The Model of the IT Impact Treated as Feedback in a Production Environment Based on a Cybernetic Model

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Abstract. This paper presents an approach on the assessment of the impact that Information Technology has in an based- knowledge economy. In order to achieve this goal, we proposed the use of feedback model from the production environment, considered as a cybernetic system. The impact of the IT is treated similarly to the technological and behavioral relationships between the main effects of feedbacks. We also studied different effects that feedback produces as an IT impact.

Feedback and economy dynamics

A cybernetic system consists of a lot of subsystems which evolve in time and are connected in a network by the means of which they influence each other. By combining, within cybernetic systems, some positive and negative feedback, one can obtain very complex behaviors, which are further studied by the economy dynamics. That is why, the study of dynamic processes in the economy starts with defining feedback and the ways that they interact within economic systems [7] The feedback has a series of properties which also lead to a certain type of economy dynamics. By modifying these properties, one can impose a desired dynamic behavior to the system as a whole or to its composing subsystems. The impact of IT on the economic process in general and on decision mechanisms in particular, can be looked upon as a feedback towards adopting the IT [4], [2]. For a correct definition in this given context, several statements regarding feedback in economic systems must be made [1], [3].

According to the inverse connection principle postulated by Wiener, "any cybernetic system contains at least one feedback loop". Applying this principle to economic systems, we know for certain that:

- Any economic system which presents practical interest contains at least one feedback;
- Any economic system is also a subsystem included in a feedback loop, which, in its turn, is also included in an upper level system;
- Any subsystem of an economic system belongs to a feedback loop of the system in its whole [5].

Thus, a whole palette of feedback loops comes to life and they practically influence each subsystem and /or element of an economic system. Because of this predominance, it can be deducted that all processes taking place in an economy – from microeconomic processes (small companies, consumers, banks etc.) to the macroeconomic processes (inflation, unemployment, market lacks of balance) – are affected, in a way or another, by the operation of one or more interconnected feedback loops [6],[7].

The general structure of a feedback is represented in Figure 1.

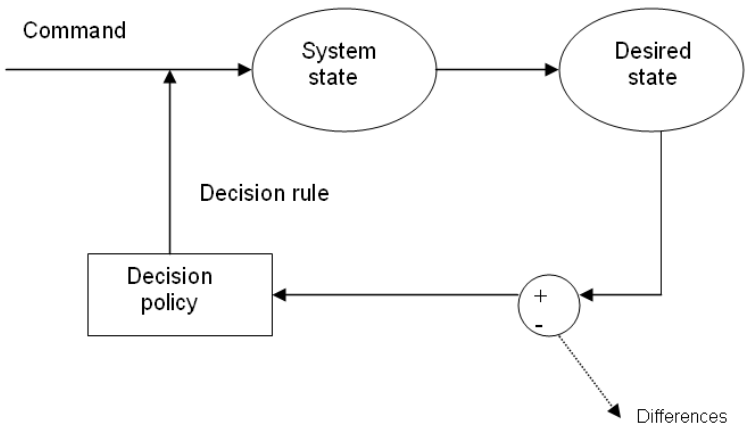

Figure 1. The general structure of a feedback

From the three main types of effects in feedback (identity, technologic and behavioral relationships) solely the last two will be analyzed, because the IT impact could correspond to these models only.

Technologic relationships are causative relationships, so they can modify the ratio between the cause of a phenomenon and the obtained effect.

Considering all the improvements in the IT knowledge in this case, as a learning process based on experience, the result is that the output from moment 2, depends on both the moment 1 inputs and the IT knowledge state at that precise moment.

These relationships between inputs and the knowledge on Information Technology represent technologic restrictions on the production of goods and services at any given moment (t).

The third type of relationship, behavioral relationships, is also causal. Regularly, they are responsible for the way that internal states of a system are determined by external decisions.

For example, past events (the amount of income, prices, existing assets supply etc.) determine the manager of a company to decide what amount of IT products to buy at a given moment. The same way, past events, like the profitability of different companies, bank rates of interest, price changes on the market etc., influence companies towards investing in IT capacities which would produce a growth in the output.

