Economic and Mathematical Modeling of Enterprises' Demand for Labor Power in the Era of Digital Economy

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Abstract

The article presents an economic and mathematical model of enterprises' demand for labor power in the form of a complex function of demand for the products of the enterprise in combination with the specific characteristics of the production process. In the presented economic and mathematical model, the demand for labor power is considered to be dependent on both the labor price and the prices of other production factors.

Keywords: *Economic and Mathematical Modeling, Economic and Mathematical Model, Digital Economy, Demand for Labor Power, Factors of Production, Integrated Indicator.*

1. Introduction

The strategy of an enterprise's behavior in the market requires the implementation of the effective forecasting of its resource capabilities and organization of time-based planning. Possible approaches to the solution of this problem depend directly on the possibility of conducting a comprehensive analysis of enterprise's resource potential.

Technological changes characteristic of the XXI century in terms of "merging" of telecommunication, IC technologies and innovations, have led to the introduction into scientific circulation of the "digital economy" concept, which is a type of economy characterized by the active implementation and use of digital technologies enabling storage, processing, and transmission of information in all spheres of human activity.

Digital transformation is a complex task. Countries that have reached the highest level of digital maturity have had to deal with complex cultural, organizational, and technical problems, and only consideration of all these factors has made these transformations successful.

"Digital vortex" [1], which is formed by digital technologies, opens unique opportunities for economic development and improvement of citizens' life quality. The rapid and profound consequences of the transition to "digit" will be possible only when the "digital" transformation becomes the basis of the society's life, including business and public institutions, becomes customary and common [2].

In the era of the digital economy, the main resource is inexhaustible, accurate, reliable, truthful, and timely information. The main platform for the digital economy development is the virtual Internet.

The implementation of the digital economy at the initial stage should take place simultaneously in three areas:

- technological, where all technical and technological solutions should be standardized, that is, they should be safe and certified;
- institutional and economic, which provides for the organization of new management models and business models, their institutional support, corresponding to the regulatory framework of social and economic relations of the society;
- production, which includes specific business applications that meet the requirements of the management models of the second direction, and is based on the technical support and infrastructure of the first direction [3, 4].

In the era of the digital economy, isolated enterprises are forced to carry out an independent search for the performance parameters based on the widespread use of formal methods of economic calculations. Today, the production management system determines the strategy of the entire production process formation. To this end, the enterprise faces the task of drawing a detailed plan of its labor power development. Particular sections of such a plan should include the definition of the enterprise's activity purpose, analysis of the environment, and the strategy of the enterprise; as well as projected planned changes in the types of products, volumes of production, and resources.

The purpose of the present study is to develop an economic and mathematical model (EMM), providing a detailed calculation of the demand projection for human resources, the numerical expression of their management strategy, and employee use programs.

2. Theoretical Substantiation of the Model of Demand for Labor Power

The general pattern of the digital economy is the focus on a particular consumer and the comprehensive use of information as

the driving resource, consideration of the specific features of a particular consumer in a particular place, and the use of digital transformation technologies of real business processes.

The total factory load and the way in which enterprises combine factors of production depend on the demand for their final product. This demand determines the number of factors of production that enterprises can obtain at given prices, as well as the choice of technologies at their disposal.

Three main markets are distinguished when modeling demand for labor power: capital, labor, and product markets. The first two markets supply enterprises with factors of production, while the last market allows selling enterprises' products.

On the one hand, labor is the main factor of production, a formative element of the capital market and the products market. On the other hand, the demand for labor depends on the economic state of production, which directly affects the income of the population, social mobility, and demography, i.e. factors of labor supply formation. Thus, the feedback principle applies to the labor market. That is why the mechanisms of labor market regulation should be studied taking into account the peculiarities of the processes taking place in the production system.

Through market influence, the external environment contributes to the formation of an appropriate system of production management and labor power and forms through them the production process and the final evaluation of management efficiency.

Thus, having come to the conclusion about the production nature of the leading structure-forming factor of demand for labor power, we note at the same time that an individual enterprise has no influence on the prices that have developed in external markets. Only the external environment determines the main parameters of the labor power demand model, namely the unit price of labor (wage level), the price of capital (investment value), and the price of the intermediate product.

