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FOREWORD

The CIM Project has developed cost-benefit models, based on the production function approach to make an assessment of economic impacts of robotics and to forecast the future penetration of robotics. The current paper is an extension of this basic approach to planned economies, by using CSSR statistics. It is especially interesting, as it provides a greater insight of penetration and future forecasts of robotics in planned economies.

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I. INTRODUCTION

One of the most important components of Computer Integrated Manufacturing (CIM) is that of Industrialized Robots (IR). We are now witnessing many attempts to forecast the future of IR penetration in many different countries [see, for example, Blair and Vickery, 1987; Edquist and Jacobsen, 1986; ECE, 1985; Filemon, 1987; and Yonemoto, 1987]. The forecast is usually based on econometric models, using mainly different forms of production functions.

It is worthwhile stressing that IR adoption entails a number of consequences, the most important of which is, from the economic point of view, labor substitution. The effectiveness of this substitution is the key point of the speed of industrial robot (IR) penetration in different manufacturing systems. It may be plausible to assume that the conditions for the rate of penetration differ with companies, enterprises and industries as well as with economic systems.

The latest newly developed models at IIASA for the forecast of robotization of industrial production -- expressed in terms of number of applied IR and worked out by Shunsuke Mori [see Mori, 1987] and Akira Tani [see Tani, 1987a and 1987b] are also based on the production function. The core of these prognostic models is the ratio of prices of individual robots to wages.

Econometric models of that kind are mainly applied to market economy countries. Models based on the ratio of IR prices to wage levels turn out to be too simplified under the conditions of centrally planned economies. For this reason one cannot use a model which is based on salaries and IR prices for centrally planned economies. Instead, one must include other factors in the model which are important for IR penetration in these economies.

The second reason is sometimes the lack of available data due to the confidential nature of a great part of the required material. The information systems, in general, need some improvement, and there exist various suggestions for improving the current situation.

The main reason, however, is that the management mechanisms of centrally planned economies are fundamentally different. While the prognosis of the future penetration in market economies is theoretically based on an equilibrium wage and IR price development, in centrally planned economies wages and IR prices are planned and regulated centrally.

Under the conditions prevalent in many centrally planned economies in the past, the use of econometric models of this type has been irrelevant. Nowadays practically all those economies are trying to improve their economic mechanism and increase the relative economic independence of enterprises and companies. The main goals of these new perestroika or restructuring policies are to increase the initiative and socialist entrepreneurship of the companies' management and to hasten technological progress and the introduction of new technologies. Such goals -- which have already been realized in some areas -- create completely new conditions for the adoption of econometric methods in centrally planned management.

The main aim of this paper is to demonstrate the possible utilization of prognostic models under the conditions of centrally planned economies, mainly on the governmental level. Under the changed economic conditions, the government can manage the planned robot diffusion by applying indirect tools, such as price and tax measures.

It must be stressed that this kind of model is one of the first attempts to forecast industrial robot penetration in centrally planned economies. In our opinion Czechoslovakia, a centrally planned economy with a very high level of industry, automation of industrial production and a relatively high population of robots per capita, provides a good case for the application of this prognostic model.

II. THE PROGNOSTIC MODEL

Let us start from the annual time series and let t be that time, which the values of the time series are referred to.

We denote the growing rate of the number of IR in a given production system in time to by the following equation:

$$I_t = \frac{U_{t+1} - U_t}{U_t} \tag{1}$$

where U_t is the number of industrial robots in time t.

We can model IR diffusion in the manufacturing process from the presumption that the rate of growth in time t is partly dependent on the relation between labor and robot costs, and partly on the relation between the marginal product of human labor and robot labor.

The marginal product of human labor is the increase in output of the manufacturing system resulting from the addition of one worker to the system while providing the system with all other manufacturing resources.

The marginal product of robot labor in that system denotes the possible increase of production of that particular system by the installation of one robot while providing the system with all other manufacturing resources.

If the ratio of labor costs to robot costs and the marginal product of one robot to the marginal product of one worker in a system is growing, then there are favorable economic conditions for IR adoption in this respective manufacturing system.