Behavioral relationships are frequently found in economic systems which's feedback loops usually represent behavioral rules for the subsystems and their components. Because all causes precede their own effects in time, the majority of relationships determining the level of a variable depending on other variables will be built in such a manner as to produce the effect (that is to say the determined variable) later than the causes (the explanatory variables) [8].

Any causality relationship can have its own delay, which varies depending on the rate that the represented processes are progressing at. Yet, by convention there can be established an average delay term, which can be tacitly taken into consideration when describing those relationships.

With such a convention in place, it can be observed that a feedback loop can have its own delay, which consists of the sum of all delays that have been defined for the relationships between the variables composing that specific feedback loop.

Thus, **the delay of a feedback** can be defined as the total amount of time that it takes an IT flux injected into that specific loop to go through the entire feedback loop. The elementary loop, which consists only of state and command, has a delay that equals 1. Indeed, as it can be observed in figure 2, the command at the t moment, u_t influences the state at the t moment, x_t, which, in its turn, influences the command at the t + 1 moment, u_{t+1} and so on and so forth.

In feedback loops and extrapolating, in economic systems considered as cybernetic systems, there are three main forms that the response of an influenced variable can take, and those are: the proportional effect, the derivative effect and the complete effect.

Each of those answers can be, in its turn, either a positive or a negative effect.

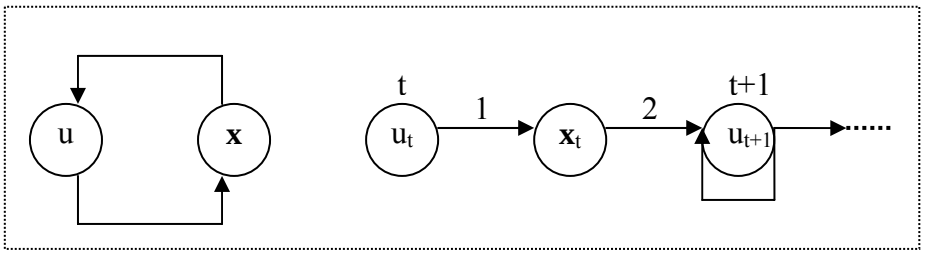

Figure 2. Delays in the command loop

The IT impact, and thus also the feedback effect, can be positive, negative or null. Let us further analyze each case separately.

If we mark the amount of available capital (income) of a company with K and the IT expenses with C^{IT} we can represent this type of relationship with the diagram in figure 3.

Figure 3. Positive and negative proportional feedback

The continuous arrow uniting K and C^{IT} indicates that K's response is a positive proportional effect, so it also indicates that a raise of K always leads to a raise in the C^{IT}.

If we take into consideration the temporal dependency of both variables, it becomes clear that the effect on the C^{IT} needs a certain amount of time in order to manifest itself. Thus, a lagging appears, which, if considered equal to the unit based on a convention, can be described by the means of the mathematical relationship associated to the positive proportional effect represented in figure 3.a. as being:

$$C_t^{IT} = aK_{t-1}$$

where $a \in (0,1)$, may be either a constant or a variable parameter that shows the ratio of the capital spent by managers in that respective company for Information Technology.

An example of **negative proportional effect**:

The smaller the price (P), the bigger the quantity of a certain computer-related product (Q) sold on a market is. Thus, the Q level is negatively dependent on the level of P. In figure 3.b. we represented the negative proportional effect by a dotted arrow which ties the P to the Q.

The mathematical relationship associated to this effect can be most easily stated by observing the influence of the price at the t moment, which manifests itself over the same period influencing the amount of products sold. Also:

$$Q_t = a - bP_t$$

where a and b are constant, *a* representing the quantity of product which would be bought if P equaled zero, and *b* a reaction coefficient (elasticity), which shows the decrease of the acquired quantity *Q* for each increment by one unit of *P*.

Usually, proportional effects (positive or negative) are modulated with the **algebraic linear equations** in the following form:

$$Y_t = a - bX_t$$

where:

$a \geq 0, b > 0, b = 0, b < 0$ depending on the proportional effect being positive, void or negative.

There can be observed that the null proportional effect corresponds to a constant value of the resulting variable: $Y_t = a = ct$ for any *t*.

