SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

CONTRACTED STUDY AGREEMENT REG / POL / 1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 1

BACKGROUND METHODOLOGIES

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A.STRASZAK

ZTS/ZPZC/ZTSW 1-36/85

WARSAW 1986

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Consisting of 3 Parts

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IX. MICROCOMPUTER SIMULATION OF THE DYNAMIC BEHAVIOR OF ECONOMIC AGENTS

by A. Straszak, J. Stefański, A. Ziółkowski

IX.1 Introduction

In each regional economy system economic agents are free to act within a certain legislative framework. An important aspect of that framework is formed by tax regulations which are used by the center (say, a governmental agency) as a tool for influencing the economic agents' (enterprises') behavior. In 1982 a economic reform was introduced in Poland. This reform can be characterized by the extensive use of economic regulators. One of the main roles in the system is played by the tax regulator directed at controlling the wage funds in enterprises, which is connected with the government's efforts to bring down inflation. Over the period 1982-85 one type of a regulator of that kind has been used. The economic authorities have learned from the four years' experience and decided to introduce, for the next years, a set of five types of regulators under consideration (the old type has been included in this set as the tax formula 1).

It is worth emphasizing that an economy in which tax regulato are used behaves in a different way than a system under a "rigid" control and also differently from a pure "market" economy. It turns out that in the process of investigating the expected results of introducing new economic regulators computer simulation is very useful. In most instances the effects that regulations may have are hard to grasp - one of the reasons is that managers and other actors influencing the economic situation have no intuition about them. In such a situation interactive computer system and simulations are very effective, Sheridan (1984), Stefański, Ziółkowski (1984), Straszak et al. (1986), Si Shi-quan (1984), Tuggle and Gerwin (1980), Witt (1985).

In the process of obtaining insights into the nature of the economic system's behavior, Kuipers (1984), the data and knowledge representation play an important role Sage, (1984), Straszak et al. (1986).

In this chapter an approach to the simulation of the effects of the introduction of a new set of economic regulators is presented, as well as some examples of results. The computer system we have used has been implemented on the Polish ComPAN-8 microcomputer and currently is being implemented on the IBM PC.

IX.2 Tax regulation in the Polish economic system

Typically, tax regulations play a twofold role. First, they enable the center to build up and then to redistribute financial resources, and second, they are used by the government as a tool for influencing the firms´ behavior. The question connected with the latter role concerns the goal the government wants to attain by influencing the enterprises´ behavior. It is reasonable to assume that the government manipulates firms for its "own" benefit which, in fact, embodies many aims a society as a whole wants to achieve. These aims depend on a particular economic situation in a country, and therefore in further considerations we focus our attention on tax regulations in Polish economy.

Each economy is a hierarchical system with a certain number of organizational levels, Auger (1985). Two of those levels, namely the governmental one and the firm´s level play especially important roles which receive some attention lately, Salman, Cruz (1981), Stefański (1984), Stefański and Cichocki (1985), Straszak et al. (1985, 1986), Takayama and Simaan (1983), Ziółkowski et al. (1984). On the other hand a firm is usually treated as a single decision maker unit which maximizes profit and/or production level, Fisk (1980), Tuggle and Gerwin (1980), Ziółkowski et al. (1982). This is however a simplifying assumption which makes it impossible to explain the true nature of the decision making process in an enterprise. If one wants to describe that process properly, he ought to take into account the fact that there exist at least two groups of people with different objectives, namely managers and workers, Stefański (1985a) (the conflict of interests between managers and shareholders is also taken into account in Atkinsen and Neave (1983)).

We have mentioned the worker - manager conflict because actually the decisions made in a firm reflect the compromise the both parties achieve, Chen and Leitman (1980), Stefański (1985b). And, on the other hand, the interest of employees, who want to maximize income, is to some extent opposite to one of the government´s goals in Poland, i.e. to the aim of reducing inflation. That inconsistency of interests was a motivation for developing a special tax system in Poland. Many various tax regulation formulas were proposed and computer simulation appeared to be the most effective way of investigating the economy system´s reactions to them.

It has turned out that the complex nature of the economic agent´s behavior can be satisfactorily explained if an economy is conceived as a system with different decision makers having different goals. We distinguish in our approach a governmental agency, which designs tax regulations, and a firm which, in turn, is under the control of its management and employees. It seems obvious that the statuses and roles of the above mentioned parties are different, and therefore the system can be represented as a hierarchical system with three or two (if managers and workers behave cooperatively) decision makers.