If we assume $g_{1,t}$ to denote the ratio of human labor cost to robot installation cost and $g_{2,t}$ the ratio of marginal product of robot labor to the marginal product of one worker, then the growth rate of the number of IR can be expressed as a function

$$I_t = f(g_{1,t}, \quad g_{2,t}) \tag{2}$$

where function f satisfies the following conditions:

$$\frac{\partial f}{\partial g_{1,t}} > 0 \tag{3}$$

$$\frac{\partial f}{\partial g_{2,t}} > 0 \tag{4}$$

These conditions are satisfied, for instance, by the function

$$I_t = k \cdot g_{1,t} \cdot g_{2,t} \tag{5}$$

If we denote human labor costs in time t $C_{L,t}$, then we can approximately define $C_{L,t}$ as follows:

$$C_{L,t} = W_t L_t + \omega_t W_t L_t + \gamma_t W_t L_t \quad , \qquad (6)$$

where

W_t is the average annual wage of one worker

L_t is the number of workers

ω_t is the wage tax rate (paid by the company)

γ_t is the rate of additional costs (e.g. for social provisions, etc.).

If we denote the operational costs of one robot by $C_{R,t}$, then the following equation holds approximately true:

$$C_{R,t} = \delta_t \; P_t \; U_t + \lambda_t \; P_t \; U_t + \alpha_t \; P_t \; U_t \qquad (7)$$

where

U_t is the number of IR (as above)

P_t is the robot price

δ_t is the robot depreciation rate

λ_t is the annual capital charge (based on the installation value of production capital goods)

α_t is the rate of additionally required costs.

Under these conditions the ratio $g_{1,t}$ holds true

$$g_{1,t} = \frac{C_{L,t}}{C_{R,t}} = \frac{W_t L_t + \omega_t W_t L_t + \gamma_t W_t L_t}{\delta_t P_t U_t + \lambda_t P_t U_t + \alpha_t P_t U_t} \qquad (8)$$

hence

$$g_{1,t} = \frac{(1 + \omega_t + \gamma_t)}{(\delta_t + \lambda_t + \alpha_t)} \cdot \frac{W_t}{P_t} \cdot \frac{L_t}{U_t} \qquad (9)$$

It is possible to derive the $g_{2,t}$ ratio from a dynamic production function of the following type:

$$Y_t = a_t\, K_t^{b_t}\, L_t^{c_t}\, EN_t^{d_t}\, U_t^{e_t} \quad , \tag{10}$$

where

Y_t is the gross production of the manufacturing system in constant prices

K_t are the production capital costs without IR in installed prices

EN_t is electricity consumption in kWh

a_t, b_t, c_t, d_t, e_t are variable proportional parameters.

The marginal product of human labor and robot labor is -- on the basis of the above-mentioned model (10) -- directly dependent on a partial derivative of the production function by the number of workers and the number of IR.

Under such conditions $g_{2,t}$ can be expressed in the following form:

$$g_{2,t} = \frac{\dfrac{\partial Y_t}{\partial U_t}}{\dfrac{\partial Y_t}{\partial L_t}} = \frac{e_t}{c_t} \cdot \frac{L_t}{U_t} \tag{11}$$

The proportional parameters of the production function can be specified, e.g., by means of the least square method in logarithmic form with exponential forgetting.[1]

The resultant relationship for the growth rate of the number of IR can be defined as follows:

$$I_t = k\, \frac{e_t}{c_t}\, \frac{(1 + \omega_t + \gamma_t)}{(\delta_t + \lambda_t + \alpha_t)}\, \frac{W_t}{P_t}\, \frac{L^2_t}{U^2_t} \quad , \tag{12}$$

or, let us say for the number of installed robots in the respective manufacturing system the following recurrent relationship holds:

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[1]The dynamic production function is a square root filter for real time multivariable regression. For more details, see [Zaruba, 1985].

$$U_{t+1} = U_t + k \frac{e_t}{c_t} \frac{(1 + \omega_t + \gamma_t)}{(\delta_t + \lambda_t + \alpha_t)} \frac{W_t}{P_t} \frac{L^2_t}{U_t} \qquad (13)$$

Constant k can be determined from the previous period by means of a simple linear regression.