Example:

Y is the profit made by a company and *X* is the capital invested in IT. The negative proportional effect of the price on the amount of acquired IT products is not the only way buyers respond to changes in price.

For example, there can be emphasized a speculative influence of price changes on the acquiring of products. In the specific case of IT products, there must also be taken into consideration the fact that they have a limited life cycle (3 to 5 years), due to obsolescence, so that a quantity acquired in the present can wind up being affected to a great extent by forecasts on the evolution of prices in the near future, like the next year, for instance. If prices are expected to go up the next year, then the quantity acquired in the present will be larger than the one that would be bought if prices were expected to be stationary or even drop.

What are the reasons which determine the changes in price in the near future? Well, let's assume for a moment that managers consider the simple scenario where prices will go up or down at the same rate that they went up or down in the recent past. For example, they compare prices observed during the current year to the ones observed during the last year. Then a positive differential effect will be obtained and it will be represented like the one in figure 4.a.

The arrow uniting the *P* and the *Q* is continuous, which shows a positive effect, while the multiple arrows show a differential effect too.

Assuming the simplest form that the time difference between the cause and the effect can take, for instance if the speculative request for *Q* at the *t* moment is affected by the current price growth only, when compared to the previous period, we can state that:

$$Q_t = b + c(P_t - P_{t-1})$$

where *b* represents the quantity of IT products to be acquired in the absence of any speculative request. The *c* reaction parameter expresses the number of units that the speculative request for that specific product will be modified with when the price changes with one unit. Obviously, in normal market conditions, that is to say in markets where a price growth determines a growth in the speculative request, $c > 0$.

Figure 4. Positive and negative differential feedback

Let us analyze the relationship between the *P* price change in information technologies and the amount of money destined for IT that the managers have in an economy (monetary balance) *M*.

If the managers expect prices to go up in the near future, then it is convenient for them to spend the money they possess in market transactions, because, in the event of a fast growth of prices (that is to say inflation), the quantity of IT products (hardware + software + IT services) that can be acquired with the same amount of money will be smaller. So the managers are interested in spending as much as they can from their monetary balances and, as a direct consequence, these will be smaller and smaller.

This relationship between prices and the possessed amount of money is represented in figure 4.b. by a dotted line (negative effect) which has multiple arrows (differential effect).

The corresponding equation for this negative differential effect has the following form:

$$M_t = m\text{-}d(P_t\text{-}P_{t\text{-}1})$$

where *m* represents the amount of money that managers will possess independently from the prices inflation and *d* is the reaction parameter that indicates how many units from the money reserve are spent for each unit that prices go up with. Obviously, $d > 0$.

Let us analyze the following example:

Let there be taken into consideration the market for a certain IT product, computers let's say. The total number of computers to be acquired during a *t* time period (a year, for example), X_t will raise proportionally with:

1. the company income;
2. the decrease in the market price for a computer unit;
3. the expectation for prices to go up in the near future;
4. a smaller number of computers possessed by the company.

Thus, we emphasized four types of relationships (influences), which determine the number of computers to be requested on the market at the t moment.

Influence (1) is a **positive proportional effect,** which can be stated as aY_{t-1} and shows that part of the income at the *t–1* moment will be spent on computers.

Influence (2) is a **negative proportional effect,** which can be stated as $A - bP_t$ where A represents the number of computers that would be requested if prices were very small.

Influence (3) is a **positive differential effect**, which can be stated as $B+c(P_t\text{-}P_{t\text{-}1})$.

Influence (4) is a **negative integral effect,** which can be stated as:

$$E - d(X_{t-1} + X_{t-2} + X_{t-3}) + X_{t-3}$$

assuming that a computer is used during 3 time periods, that is to say for three years.

In figure 5 we represented the main introduced effects. In fact, it is a model based on a simple feedback loop, which's operation depends on the *Y* and *P* exogenous variables.

Summarizing, the equations for the four effects can be stated as:

$$X_t = aY_{t\text{-}1} + A - bP_t + B + c(P_t - P_{t\text{-}1}) + E - d(X_{t\text{-}1} + X_{t\text{-}2} + X_{t\text{-}3}) + X_{t\text{-}3} \text{ or}$$
$$X_t = F + aY_{t\text{-}1} + (1\text{-}d)X_{t\text{-}3} + (c - b)P_t - cP_{t\text{-}1} - dX_{t\text{-}1} - dX_{t\text{-}2},$$

where $F = A + B + E$.