During computer simulations we focus our attention on the influence of various tax regulation upon an enterprise´s behavior. The aspects of competition among firms is neglected. A firm is described by the state equation

$$x\,(t+1) = F\,(x\,(t),\ u_o(t),\ u_1(t),\ z(t)) \qquad \text{(IX.1)}$$

where t is time period (in our case a year), $x(t) \in X$ vector of state variables, $u_o(t) \in U_o$ is the government´s control variable, in our case it is the amount of money paid as taxes (we confine our interest to a special tax strongly connected with the employees´ income), $u_1(t) \in U_1$ is the vector of the firm´s decisions, and $z(t) \in Z$ is the vector variables describing environment (inflation rate, market characterization). The vector of firm´s decisions contains the following variables: production level, employment, wages, investments, advertisement expenditures, cost of raw materials and energy (which is connected with the technology chosen), and R & D expenditures.

We interpret tax regulations as the government´s strategy

$$\gamma_o : X \times U_1 \rightarrow U_o \qquad \text{(IX.2)}$$

Thus $u_o(t) = \gamma_o(x(t), u_1(t))$ is the money paid by a firm as a tax. The government faces the problem of designing tax regulations in such a way as to attain its goals represented by the objective $J_o = \Phi(J_o^1, \ldots, J_o^M)$,

$$J_o^i(\gamma_o, \gamma_1) \stackrel{\wedge}{=} \sum_{t=0}^{T} g_o^i(x(t), u_o(t), u_1(t), z(t)) \qquad \text{(IX.3)}$$

where T is time horizon (in our simulations five to ten years), γ_o is tax regulation, and γ_1 the firm´s strategy $\gamma_1 : H_1 \rightarrow U_1$, where, in turn, H_1 is the firm´s information set. In our case

$$H_1 = (\gamma_o, x(t), z(t)) \subset \Gamma_o \times X \times Z \qquad \text{(IX.4)}$$

by which we mean that the decision makers in a firm know its state $x(t)$, tax regulations γ_o, as well as the current features of the market and the inflation rate. From (IX.4) and (IX.2) it follows that the system under consideration is hierarchical, and the task of designing γ_o can be formulated as an incentive design problem, Ho, Luh and Olsder (1982), Zheng, Basar, Cruz (1984). Namely, the government wants to find γ_o^* such that

$$\gamma_o^* = \arg\max_{\gamma_o \in \Gamma_o} J_o(\gamma_o, R(\gamma_o)), \qquad \text{(IX.5)}$$

where $\gamma_1 = R(\gamma_o)$ describes the optimal firm´s behavior as a function of the announced tax regulations γ_o:

$$R(\gamma_o) = \arg\max_{\gamma_1 \in \Gamma_1} J_1(\gamma_o, \gamma_1), \qquad \text{(IX.6)}$$

where J_1 is the firm´s objective.

The government is faced here with three problems. First, it is very difficult to solve (IX.5). Second, typically firms are not in a position to solve (IX.6) in order to adapt optimally to a tax regulation. And third, γ_o must be valid for various firms, with various cost structures, operating in different maketo, and the final regulation γ_o ought to be a compromise among many solutions of the problems like (IX.5). Because of the above mentioned difficulties the authorities in Poland consider five different tax formulas $\{\gamma_o^1, \gamma_o^2, \ldots, \gamma_o^5\} = \Gamma_o$, and computer simulations play an important role in obtaining insights into the enterprises' behavior under different γ_o^i and in suggesting the proper values of parameters of the tax functions $\gamma_o^i \in \Gamma_o$.

IX.3 Microcomputer simulation of the Polish tax regulation system

As it has been mentioned in section 2 of this chapter we confine our interest to the simulation of tax regulations connected with the increase of wage funds in enterprises. The main aim of introducing the special tax of this kind in Poland was to bring down inflation through high taxes on the wage fund increase in each firm, and through stimulation of the production level increase.