Modeling of an enterprise's demand for labor power is based on the economic and production characteristics of its activity. The following approaches can be used to identify the method of constructing the EMM: the approach based on the application of the fundamental laws of object development, hierarchical method, the principle of analogies, and variational principles.

The first approach applies to the EMMs, the operation environment of which is based on generally recognized laws repeatedly confirmed by experience. The hierarchical method consists in the implementation of the principle, according to which the next step of refinement of EMM is carried out after a detailed study of the simplified source model. At that, a hierarchy of increasingly complete step-by-step models is built. The most widely used approaches in modeling include variational principles which are used in the form of analogies. This method makes it possible to build the model if it is impossible to point directly to the fundamental laws to which it is subjected. The variational principles represent extremely generalized representations about the economic object that is being studied and assume that only those behaviors are chosen from all possible options that satisfy a certain set of conditions. This principle has found a wide application in the EMMs, which are based on the use of the marginal productivity concept and the utility theory, at which the selected economic object is subjected to clear criteria of optimality.

3. EMM of Demand for Labor Power in the Era of Digital Economy

Construction of the demand function of enterprises for labor power in the era of the digital economy is implemented in two stages:
− at the first stage, a generalized identification of the labor management system is carried out; the main task of the stage is to determine the movement dynamics of the enterprises' personnel potential at a given amount of labor required;

− at the second stage, economic parameters of the production management system (production process) are formalized to determine the formation strategy for the necessary amount of labor power.

Assuming that the amount of labor power L_f required for the implementation of the entire production process is pre-defined, the dynamics of the size of the workforce $L(t)$ can be described by the following equation:

$$\frac{dL}{dt} \alpha L(t) + \beta U(t) \tag{1}$$

where α and β, respectively, are the percentage of hired and dismissed employees; $L(t)$ is the amount of personnel at time point t; $U(t)$ is the management parameter describing the number of hired and dismissed employees at time point t.

Rewriting equation (1) as

$$\frac{dL}{dt} - (\alpha - \beta)L(t) = \beta L_f \tag{2}$$

we obtain the equation, which is a linear differential equation of the first order, whose general solution can be determined from the equality:

$$L = e^{-(\beta - \alpha)t}\left(C + \beta L_f \int e^{(\beta - \alpha)t} dt\right) \tag{3}$$

where C is the arbitrary constant.

The solution to the equation (3) will take the form:

$$L(t) = Ce^{-(\beta - \alpha)t} + \frac{\beta}{\beta - \alpha}L_f \tag{4}$$

The movement dynamics of the enterprises' personnel potential represented by the latter equality, is a function of the enterprises' demand for labor power in the case of a given amount of necessary labor.

Given that the relationship between the various economic indicators is usually nonlinear, the need to introduce simultaneously a time factor into the equation may arise.

This approach to the construction of the regression model differs significantly from the classic approach since in this case observations are made over the change of ratios of two values during a certain period of time rather than over the change of their absolute values relative to each other. This allows approximating the ratio of economic indicators by the time function, as well as avoiding the presence of "field" of observation points, where the issue concerning the existence of a relationship remains open.

The choice of polynomial dependence is due to the fact that the system of equations obtained by using the least squares method will have an exact solution, which ultimately affects the design quality of the approximation.

When using a different type of relationship, the following difficulties may arise: not all functions are amenable to direct linearization, the use of the least squares method can lead to a nonlinear optimization problem that complicates the modeling process. The iterative methods applied in this case will not serve an easier way to solve the problem.

In the framework of the implementation of the second stage for the construction of a demand function for labor power, we determine the formation strategy of the required scope of work.

The demand for labor power, according to the theory of marginal productivity, is determined by the marginal income of the enterprise, obtained from the sale of the product produced in connection with the attraction of additional labor power per unit of product.

Let us consider a method of constructing a static variational model of enterprises' demand for labor power using the marginal productivity theory.