The obtained relationship synthetically expresses the operation of feedback loops represented in figure 5. It shows that the level of *X* during the *t* time period depends on the levels of *X*, *Y* and *P* during previous periods and also on the values of the *F* constant and on the *a, b, c* and *d* reaction parameters. Thus, separating the endogenous variable of the feedback loop from the exogenous variables, we obtain:

$$X_t + dX_{t\text{-}1} + dX_{t\text{-}2} - (1\text{-}d)X_{t\text{-}3} = aY_{t\text{-}1} + (c - b)P_t - cP_{t\text{-}1} + F$$

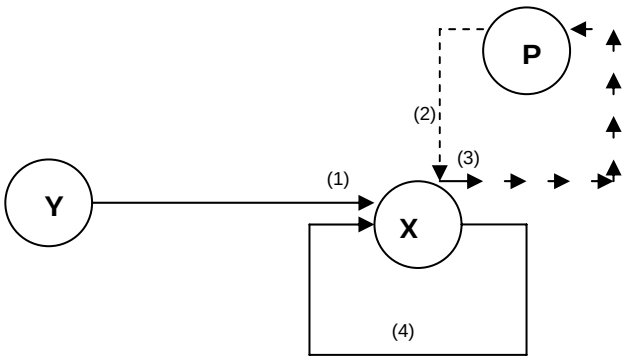

Figure 5. The effects introduced in the model

If we know, based on certain hypothesis or existing knowledge, the evolution of the Y and P exogenous variables, then we can determine the solution for this dynamics equation of the feedback loop represented in figure 5. Mathematically, it is an equation with n order finite differences, where n stands for the total amount of delay for the specific feedback loop.

According to the cybernetic system theory, feedback loops can be positive or negative. The following part will analyze the impact of IT as either a positive or negative effect in a feedback loop.

Let us consider the following example. The IT industry uses a certain type of work. The employees possessing an IT degree can obtain a certain wage *w** in other industries.

Workers can be attracted in that certain industry at a rate that becomes greater as the difference between the medium wage rate in that industry (w) and the medium wage rate outside that industry, that is to say IT (w*) increases.

The labor request N^D in a certain industry depends on the size of the wage rate *w;* a big wage rate determines a small labor request. More, wage rate *w* goes up or down depending on the excess of deficit between the offer N^S and request N^D for jobs in that given industry.

In this example, we can emphasize two negative feedback loops which act interdependently.

The first loop: If the industry wage rate is bigger, then the request for jobs N^D will be smaller; then there will be a request deficit (offer excess) for labor, the request N^D being smaller than the offer N^S. This results in a decrease in the salary rate *w* for that specific industry.

Summarizing, there can be observed that a high wage rate *w* will lead to a decrease of the wage, so the feedback loop is negative. This feedback loop is described in figure 6.

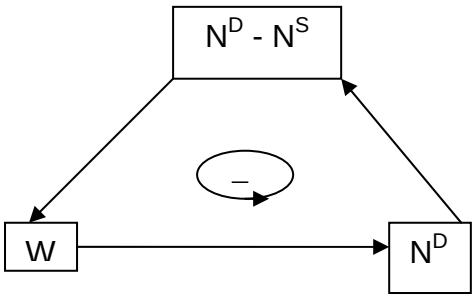

Figure 6. The first negative feedback

Also, the effect induced by the described feedback loop can be represented using the *transmission effect diagram:*

$$w\uparrow \Rightarrow N^D\downarrow \Rightarrow (N^S - N^D)\uparrow \Rightarrow w\downarrow$$

Second loop: If the wage rate in the industry (*w*) is bigger than the rate of the wage in the IT industry (*w**), then the IT workers will be more rapidly attracted into the industry and the IT job offer (N^S) will go up. Sooner or later, an excess of IT labor offers ($N^S - N^D > 0$) will occur and it will determine the decrease of the wage rate *w* in the industry. In figure 7 we represented this new feedback.

