, where x_n is a k-dimensional vector. We shall restrict our analysis to one-dimensional spaces, in fact most stability problems can be studied on one-dimensional iterations.

Notations:

(1) the point x^* is a fixed point of the mapping $f(x)$ if $f(x_n)=x^*$ for all $n \geq 0$;

(2) a fixed point x^* is called attracting, if there exists a domain R, where $x^* \in R$ such that for any point $x_0 \in R$ $\lim_{n\to\infty} f(x_n) = x^*$;

(3) attracting fixed points of an iteration are stable if the mapping is Ljapunov-stable, i.e., the trajectory of the point stays near the equilibrium point.

If an attracting fixed point is not stable, the behaviour of the dynamical system might be very complex. In some cases there exists a neighbourhood of the fixed point that all trajectories starting from this neighborhood diverge (a rejecting fixed point). In other cases there exist periodic trajectories, or e.g. the points of a Cantor set in the neighborhood of the fixed point converge to the fixed point, but all the other points diverge under the iteration.

Structural stability is a property of dynamical systems, not the equilibrium points. Here we restrict ourselves to an intuitive description rather than mathematical definition. For an exact definition see [4].

A dynamical system is structurally stable in a given domain if all systems, sufficiently close to it possess similar dynamical properties. The distance between two systems is defined by the distance of the iterative mappings and their derivatives. Dynamical similarity means that fix points in one system match fixed points in the other system, periodic points match periodic points with the same periods. Closeness means topological conjugacy, or more explicitly, structural stability means that small perturbations do not change qualitatively the trajectory of the system.

As we have seen, the stability criterion for Watt's governor was defined by Vishnegradsky, using the Ljapunov stability theory [10] which he applied to the system of differential equations that described the motion of the governor.

We did not produce similar stability conditions for economic systems, we investigate the stability of equilibrium points of economic systems defined by classical economic theories instead. The equilibrium points are fixed points of dynamical economical systems and structural stability of those systems is of economical interest. We shall demonstrate the possibility of appearance of structural instability or, more precisely of lack of stability. We also shortly discuss the problem how to restore stability.

4. Fixed points and equilibrium in economy

In the 1870-ies Leon Walras published his famous work on the theory of general equilibrium, one of the most important works of neoclassical economy. The theory analyses the fixed points of economy and how to reach the equilibrium. The economy is without doubt a dynamical system and Walras' theory in fact is the analysis of the behaviour of a dynamical system. Walras himself declared that neither the existence of the equilibrium, nor stability, nor uniqueness are not guaranteed in his theory. The general equilibrium theory was redefined and redeveloped in the 1950-ies (Arrow, Debreu [1]; Debreu [2]). In the contemporary models – if a few conditions are satisfied – the existence of equilibrium states can be proved, however uniqueness of the equilibrium states is not common.

It is well known, that equilibrium or the attempt to reach equilibrium are not absolute values or ultimate objectives in economy [6], but a great number of descriptive or decision models are based on the equilibrium situations or fixed development trajectories, which is mathematically similar to the fixed points. Equilibrium situations are predictable and computable, and planners like predictability and computability.

Stability of equilibrium states is a practical problem of great importance in everyday economy, the question is whether the system returns to the original equilibrium after perturbations (and we could see quite serious perturbations in the past few years) and if yes, how fast the system returns to the original status. Another problem is that if a perturbation occurs, the systems might „switch" to another attractive fixed point, leave the attractive neigbourhood of the original equilibrium and enter the attractive neigborhood of another one. The new equilibrium might be quite different from the old one.

In the following we shall demonstrate that the stability analysis might provide complex results even in simple models.

The simplest equilibrium model is that of the Marshall crest, which illustrates the demand and supply function. The independent variable is the price of the product. To make our example extremely simple, we suppose linear demand and supply functions (Fig. 1).