The augmentation of the number of installed robots can then be expressed on the basis of the following five partial factors:

f_1: $\frac{e_t}{c_t}$ expresses the ratio of the influence of technological conditions of the manufacturing system on the IR adoption;

f_2: $\frac{1 + \omega_t + \gamma_t}{\delta_t + \lambda_t + \alpha_t}$ expresses the ratio of the influence of the government on the penetration of IR in the respective manufacturing system;

f_3: $\frac{W_t}{P_t}$ expresses the influence of the robot price and wages on the penetration of IR;

f_4: $\frac{L_t}{U_t}$ expresses the influence of the so-called regressive effect of robotization. During the first phase the robots are introduced above all at the workshops with a low labor productivity and in the course of time the substitution process involves the workshops with increasingly higher labor productivity, which is inhibiting IR diffusion;

f_5: L_t expresses the influence of the tendency of release of man-power from the production area and the shift to the other areas (e.g. service).

III. UTILIZATION OF MODEL RESULTS

When we analyze the prerequisites and conditions for the adoption of the model results in detail, we can state that in centrally planned economic systems there is a very broad field for model results application. But the effective utilization of the models of this kind is only possible under the conditions of a so-called relative independence of the companies and enterprises, when centrally planned management is combined with the initiative and entrepreneurship of the company and enterprise management.

Under such specific conditions the government has very effective indirect economic tools to reach the target in production automation. The results obtained from the prognostic simulation model are very useful guidelines for specifying the level of IR prices, differentiation of taxes, assessment of production resources, such as capital goods, man-power, and inventories. Adoption of such tools can eliminate the bottlenecks which currently hamper the plan, and -- what is much more important --, the automation devices will be adopted more effectively.

If we assess the possibilities of utilization of prognostic simulation model results in the market and centrally planned economies mentioned above from a purely theoretical point of view, we come to the conclusion that the market economies can use the results "ex post", but the centrally planned economies have the possibility of utilizing the model results "ex ante", under the conditions of a combined centrally planned management and company management initiative and entrepreneurship.

An elaborated prognostic simulation model can serve for the simulation of robot diffusion in manufacturing systems in the different stages of aggregation, from the enterprise or company level to the whole industry. The model can be used mainly for the following situations and preconditions:

- for the simulation of the number of installed IR in the future at the current tax level of wages and production capital good charges, under the existing technological conditions, the existing wage development, the assessed price development and the disposable number of workers;

- for the analysis of the necessary changes of taxes in order to stimulate the manufacturing system to adopt the planned number of IR in that particular system;
- for the analysis of the IR price development under the existing conditions in order to stimulate the manufacturing system to adopt the planned number of IR in that particular system;
- for the analysis of robot demand in the respective manufacturing system.

Compared with the model so far used for market economies, which concentrates on labor substitution, other additional factors are included in our model and its utilization is logically broader.

For the future development of the model it will be useful to take into account the substantial difference in costs between individual and group implementation of IR. The other factor which can contribute to a higher precision of the model results is the division of IR into groups. Such attempts have, however, so far stumbled over the obstacle of the lack of necessary information.

IV. APPLICATION OF THE MODEL IN THE CZECHOSLOVAK INDUSTRY

The proportional parameters of the dynamic production function were specified from the input data (shown in Table 1), where Y_t, K_t are expressed in thousand Czech crowns, L_t is the number of so-called physical persons, EN_t is expressed in kWh and U_t is the number of IR.

In Table 2 the development of proportional parameters is calculated with the factor of exponential forgetting . = 0.9.

Table 3 shows the comparison of the real and the modelled value of Y_t and the relative error in % for various years.

Table 4 shows the testing of the model on the historical data. MAD (Mean Absolute Deviation) is 35,62. It proves that the model is of high sensitivity.