Let the production volume of the enterprise to be described by the production two-factor function Q = Q(K, L), where K is the production capital, and L is the size of the workforce. We express the profit of the enterprise PR in the form of the following dependence:

$$PR = pQ(K, L) - wL - xK \tag{5}$$

where x is the cost associated with the use of production capital, including depreciation. Then, for the long-term period of activity, ensuring enterprise's maximum efficiency will consist in finding the global absolute maximum of the profit function at K > 0 and L > 0.

It is known from the mathematical analysis that the points of the local absolute maximum should be sought among the solutions of the system of equations, which after the transformation will take the form:

$$\begin{cases} p\dfrac{\partial Q(K, L)}{\partial K} = x, \\ p\dfrac{\partial Q(K, L)}{\partial K} = w. \end{cases} \tag{6}$$

If the second derivatives of the production function for all K > 0 and L > 0 are such that the following conditions are true:

$$\left\| \begin{matrix} \dfrac{\partial^2 Q(K,L)}{\partial K^2} & \dfrac{\partial^2 Q(K,L)}{\partial K\,\partial L} \\ \dfrac{\partial^2 Q(K,L)}{\partial K\,\partial L} & \dfrac{\partial^2 Q(K,L)}{\partial K^2} \end{matrix} \right\| > 0 \tag{7}$$

$$\dfrac{\partial^2 Q(K,L)}{\partial K^2} < 0$$

then the production function graph Q = Q(K,L) in the three-dimensional space OKLQ will be represented as a surface convex upwards.

Since the profit PR(K,L) is obtained by subtracting the expense plane wL+xK from pQ (K, L), the system (6) has a unique solution (K0,L0), which is exactly the point corresponding to the global maximum profit. The vector (K0,L0), which is a solution to the profit maximization problem, is a local market condition for the enterprise's equilibrium over a long period of time.

After substituting (K0, L0) in the equations of the system (6) and termwise division of the deduced identities, we obtain the limit rate of capital replacement by labor at the point (K0, L0), which is equal to the ratio of market prices for these resources. The values of K0 and L0, which are obtained as a solution to the system (6) and are price functions (p, w, x), represent an expression of the demand for factors of production. In particular, the labor demand function has the form:

$$L_D = L^0(p, w, x) \tag{8}$$

The construction of the demand function of enterprises for labor power for a short period of time has its own peculiarities because the capital K is considered to be constant throughout the concerned time period. At that, the system (6) is reduced to the equation:

$$P\dfrac{\partial Q}{\partial L} - w = 0 \tag{9}$$

The solution to equation (8) with respect to L is the demand function for labor power during the short term of the enterprise:

$$L_D\left(\frac{w}{p}, K, v\right) = K(v(1 - \alpha))^{\frac{1}{\alpha}}\left(\frac{w}{p}\right)^{-\frac{1}{\alpha}} \tag{10}$$

As a result, we obtain the demand function for labor power depending on the parameters of the external environment (w/p, K, v). In addition, the obtained result corresponds to the assumption concerning inverse dependence between the demand for labor power and wages [5].

On the one hand, the investigated model is of static nature because it lacks time factor, and on the other hand, the marginal productivity theory is dynamic in nature, since the processes under consideration occur in time and cannot be isolated from time. However, it should be noted that the result obtained represents the limiting condition of the dynamic model of demand for labor power.

4. Conclusion

Contemporary business and organizations of the customary economy should overcome resistance to changes on a goal-oriented basis, relying on independent scientific and technological research, having it as a cultural digital imperative in order to be successful in the digital transformation model, and setting the task of becoming a digital leader.

Today, the demand for labor power has a production nature. In most cases, enterprises hire labor power not so much for obtaining an immediate economic benefit, as for expecting the labor power to be able to contribute to the production of goods for sale in the long term.

Therefore, the demand for labor power by enterprises in the era of the digital economy should be seen as a function of the demand for goods of their production. At the same time, the demand for labor power is a function of the particular production process characteristics. This means that demand demonstrates numerically how much labor power can be replaced by capital and other factors of production. And, as a consequence of EMM, the demand for labor power appears to be a function not only of labor prices but also of the prices of other factors of production.

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