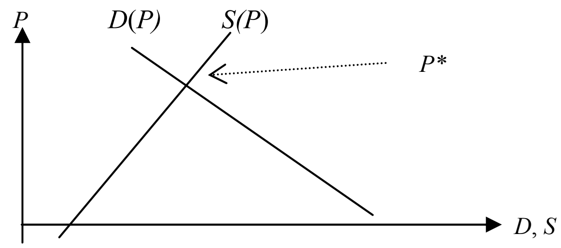

Fig. 1. Marshall crest

On Fig. 1 P is the price of the product, $D(P)$ and $S(P)$ are the demand and supply functions respectively.

It is well known, that the condition for arriving to the equilibrium P^* is:

(2) $$\left|\frac{dS}{dP}\right| < \left|\frac{dD}{dP}\right|.$$

If we suppose a very simple iteration (Fig. 2) it is intuitively obvious, that the equilibrium point is attractive, there exists an interval $\left(P^* - \varepsilon, P^* + \varepsilon\right)$ where the points iterate to the fixed point (Fig. 2a)

In Fig. 2a condition (2) is satisfied at point P^*. If one starts the iteration with a possible supply value, which also defines a given price, and jumps to the demand with the same value, the demand will result in a higher price. This higher price will be associated with a higher supply and if one continues the iteration, one gets closer and closer to the equilibrium. In this case the equilibrium is an attractive fixed point. As far as we applied linear supply and demand functions, the attractive domain of the fixed point is the whole positive quadrant.

In Fig 2b at point P^* the two derivatives are equal. If one starts from any supply value one gets a cycle, and the equilibrium point is not attractive.

In Fig. 2c at point P^* the opposite to the relation (2) is valid and the process is obviously divergent.

The above examples are illustrations only, the limitations of the model are straightforward. We wanted to demonstrate that in everyday business practice the equilibrium is reached as a result of a sequence of decisions. (Walras described the „tatonnement" process of reaching the equilibrium, which is in fact an iterative process).

For example, if a new product is marketed (a new mobile phone, a DVD player, flat-TV) it usually starts with a high price, and the prices are stabilized on a lower level after an iterative process, i.e., after some iterations the consumers will pay the same price for a long period of time for the products, representing the same relative category. (With the assumption that the players can provide the validity of the relation (2)). If not, the product will disappear (e.g., HD TV technology.)

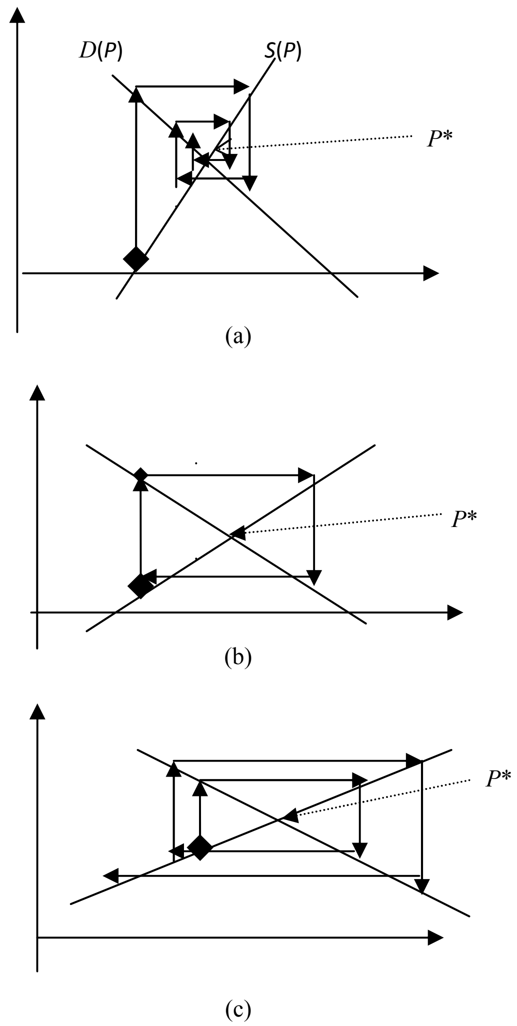

Fig. 2. An attractive fixed point (a), a periodic cycle (b), a repelling fixed point (c)

It is important to find out more about the real properties of the above iteration, how different players act in practice and construct a plausible model. It is a complex question, a great number of factors beyond economical rationality should be considered like psychology of consumers, social issues, etc. Now we are not aimed at modeling of the practical process, but the description of the dynamic phenomena, we shall use the widely applied logistic model for the description of the dynamics. Logistic models are used in mathematical biology and ecology with success and also for description of economic systems [16].