There are five different tax formulas which the government wants to apply and we represent them here as a a set of the government's strategies $\Gamma_o = \{\gamma_o^1, \gamma_o^2, \dots, \gamma_o^5\}$. All the functions $\gamma_o^i \in \Gamma_o$, $\gamma_o^i : X \times U_1 \to U_o$, are nonlinear and strongly progressive, their value determines the amount of money a firm must pay as the tax under consideration (under the ith formula, $i \in \{1, \dots, 5\}$) i.e. $u_o^i(t) = \gamma_o^i(x(t), u_1(t))$. The four first functions from Γ_o are defined in the following way:

$$u_o^i(t) = \begin{cases} f(r(t)) & \text{if } q(t) > v^i(t) \\ 0 & \text{if } w(t) < v^i(t), \quad i=1,2,3,4, \end{cases} \tag{IX.7}$$

where $w(t)$ is the wage fund, $r(t)$ is the relative wage fund increase in period t:

$$r(t) = \frac{w(t) - w(t-1)}{w(t-1)}, \tag{IX.8}$$

$v^i(t)$ is a threshold value, and f is a nonlinear increasing function depicted in Figure IX.1.

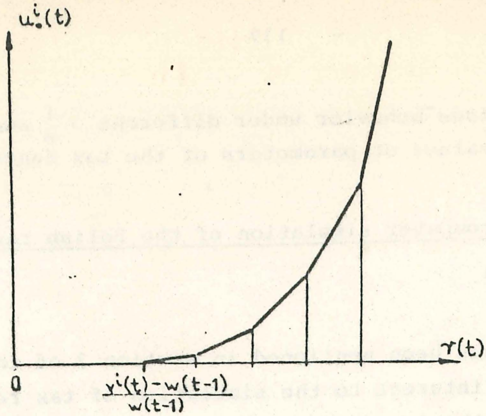

Fig. IX.1 Illustration of the form of strategies $\gamma_o^i \in \Gamma_o$, i=1,2,3,4 (see (IX.7)).

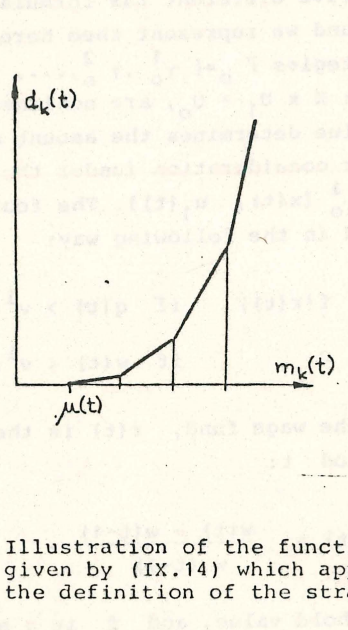

Fig. IX.2 Illustration of the function $d_k(t)$ given by (IX.14) which appears in the definition of the strategy $\gamma_o^5 \in \Gamma_o$.

The threshold value $v^i(t)$ is computed in each year, in a different way for each of the four formulas γ_o^i, $i=1,\dots,4$. For $i=1$ its definition depends on the production level $q(t)$ (compared to $q(t-1)$):

$$v^1(t) = v^1(t-1)\left(1 + k_1 \frac{q(t) - q(t-1)}{q(t-1)} + p_1\right), \qquad \text{(IX.9)}$$

where k_1 and p_1 are parameters. In γ_o^2 the definition of the threshold is simplified:

$$v^2(t) = v^2(t-1)\,(1 + p_2). \qquad \text{(IX.10)}$$

In the case of γ_o^3 it also depends on the production level $q(t)$:

$$v^3(t) = v^3(t-1)\left(\frac{k_3\, q(t)}{q(t-1)} + p_3\right). \qquad \text{(IX.11)}$$

The fourth formula is bound up with the profit in year t,

$$\pi_t = \pi(x(t),\ u(t),\ z(t)),$$

$$v^4(t) = v^4(t-1)\left(1 + k_4 \frac{\pi_t - \pi_{t-1}}{\pi_{t-1}} + p_4\right). \qquad \text{(IX.12)}$$

The last, fifth strategy is defined in a quite different way which is based on individual employees' wages. Let us denote the income of the k-th employee in year t by $m_k(t)$. Then the whole firm's wage fund is

$$w(t) = \sum_{k=1}^{K} m_k(t), \qquad \text{(IX.13)}$$

if the number of employees is K. The due connected with the k-th employee is determined in the following way:

$$d_k(t) = \begin{cases} \rho\,(m_k(t) & \text{if} \quad m_k(t) > \mu(t) \\ 0 & \text{if} \quad m_k(t) \leqslant \mu(t), \end{cases} \qquad \text{(IX.14)}$$

where ρ is a progressive function (see Fig. (IX.2) and $\mu(t)$ is a threshold announced in each year by a governmental agency.

