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On Some Models and Methods of Forecasting Technological Changes

The paper presents some results obtained by the authors in the study of the substitution process of various processes of steel smelting in the S. R. of Romania, on the ground of some recent models [4], [11], [13] of the technological substitution processes.

Simulating, with various parameters, the substitution process of the steel smelting processes, and taking into account some series of historical data of various lengths and/or time intervals, the obtained results lead to the conclusion that the substitution process is steady and that the considered models can contribute in widening the investigation methods and techniques, and they can be used for determining some prognosis functions, useful in drawing up certain development strategies of the ferrous metallurgy industry in countries with planned economy.

1. RECENT MODELS AND METHODS OF STUDYING THE TECHNOLOGICAL SUBSTITUTION PROCESSES

The progress in technology may be considered as a continuous historical process, in which the various existing forms of satisfying human necessities are replaced by certain new and superior forms.

The simulation, by means of some mathematical models of the phenomenon of substitution of an old technology by a new one, of a product on the market by another one, has special importance for evaluating the metal production, for *evaluating the main directions of structural modifications* within certain branches, as well as for the interdependency with the other branches of the national economy.

The empirical process of substitution was signalled and analysed by several research workers, among others, J. C. Fisher and R. H. Pry [4], C. Mar-

chetti and N. Nakicenovic [11], N. Nakicenovic [12]. The theoretical bases of the substitution are due to the work of V. Peterka [13].

J. C. Fisher and R. H. Pry's model is a binary substitution model, described by a logistic function with two parameters:

$$f/(1-f) = exp\ (\alpha t + \beta) \tag{1}$$

where:

f = the fractional share of production carried out through the new technology;

$1-f$ = the fractional share of production carried out through the old technology;

t = independent variable representing the time;

α, β = coefficients which can be estimated from the historical data of the fractional shares of production carried out through the competitive technologies.

The analysis effected with this model show that parameters α and β are sufficient for describing the binary substitution process with a good accuracy.

Fisher-Pry's model was extended (1979) to n technologies by C. Marchetti and N. Nakicenovic. Besides this, C. Marchetti and N. Nakicenovic discern within the substitution process three phases: growth, saturation and the decline phase.

The growth phase is similar to the Fisher-Pry logistic substitution:

$$f_i(t) = 1/(1 + exp(-\alpha_i t - \beta_i)),\ i = 1, ..., n. \tag{2}$$

The saturation phase is no longer logistic, as the share corresponding to the saturation technology is determined as residual share, as aganist the other technologies in the whole production:

$$f_s(t) = 1 - \sum_{i \neq s}^{n} f(t) \tag{3}$$

Concerning the decline phase, it is also logistic, and when the technology which was in saturation phase enters the decline phase, the next appearing technology enters the saturation phase, and the process repeats itself further.

C. Marchetti and N. Nakicenovic [11] carried out, by using this model, calculations and interesting analysis, concerning the process of substitution of the various forms of energy, considered as technologies, for the world's energy consumption, both by groups of countries, and for certain countries as: Federal Republic of Germany, France, England, U.S.A., Austria, Belgium Holland, Italy, Canada and Japan.

Both Fisher-Pry's and Marchetti-Nakicenovic's models are based upon the analysis of the empiric data of the development of some substitution processes. It is obvious that such an analysis, even if the model leads to the delivery with accuaracy interpolation and extrapolation values, cannot disclose the intimate qualalitative aspects of the phenomenon, if it is not based upon economic hypothesses. The first attempt to build a mathematical model for the substitution process of technological changes, starting from economic considerations, has been made by Victor Peterka [13].

V. Peterka considers that the evolution of the competitive technologies is influenced by the differences between the production costs, by the specific investments and by the growth rate of the total production.