It turns out that for the conditions of the Czechoslovak

Table 1. Historical input data for the Czechoslovak industry

Year	Gross Output Y_t	Installed Capital (ex. IR) at cost K_t	Labor (Workers) L_t	Electricity Consumption EN_t	Industrial Robots U_t
1978	589589	643434	2489331	38345	2600
1979	611388	687297	2507768	38947	2750
1980	631502	734903	2520351	39090	2800
1981	645816	790480	2530154	39648	2900
1982	654706	833595	2548929	39923	3000
1983	673984	882474	2560260	40903	3119
1984	701482	936808	2576218	41807	3430
1985	726771	988645	2591187	43023	4033
1986	749817	1041010	2604136	43896	5027

Table 2. Development of proportional parameters of the dynamic production function

Year	a_t	b_t	c_t	d_t	e_t
1978	0.720496	0.286703	0.380626	0.359118	0.049482
1979	0.720751	0.286707	0.380627	0.359119	0.049483
1980	0.722394	0.286756	0.380659	0.359154	0.049508
1981	0.722334	0.286745	0.380657	0.359152	0.049506
1982	0.720989	0.286710	0.380639	0.359132	0.049489
1983	0.720131	0.286670	0.380635	0.359128	0.049485
1984	0.720901	0.286657	0.380636	0.359129	0.049486
1985	0.721373	0.286665	0.380636	0.359129	0.049486
1986	0.721139	0.286667	0.380636	0.359129	0.049486

Table 3. Comparison of real and modelled production Y_t

Year	Reality	Model	Rel. error, %
1978	589589	592291	0.45
1979	611388	610652	-0.12
1980	631502	627549	-0.62
1981	645816	645959	0.02
1982	654706	658505	0.58
1983	673984	676389	0.35
1984	701482	699056	0.34
1985	726771	725206	0.21
1986	749817	750673	0.11

Table 4. Testing of the model on historical data (Normalized to 1978)

Year	Real U_t	Model	Difference
1978	2600	2600	0
1979	2750	2725	25
1980	2800	2836	36
1981	2900	2940	40
1982	3000	3015	15
1983	3119	3084	35
1984	3430	3355	75
1985	4033	4050	17
1986	5027	4985	42

industry the ratio of proportional parameters is practically constant and the real figure is

$$\frac{e_t}{c_t} = 0.13.$$

In the Czechoslovak industry the ω_t, γ_t, δ_t, λ_t, α_t, W_t, P_t currently have the following values:*

$\omega_t = 0.2$

$\gamma_t = 0.15$

$\delta_t = 0.14$

$\lambda_t = 0.1$

$\alpha_t = 0.15$

$W_t =$ 36 780 Kcs

$P_t =$ 377 400 Kcs

Under the conditions presented above the value of constant $k = 1.41379 \cdot 10^{-5}$.

The prognoses of the number of workers in the Czechoslovak industry was taken from the official plan-prognosis by the year 2000.

1987	2 611 450
1988	2 617 500
1989	2 622 900
1990	2 627 700
1991	2 640 400
1992	2 652 800
1993	2 665 700
1994	2 679 000
1995	2 690 100

Four scenarios of IR diffusion in the Czechoslovak industry were carried out, using the above-mentioned model:

1. Scenario – V_1: For the same taxes as already applied with constant wage level and IR prices (most pessimistic with regard to economic changes);

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*Raw data have not been released for publication.

2. Scenario - V_2: For the same taxes as already applied, but with 2% annual growth of wages and 1% annual decline of IR prices;

3. Scenario - V_3: For a deliberate increase in wage taxes of man-power at a rate of $\omega_t = 0.5$ and a constant level of wages and robot prices;

4. Scenario - V_4: For a deliberate increase of the taxes of wages at a rate of $\omega_t = 0.5$, but with a 2% annual growth of wages and a 1% annual decrease of IR prices (most optimistic from the point of view of economic changes).