Next, the amount of money which must be paid by a firm is computed as a difference between the sum of all dues in the current, and in the previous year:

$$u_o^5(t) = \sum_{k=1}^{K} d_k(t) - \sum_{k=1}^{K} d_k(t-1) \qquad \text{(IX.15)}$$

In order to investigate the behavior of the economic system roughly outlined here in section IX.2, the specialized interactive system described shortly in the Appendix to the Report (Part 3), has been used. Extensive possibilities the system offers greatly faciliate the process of obtaining insight into the influence of tax regulations $\gamma_o^i \in \Gamma_o$ upon the system´s behavior. In the sequel some examples are mentioned.

Although the analytic forms of the strategies $\gamma_o^i \in \Gamma_o$ seem to be uncomplicated, the effects these tax regulations may have are in many cases hard to grasp. Let us take as an example the influence of the strategies´ parameters upon a firm´s profit. Figure IX.3 illustrates the situation under γ_o^3, namely the sensitivity of the firm´s profit to changes in the parameter p_3 in different time periods (see (IX.11)). Note that there exist two characteristic values p_3' and p_2'' such that for $p_3 \leq p_3'$ profit decreases in time, for $p_3 \geq p_3''$ it increases with time, while for $p_3' < p_3 < p_3''$ there is an optimum of profit behavior in time. In Figure IX.4 the second and the third case in illustrated by the profit changes over the period of five years.

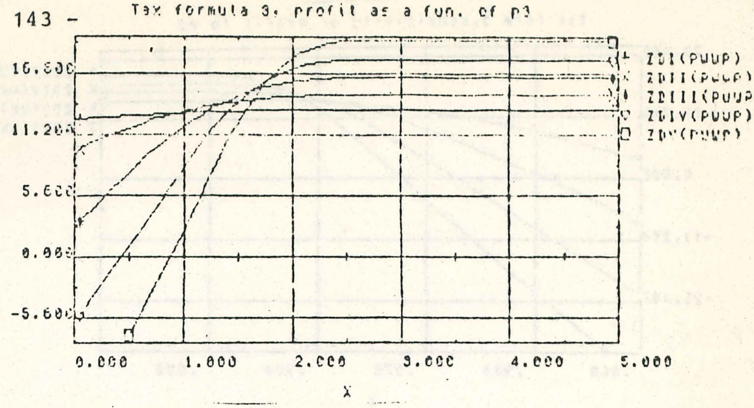

Fig.IX.3 Sensitivity of the firm's profit to changes in p_3 (see (IX.11)) in different years t=1 (+), 2(x), 3(*), 4(♡), 5(□).

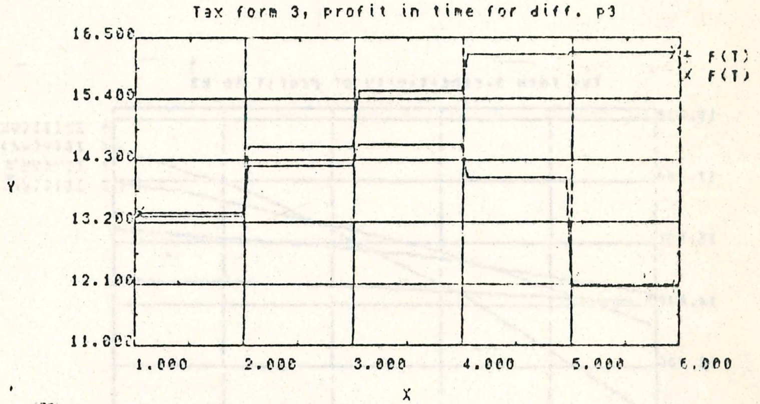

Fig.IX.4 Firm's profit in time for two different values of the parameter p_3 ($p_3 > p_3''$ and $p_3' < p_3 < p_3''$, in the latter case there is an optimum).