Let $F(P)=S(P) - D(P)$, where P is the price of the product, $S(P)$ denotes the supply, $D(P)$ the demand at price P. According to the logistic model the change of $F(P)$ is proportional to $F(P)$ and the difference between $F(P)$ and a fixed limiting value. One can interpret the model in a way, that the change in the difference between demand and supply depends on the difference itself, and the growth of difference is limited from above by the limit L.

Formally, the differential equation (3) gives the description of the above model:

(3) $$\frac{dF}{dP} = \lambda * F(P)(L - F(P)),$$

where λ>1.

As one can see, the equation (3) is consistent with condition (2), i.e., if $F(P)=L$, we have a cycle, if $F(P)<L$, the process is convergent, and, if $F(P)>L$, it is divergent.

Further on we shall describe the dynamic phenomena occuring in the process of approaching the equilibrium. The differential equation (3) will be replaced by the equivalent discrete model (4) which provides a relatively easy tool for studying the dynamical behaviour. Anyway, the sequence of an economic decision is a discrete process.

(4) $$F_{n+1} = \lambda * F_n(1 - F_n),$$

where $\lambda > 1$.

The iteration (4) is analyzed in the domain [0, 1] as outside this domain the process is divergent for any $\lambda > 1$.

The points of the domain [0, 1] will move on various trajectories. (Trajectory of point P_0 is the infinite sequence of points P_0, $F(P_0)$, $F(F(P_0))$, …)

The properties of a trajectory are defined by the value of λ. A detailed mathematical explanation is given in [4], we present only the most important results for our purposes.

If $1< \lambda < 3$, the iteration has an attractive fixed point $(\lambda - 1)/\lambda$ and a repelling fixed point 0 for any initial value from the domain [0, 1]. If we continuously increase the λ value from 3 up to 4, instead of one fixed point, more and more periodic points will appear. The phenomenon is called the Hopf bifurcation, and the sequence of the periodicities is given by Sarkovsky's theorem [8].

It must be noted that the number of periodic points – if there exists an iteration where the period is not the power of 2 – is infinite. If $\lambda > 4$, the set of points, whose trajectories remain in the domain (0, 1) is a Cantor set. Practically this means, that in the infitesimally small neigbourhood of any point, whose trajectory remains in the domain (0, 1) there exists another point, whose trajectory diverges to the infinity. Without presenting the exact definition of chaotic dynamics, it should be mentioned that the iteration at $\lambda > 4$ is chaotic.

One can see that for small λ values the system's behaviour is predictable, while for larger λ values oscillations and chaos will appear. Even a very small change in λ can change dramatically the system's behaviour. The Hopf bifurcation doubles or multiplies the number of periodic points, one can observe a typical example of structural instability.

In decision making the processes λ can be interpreted as efficiency of the system, the greater λ value the model assigns, the greater weight to the actual status of the system and the gap between the actual status and the limiting value. Here we again identified a situation (in a very simplified model construction) where growth of effectiveness results in destabilization of the system. The similarity with Watt's governor is obvious. It can be proved that the stability condition is $\lambda < 3$.

We have demonstrated with a simple model that if we apply a simple iterative process, it is impossible to get into the equilibrium point, if the process is very effective. The behaviour of the system will be incomputable.

Further on we return to analysis of the impact of ICT on economy. It will be shown that ICT, as a driver of increasing efficiency might have a destabilizing effect.