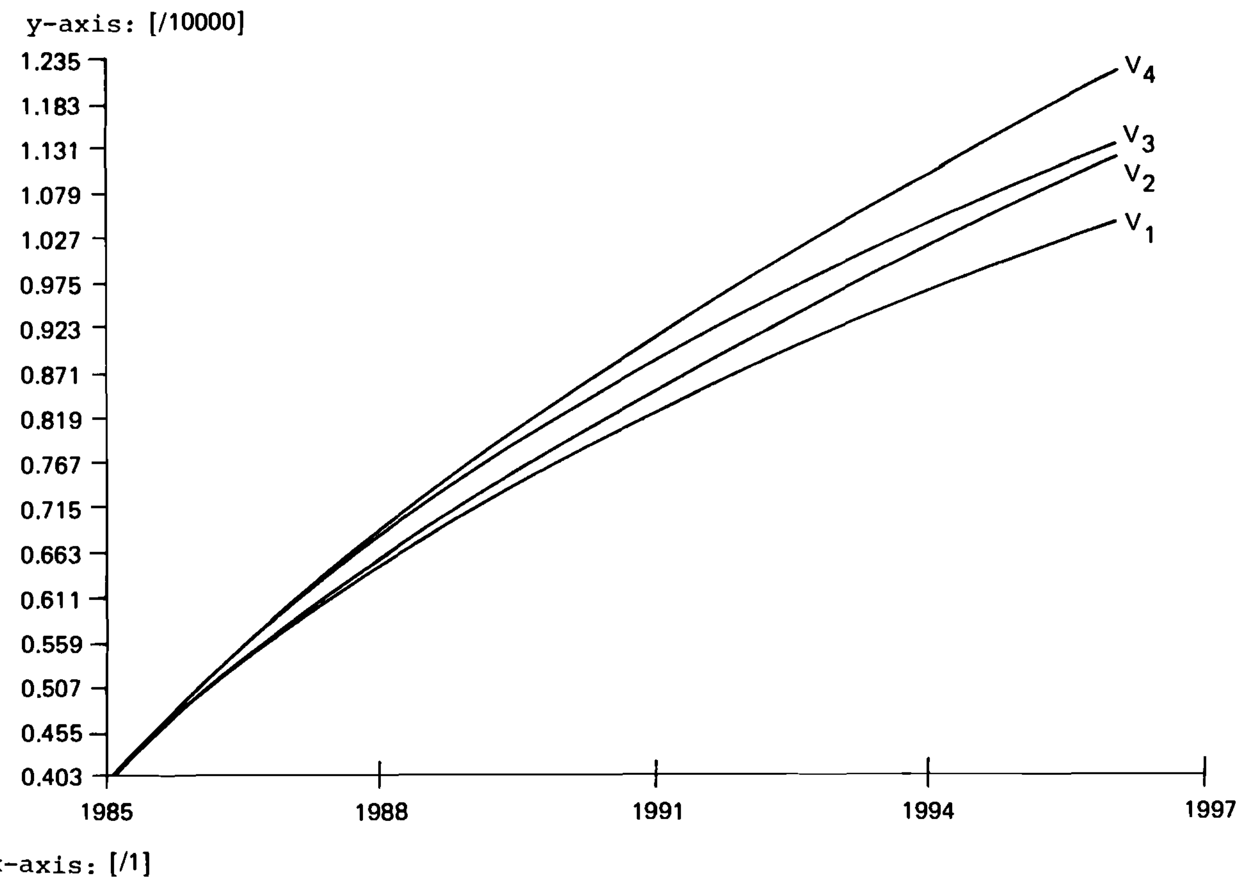
The figures for the different scenarios V_1, V_2, V_3, and V_4 are shown in Table 5.

The graphical illustration of these four scenarios is given in Figure 1.

From the current development of the economic conditions in Czechoslovakia we can infer that the most probable scenario is V_4.

Table 5. Scenarios of robot penetration in Czechoslovakia

Year	V_1	V_2	V_3	V_4
1987	5832	5856	6018	6048
1988	6530	6594	6851	6927
1889	7156	7273	7585	7722
1990	7730	7909	8252	8460
1991	8264	8514	8867	9156
1992	8767	9099	9444	9825
1993	9247	9668	9992	10474
1994	9705	10225	10515	11103
1995	10147	10773	11016	11728
1996	10573	11314	11499	12339



Notes:
x-axis: years
y-axis: number of IR expressed in 10 000 pieces

Figure 1. Graphical representation of the scenarios of IR penetration in Czechoslovakia.

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