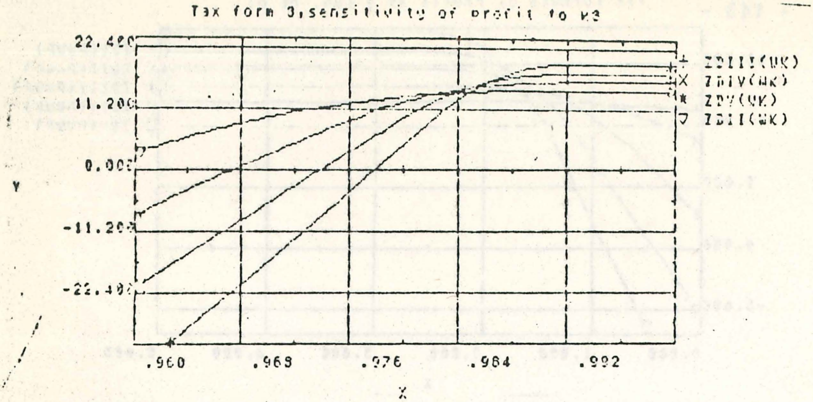

Fig.IX5a. Sensitivity of the firm's profit to changes in the parameter k_3 in different years (t=2(▽), 3(+), 4(x), 5(*).

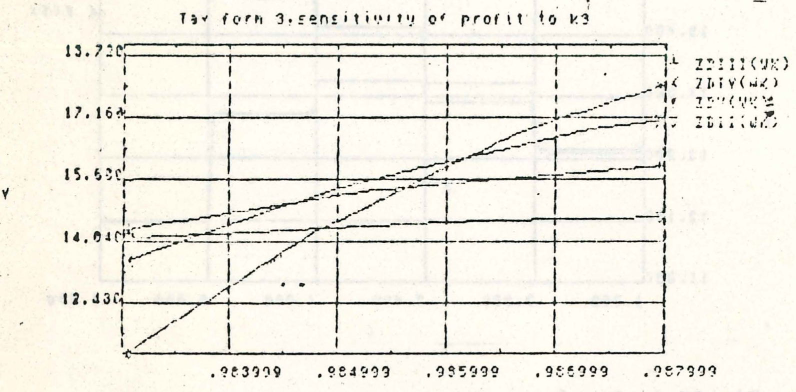

Fig. IX5b. Enlargement of a part of the Figure IX.5a.

In Figure IX.5a the sensitivity of profit in different years to changes in the parameter k_3 (see (IX.11)) is depicted. The situation is here similar to the one previously considered, but the enlargement of a part of Figure IX.5a in Figure IX.5b enables us to note an interesting property. In figures IX.5a and IX.5b we have distinguished three characteristic values of k_3, i.e. $k_3^{(1)}$, $k_3^{(2)}$, and $k_3^{(3)}$. From Figs. IX.5a, 5b it follows that (if we consider the time periods $t=1,\dots,5$) for $k_3 < k_3^{(1)}$ profit is maximized in the second year, for $k_3^{(1)} < k_3 < k_3^{(2)}$ in the third year, for $k_3^{(2)} < k_3 < k_3^{(3)}$ in the fourth, and for $k_3 > k_3^{(3)}$ in the fifth year. Thus, for instance , if the government agency choses $k_3 \in [k_3^{(1)}, k_3^{(2)}]$ it is very likely that the firm will continue its policy up to $t=3$, and then a change in the firm's strategy can be expected.

As we have already mentioned in section IX.2 we consider an enterprise to be a coalition of the employees and the management. There is no doubt that the main employees' goal is to maximize the wage fund. On the other hand it is natural that one of the main components of the management's objective is profit.

Thus, the cooperative agreement between those two parties must be based on the profit and wage fund they want to attain. Roughly speaking we can say that the pair (π_t, $w(t)$ describes to some extent the situation in a firm. In Figure IX.6 the influence of the parameter k_1 of tax regulation γ_o^1 upon the dynamic changes in the enterprise's situation is illustrated.

Figure IX.7 is an example of the study of influence of changes in the firm's strategy upon the economic system's situation over time. When making this figure we assumed that the coalition of employees and managers, i.e. the firm's joint decision ..