Starting from the hypothesis that on a long term, a certain technology develops itself on its own resources, i.e. the mean value of the external sources is equal to zero, he develops both a determinist model, and a stochastic model, both based upon the following differential equations system:

$$f_i + f_i \sum_{j=1}^{n} c_{ij} f_j / \sum_{j=1}^{n} a_{ij} f_j = 0, \; i = 1, \ldots, n \tag{4}$$

where:

f_i = the fraction of production given by the technology i (function of time);

a_{ij} = α_i/α_j, q_i = specific investment, i.e. the necessary investment for increasing production by a unit;

$$c_{ij} = \frac{c_i - c_j}{\alpha_j} + \left(\frac{\alpha_i}{\alpha_j} - 1\right) \rho$$

c_i = specific production cost of technology i;

$$\rho = \frac{\dot{P}}{P} = \text{growth rate of total production.}$$

For $\alpha_i = \alpha_j$ the $a_{ij} = 1$ and the solution is:

$$f_i(t) = \left[1 + \sum_{j \neq 1} exp\{\ln (f_{j0}/f_{i0}) - c_{ij}(t - t_0)\}\right]^{-1} \tag{5}$$

$i = 1, \ldots, n$.

For $\alpha_i \neq \alpha_j \Rightarrow a_{ij} \neq 1$ the system is solved numerically with algorithm *PENETR*, within which the main part of the calculation is reduced to finding, by means of Newton-Raphson's method, the root ψ^* of the equation $\xi(\psi) = 0$ where:

$$\xi = \sum_{j=1}^{n} \{f_i \, exp[\psi - (c_i - \alpha_i \rho)(t - t_0)/\bar{\alpha}] a_i\} - 1 \tag{6}$$

where:

$$a_i = \bar{\alpha}/\alpha_i$$

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} \frac{1}{\alpha_i}}{\sum_{i=1}^{n} \frac{1}{\alpha_i^2}}$$

starting with the initial point

$$\psi_0 = -\ln\left\{\sum_{i=1}^{n} f_{i0} exp[-(c_i - \alpha_i \rho)(t - t_0)/\bar{\alpha}]\right\}$$

After determining ψ^* we compute $f_i(t)$ as:

$$f_i(t) = f_{i0}\, exp\{[\psi^* - (c_i - \alpha_i \rho)\,(t - t_0/\overline{\alpha}] \cdot a_i\} \qquad (7)$$

Hence, in the determinist model, the coefficients of the model are given exogenously, and the shares f_i are determined either explicitly, or numerically, by means of the PENETR procedure.

These coefficients are computed, in the case of the probabilist model, as the maximum likelihood Bayes estimates, namely through a procedure called MLEST. V. Peterka mentions, in his paper [13], that he does not dispose of a convergence proof of MLEST procedure.

Starting directly from the necessary condition of vanishing the gradient at the point of optimum, the authors of the present paper have shown in [3] that the Peterka's MLEST procedure for solving the maximum likelihood problem: $max\, L(x) = \prod_{j=1}^{N} f_j(x)/(xHx)^{N/2}$, where $x \in R_+^n$: $x_i = \alpha_r/\alpha_i$ are the model's unkonwn parameters, $f_j \in R_+^n$ are the market shares technology vectors known at the time $j = 1, \ldots, N$ and H is a positive definite constant matrix, can be identified with successive approximation method for solving the system of nonlinear equations obtained from $\nabla L(x) = 0$. As a consequence, the algorithm converges if the convergence conditions, derived from fixed point theorems, for the successive approximation method applies.

2. ANALYSIS OF THE TECHNOLOGICAL SUBSTITUTION PROCESSES IN THE ROMANIAN STEEL INDUSTRY

A programme package was achieved [6], including the PENETR and MLEST procedures, as well as a plotting subroutine with a view to studying the applicability of V. Peterka's model to the technological substitution processes in the Romanian ferrous metallurgy.

Florica Luban [6] studied, by using this package and determined quantitatively the evolution up to the present of the technological substitution process in the°steel production in the S.R. of Romania and the also achieved forecasts on this process, within different horizons of prognosis (2000, 2025, 2050), using the data in the period 1950—1978, given in the Economic Statistic Yearbook of Romania.

We shall present further down some of the results obtained by Florica Luban in [6].

For the two competitive processes namely, the process of electric steel plus oxygen converter steel, versus the old process of Martin steel, the best description of the substitution phenomenon was given by V. Peterka's stochastic model (Fig. 1).