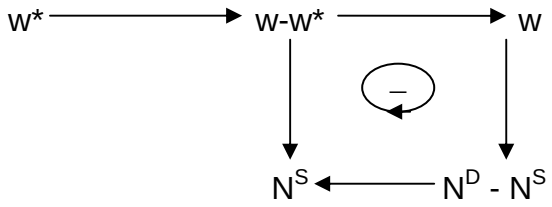

Figure 7. The second negative feedback

The diagram for the transmission effect associated to this feedback is stated like this:

$$w \uparrow \Rightarrow (w - w^*) \uparrow \Rightarrow N^S \uparrow \Rightarrow (N^S - N^D) \uparrow \Rightarrow w \downarrow$$

The model for the two feedback loops will be:

$$N_t^D = \overline{N}^D - \alpha w_t \quad (1)$$

$$w_t - w_{t-1} = \lambda(N_{t-1}^D - N_{t-1}^S) \quad (2)$$

$$N_t^S - N_{t-1}^S = \mu(w_{t-1} - w^*) \quad (3)$$

The relationship shows that the request for IT work in that specific industry at the *t* moment is inversely proportional with the wage rate offered at the beginning of the *t* period. So the function for the work request is linear, $\overline{N}^D$ representing the work request in the case where the wage rate $w_t < 0$, and α represents the number of employees by which the request drops for each increment with one unit of the wage rate w_t.

Equation (2) describes the way that the excess or lack of IT labor demand can determine a growth or a drop in the IT wage rate for that industry. Thus, if during the period *t-1*, $N^D_{t-1} > N^S_{t-1}$, then an excess of labor demand will occur, which will determine a growth of the IT wage rate in the industry.

In order to establish the dynamics of w_t, under the influence of the joint action of the two feedback loops, equations (1) – (3) will be solved, considering that $\overline{N}^D$, N_0^S, w* and the α, λ and μ coefficients are known.

By replacing equation (1) inside equation (2), we obtain:

$$w_t - w_{t-1} = \lambda(\overline{N}^D - \alpha w_{t-1} - N_{t-1}^S) \quad (4)$$

Relation (3) can be rewritten:

$$N_t^S = N_{t-1}^S + \mu(w_{t-1} - w^*) \quad (5)$$

and

$$N_{t-1}^S = N_{t-2}^S + \mu(w_{t-2} - w^*) \quad (6)$$

Replacing (6) in (5) results in:

$$N_t^S = N_{t-2}^S + \mu(w_{t-1} - w^*) + \mu(w_{t-2} - w^*) \quad (7)$$

After t-1 steps we obtain:

$$N_t^S = N_0^S + \mu(w_{t-1} + w_{t-2} + \ldots + w_0) + \mu(t-1)w^*$$

so also:

$$N_{t-1}^S = N_0^S + \mu(w_{t-2} + w_{t-3} + \ldots + w_0) + \mu(t-2)w^* \quad (8)$$

By replacing relationship (8) inside relationship (4) we obtain the equation:

$$w_t - (1 - \alpha\lambda)w_{t-1} + \lambda\mu(w_{t-2} + w_{t-3} + .. + w_0) = \lambda\left[\overline{N}^D - N_0^S - \mu(t-2)w^*\right]$$ the solution of which represents the dynamics of the IT wage w_t in the considered industry.

A positive feedback loop has the following equations:

$$\begin{cases} N_t^D = \overline{N}^D - \alpha w_t + \beta(w_t - w_{t-1}) \\ w_t = w_{t-1} + \lambda(N_{t-1}^D - N_{t-1}^S) \\ N_t^S = N_{t-1}^S - \mu(w_{t-1} - w^*) \end{cases}$$

The transmission effect associated to this loop is:

$$w \uparrow \Rightarrow N^D \uparrow \Rightarrow \left(N^D - N^S\right) \uparrow \Rightarrow w \uparrow$$

Conclusions

In the above paper we tried an approach on the impact that IT has, as a component of a feedback, on the production system of a company.

This method can be classified as an « a priori » quantitative analysis and assessment way for the IT impact. Obviously, some simplifying has been done for the hypothesis and information technologies have been separated from other economic indicators.

Yet, as it was emphasized [Nov 11], the IT impact is a *sumum* of impacts for different performance indicators that are taken into consideration.

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