5. Role of ICT in economic decisions

The economic development of a small or large business, or of a country, or of the global world economy depends on human decisions. The various branches of decision theory provide a throughout description of the role of economic rationality, human psychology, social factors in decision making. We shall analyze the relation of rational decisions and ICT.

The following conclusions are "soft" in a sense that no mathematical proofs will be provided.

In the fifties of the 20th century Herbert Simon [13] demonstrated the thesis of limited rationality, saying that rationality in decision making and optimization have their limits. The "rational man" has boundaries. Boundaries are of different types, e.g., information used by the decision maker is not complete or not correct, outdated, or, the man who tries to be rational doesn't possess adequate tools for processing great amount of information and make optimal decision, it is not always possible to identify unambiguous and computable optimality criteria. The rational decision making is in most cases bounded by cognitive and social factors.

Simon's theory of bounded rationality however, became the part of economic research only in the last twenty years when mathematical models were constructed to describe the decision systems with bounded rationality for finding satisfactory (in opposite to optimal), economic solutions.

In the following we focus on the case of bounded rationality when the most important boundaries are capturing, storing and processing relevant information. Rubinstein [11] set up a few formal models to describe decisions made with bounded information capture, storage, communication and processing. These models show, that with the decrease of the costs of information gathering, processing, etc., the decisions are more and more effective. One can observe, that using Rubinstein's models it can be formally proved, that if one sets aside the psychological and social aspects, which were emphasized by Simon, the fast development of ICT – where development means less cost, higher speed, easy access of the services and applications – increases the effectiveness of the economic decisions.

In the following part we shall analyze how these stability issues appear in practice.

6. Stability of economic systems, is it necessary to throw sand in the gears?

Local and global "crisis" phenomena are in fact unstable behaviour of the system. In the time of a crisis the systems show typical properties of structural instability, while in a "normal" status of the system one can expect, that small changes in the decisions or regulations result in small, predictable changes of the system's behaviour, in the status of structural instability even a small change in the input, e.g., additional information might result in significant oscillations.

The fact that crises usually do not end with a full collapse of the economy is due to the fact, that the communities of countries apply anti-crisis measurements, which are beyond the boundaries of usual economy (intervention of central monetary banks, IMF, government help to the banks, etc.)

The fast development of information technology and telecommunication might lead to instability, as development of manufacturing technology resulted in the instability of the Watt's regulator.

In the past decades one could witness the intensive commerce of complex financial package-products, adding its share to the outburst of the global crisis. Those products were so complex, that their exact components and risks were known and "understood" only by the computers. The complexity and speed of the processes excluded the human decision as a limiting factor. The consequence was the unpredictability of the systems's behaviour.

There is no question that the development of ICT will not be hindered at all by the fear of a possible instability. The stability issue should not be addressed by slowing down the technological development.

The idea of implementing feedback control systems to preserve stability is not new. E.g., Keynes [5] in 1936 suggested to launch a new federal taxation of the stock exchange transactions in order to break down the speculative trade on Wall Street. Tobin [15] in 1978 suggested the idea of international taxation of the currency exchange transactions to prevent the destabilization of the international financial system. Palley [9] demonstrated on a microeconomic model, that the Tobin tax will provide a comparative advantage for the fundamental investors, who prefer stable economy over speculative noise traders, who are interested in instability. The various taxes will reduce the effectiveness of the trading, and in fact they will contribute to the preservation of the stability.

7. Conclusions

The case of Watt's governor demonstrates that the increase in effectiveness might lead to instability. We have also demonstrated on a simple model, that a generally accepted iteration method leading to the equilibrium point, if it is effective, might destabilize the system. Information technology and telecommunication are generally used in decision making as tools to increase effectiveness, and thus can lead to destabilization of the economic systems. The simplest method of preserving stability is the application of taxes, which in turn reduces effectiveness.

The question "how much sand should be thrown in the gears" could be answered only by further research. Several publications aim at the determination of the optimal volume the Tobin tax (e.g., [12]) in special cases, but for general results more exact dynamical models should be built and analyzed.

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