The substitution process presents nevertheless in the period 1959—1968 an irregularity, as in this period, both the production and the share of the Martin steel in the total steel production shows up a growth as against the general trend of decreasing. This can be explained by the fact that, in that period, important capacities, whose investment was decided a long time before, started to produce. It is interesting to underline that, on a long term, the

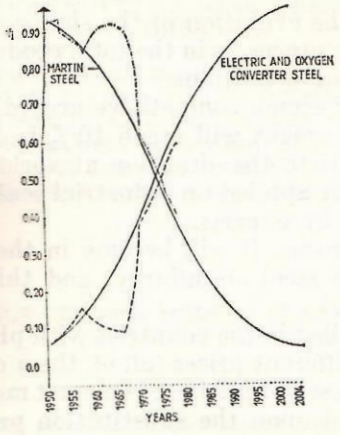

Fig. 1

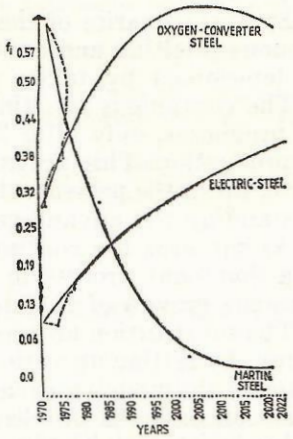

Fig. 2.

substitution trend appears obviously, the perturbation after 1968 was reabsorbed and the secular trend resumed.

We obtain also, in the case of three competitive technologies (Fig. 2), each of the above taken separately,a very good adjustment of the real data and, at the same time, we get the prognosis of the evolution until 2025. According to this, the Martin steel production will diminish irreversibly from now on, the electric-steel production will grow moderately, and around the year 2000, the oxygen converter steel will become dominant.

We must mention that through integration, the model parameter variation is made uniform, so that the output of the model is not very sensitive at the fluctuations of those parameters around their mean values.

It is difficult to suppose, nevertheless, that the parameters could be even only approximately constant, for a long time period (1950—1978). Several periods were considered with a view to estimating parameters, in order to investigate this problem. We obtained, in all cases, remarkable adjustments as against the historical data, both for the backward and for the forward forecast, though the values of the estimated model's parameters, obtained by taking into account different time periods, are different. This points out the great stability of the process and strengthens our faits in the forecast based upon the model.

But any scientific approach of the prognosis problem can lead only to conclusions based upon certain hypothesis. A limit of the model consists in the fact that it cannot forecast the appearance of a new technology. This must be introduced into the model from outside.

In order to give to our developing forecast of the substitution process in the Romanian steel industry more accuracy, two new technologies have been considered also: the process of continuous smelting and the process of continuous casting. The results of some studies given in [15] were used in these cases, both for determining the initial conditions, and for estimating the parameters.

Several scenarios of the prognosis of the evolution of the shares of the continuous smelting and continuous casting processes in the total production were determined by taken different initital conditions.

The continuous smelting process will become competitive according to these prognoses, only after 2050, when its weight will reach 10% from the total production. This prognosis corresponds to the situation at world level, because, up to the present, this process is not applied on industrial scale, not with standing the advantages pointed out by experts.

As concerns the continuous casting proces, it will become in the year 2000 a dominant process in the Romanian steel metallurgy, and this will lead to the growth of the steel production.

The substitution process can be controlled in the countries with planned economy, by setting up various taxes and different prices (all of them can be reflected in the model) for reaching the proposed objectives. We must mention also, as concerns the problem of the control upon the substitution process, that the size of the initial investment determines the inititial conditions of the model and can speed up (or slow down) the substitution process, due to the fact that no technology can start from zero, without an external financial input.

In order to know how much we can trust the estimation of the parameters obtained through MLEST, the shape of the density functions around the optimum points must be studied. The model of evaluating errors and the significance of the estimates of V. Peterka' model are presented both in [13] and in Annex 4 from [6].