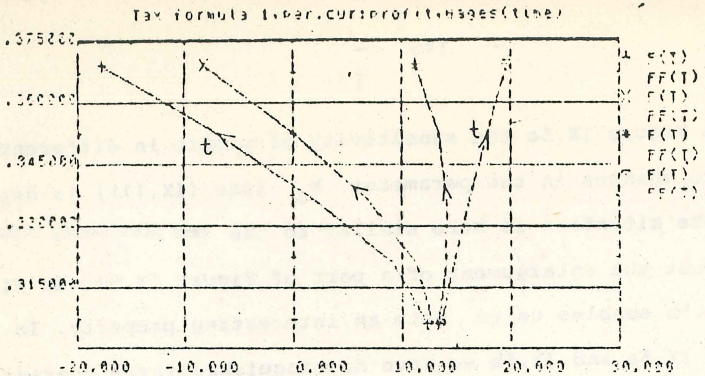

Fig.IX.6. Illustration of the influence of the parameter k_1 (under γ_o^1) upon the dynamic changes in the situation inside a firm (parametric curves for different k_1: firm's profit and wage fund with time as a parameter; $k_1^{(1)}(\nabla) > \ldots > k_1^{(4)}(+)$).

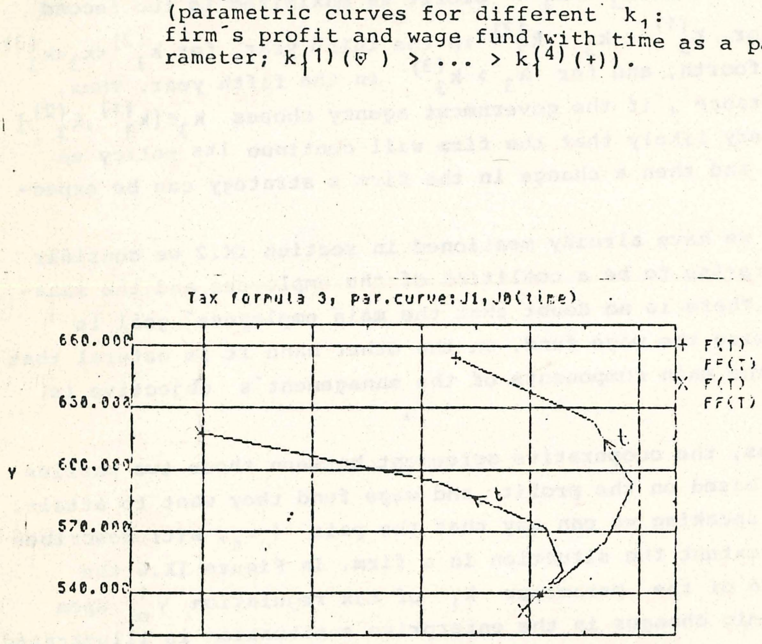

Fig.IX.7. Illustration of the dynamic changes in the government's (J_o) and the firm's (J_1) objectives for two different firm's strategies (curve denoted by + : if the more effective technology is chosen).

maker, wants to maximize the sum of profit and wage fund. On the other hand it is assumed that the government s goal is to reduce inflation, which can be reflected by the minimization of w(t)/q(t), where q(t) is production level and w(t) the wage fund. In Fig.IX.7 we have two parametric curves, with time as a parameter, for different firm s strategies. The difference consists in the change of technology - for the curve designated the more economical technology has been chosen.

IX.4 Concluding remarks

The main purpose of the approach we have outlined in this chapter is to help the central planner in a regional economy system to obtain insights into the nature of the consequences of his decisions concerning tax regulations. In investigating these consequences we take into account the disagreement of interests among economic agents at different levels of hierarchy. Such an approach turned out to be very useful because in the process of designing new tax regulations it is often very difficult to grasp the way in which they could influence the behavior of economic agents. It is worth emphasizing that an important role in the approach is played by the interactive computer system specially built to support simulations of economic systems.

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STUDY REPORT

PART 1: B

AUTHORS: A
J.
A
J.
K
M
W
J.
A

PART 2: POLISH CASE STUDY REPORT

AUTHORS: J.W. OWSIŃSKI
W. CIECHANOWICZ
J. BABAROWSKI
A. STRASZAK
A. JAKUBOWSKI

PART 3: APPENDIX: SOFTWARE AVAILABLE

AUTHORS: L. KSIĘŻOPOLSKA
S. ZADROŻNY
J.W. OWSIŃSKI
T. ROMANOWICZ
A. ZIÓŁKOWSKI
W. CICHOCKI
C. IWAŃSKI
A. KAŁUSZKO
P. HOLNICKI

ABC — UZP