REFERENCES

1. BLACKMAN, A. W.: *A Mathematical Model for Trend Forecasts.* Technological Forecasting and Social Change, 3, (1972), 441—452.
2. BLACKMAN, A. W.: *The Market Dynamics of Technological Substitution.* Technological Forecasting and Social Change, 6, (1974), 41—43.
3. DUMITRU V., LUBAN FLORICA: *On the Convergence of Peterka's Algorithm for a Maximum Likelihood Problem.* Proceedings of the Fifth Symposium of Operations Research, Köln, August 25—27, 1980, R.E. Burkard and T. Ellinger Eds., Verlag Anton Hain 1981.
4. FISHER, J. C., PRY R. H.: *A Simple Substitution Model of Technological Change.* Report 70—C—215, General Electric Company, Research and Development Center, Schenectady N. Y., Technical Information Series, June, 1970; see also Technological Forecasting and Social Change 3, (1971), 75—88.
5. GRILICHES, Z.: *Hybrid Corn: An Exploration in the Economics of Technical Change.* Econometrica 25 (1957), pp. 501—522.
6. LUBAN FLORICA: *Modele de optimizare a activităţilor economice din metalurgie* (Optimization Models of Some Economic Activities in Ferrous Metallurgy). Doctor's Degree Dissertation Bucharest, 1980.
7. MANSFIELD E.: *Technical Change and the Rate of Imitation.* Econometrica 29, 4 (oct. 1961).
8. MARCHETTI C.: *Primary Substitution Models.* IIASA Internal paper, June, 1975.
9. MARCHETTI C.: *On Strategies and Fate.* in W. Häfele et al Second Status Report on the IIASA Project of Energy Systems, 1975, RR—76—1, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.
10. MARCHETTI C., NAKICENOVIC N., PETERKA V., FLECK P.: *The Dynamics of Energy Systems and the Logistic Substitution Model.* Reports AR—78—1, A.B.C. International Institute for Applied Systems Analysis, Laxenburg, Austria, 1978.
11. MARCHETTI C., NAKICENOVIC N.: *The Dynamics of Energy Systems and the Logistic Substitution Model.* IIASA Report RR—79—13, IIASA, December 1979.

12. NAKICENOVIC N.: *Software Package for the Logistic Substitution Model.* IIASA Report RR—79—12, IIASA 1979.
13. PETERKA V.: *Macrodynamics of Technological Change: Market Penetration by New Technologies.* IIASA Report RR—77—22, IIASA 1979.
14. PRY R. H.: *Forecasting the Difussion of Technology Report.* 73 CRD 220, General Electric Company, Corporate Research and Development, Schenectady N. Y., Technical Information Series, July, 1973.
15. * * *: *The Increasing Use of Continuous Processes in the Iron and Steel Industry and Their Techno-Economic Aspects.* ECE/Steel/25, United Nations, New York, 1979.

SUR CERTAINS MODELES ET METHODES DE PREVISIBILITÉ DES CHANGEMENTS TECHNOLOGIQUES

On présente quelques résultats obtenus dans l'étude du processus de substitution de différents procédés d'élaboration de l'acier en Roumanie, utilisant certains modèles récents [4], [11], [13] des processus de substitution technologique.

Par la simulation du processus de substitution des procédés d'élaboration de l'acier, utilisant divers paramètres et prenant en considération certaines séries de données historiques de longueurs et (ou) d'intervalles de temps différents, les résultats obtenus ont mené à la conclusion que le processus de substitution est stable et que les modèles considérés peuvent contribuer à l'élargissement des méthodes et des techniques d'investigation et peuvent être utilisés pour déterminer certaines fonctions de prévisibilité utiles à l'élaboration des stratégies de développement de l'industrie sidérurgique dans les pays à économie planifiée.

О НЕКОТОРЫХ МОДЕЛЯХ И МЕТОДАХ ТЕХНОЛОГИЧЕСКИХ ИЗМЕНЕНИЙ

В работе приводятся некоторые результаты, полученные авторами при изучении процесса замены радличных способов выработки стали в С. Р. Румынии, на основе новых моделей [4], [11], [13] процесса технологической замены.

Симулируя по раным параметром процесс замены способов выработки стали, с учётом статистических рядов разных размеров и (или) разных периодов, были получены результаты, которые приводят к выводу, что процесс замены является стабильным, а использованные модели могут способствовать расширению круга методов и способов исследования и могут быть использованы для определения некоторых функций прогнозирования, пользных при разработке стратегии развития чёрной металургии в странах с планированной экономикой.

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