Modelling approaches to innovative development of forestry enterprises using the sigmoid function

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Abstract. At the present stage of development of enterprises of the timber industry complex, it is necessary to systematically consider all active processes occurring within the enterprise, as well as their response to external influences and variable factors affecting innovative activity. The aim of the study is to apply multisigmoidal modelling approaches that take into account the use of an innovative approach in the renewal of forest areas in the process of eliminating the consequences of forest fires and the production of competitive timber products. The study uses a multisigmoidal approach, which is based on a variety of empirical data and indicators calculated based on statistical reporting on the economic development of forestry manufacturing enterprises. Thanks to the developed model based on the multisigmoidal modelling approach, it became possible to identify ineffective economic phenomena and innovation processes taking place in the context of the innovative development of forestry enterprises. The application of this approach made it possible to identify bottlenecks and weaknesses of the entire production process in the forest industry, taking into account the application of measures for the prevention and extinguishing of forest fires in conditions of accelerated renewal of forest resources.

1. Introduction
At the global level, there are enough scientific developments aimed at innovative development, but they, to one degree or another, do not reflect the specifics of the activities of timber industry enterprises.

A set of measures is needed to increase the level of innovative development of forestry enterprises. The application of the multisigmoidal modelling approach will provide an objective interpretation of the empirical data obtained and determine the initial and final points of the process under study for each indicator, in order to build the priority directions of the policy of innovative development of forestry enterprises. This methodology will serve as a very effective way of building a model for analyzing and predicting the innovative development of the priority areas of the policy of innovative development of forestry enterprises.

So in one of the scientific studies it was noted that innovative development must be carried out on the basis of optimizing resource-efficient production, using a number of technological improvements and increasing economic efficiency. The authors use a data coverage analysis (DEA) approach, which uses a nonparametric linear method to measure the relative efficiency of a set of manufacturing decision units (DMUs). However, in these developments it is impossible to evaluate several simultaneously occurring production, economic, innovation, and technical processes [1].
The group of authors from the city of Zvolen, Slovak Republic consider innovative development as an engine of the forest industry aimed at achieving the set goals, identifying innovative trends in the forest sector using Q-methodology. Their scientific development is based on subjective assessment and the possibility of technical progress in the timber industry. But this does not take into account an important component of the practical application of scientific developments [2].

In turn, another group proposes to increase innovation activity through a combined study of the categories of innovation management, pure innovation, building an innovation management model. However, in this study, the idea of innovative development has not been formed [3].

In the author's research on modelling innovation activity for enterprises in the construction industry, a modelling methodology based on the least squares method is proposed with the construction of a linear equation and the identification of a square-law error. In this case, it is possible to apply this methodology for forestry enterprises, but it does not take into account the heterogeneity of production and the specifics of the activity of the timber industry [4].

It should be noted that in the process of research to increase the level of innovative development, it is necessary to take into account the innovative component in terms of social responsibility, caused by the need to maintain the ecological environment in the regions and minimize the consequences of forest fires. In the presented research results, a ‘Content Model’ is proposed based on the cognitive modelling methodology, which takes into account the descriptive explanatory and predictive components of modelling. This approach does not reflect the influence of factors on the environment, including technogenic ones, caused by forest fires [5].

In a number of studies on the development of measures to improve the efficiency of innovation and investment activities aimed at achieving commercial and innovative success of an enterprise, it is proposed to combine investment and innovation processes into an integrated system of criteria, with the construction of an investment and innovation model for sustainable development. This model takes into account almost all innovative indicators, but here, in the conditions of the timber industry complex, innovations for the accelerated renewal of forest resources are not taken into account [6].

In this regard, a key condition for increasing the efficiency of innovative development and the practice of introducing innovations at forestry enterprises is the development of priority directions of the policy of innovative development of forestry enterprises, based on modelling using a sigmoidal function [7].

The development of priority directions of the policy of innovative development of forestry enterprises is based on the process of substantiation and selection of promising and relevant vectors, taking into account a number of main priority problems and tasks aimed at identifying possible prospects and solving the main goal - innovative development. The economic indicators of the enterprise, obtained because of the analysis, reflect each internal and external parameter of the process of its development.

The process of increasing the level of innovative development is carried out because of collection, analysis and generalization of problems in the timber industry complex, scientific hypotheses, innovative developments and the degree of their implementation in the production process, regulatory documents. Based on the analysis and generalization of the data obtained, the priority directions of the policy of innovative development of enterprises of the timber industry complex are formed. In the study, the formation of priority vectors was based on the application of a multisigmodal modelling approach [8].

2. Material and methods
The study used modelling methods using the sigmoid function, the data were analyzed through computer calculations based on mathematical modelling, the study also used the system analysis methodology, and the graphical method was used to display the results [9,10].

Carrying out modelling based on the sigmoid function must begin with plotting the dependence of the studied transition process of the economic indicator E in the simplest version with a smooth graphical transition from one state (level) to another state (level) in the time interval t. During 7 years
from 2012 to 2018 of research in the field of ensuring the use, protection, protection and reproduction of forests, the transition of the E indicator from the level of 1.0 to the level of 2.0 will be reflected in figure 1 in the simplest version of maximizing simplification. The resulting smooth transition reflects the proposed method, mathematically described by the Boltzmann sigmoid function.

Figure 1. Graph of the dependence of the process of transition of economic indicator E from 1.0 to 2.0.

Such dependence in mathematics is called sigmoid or S-shaped, since the graph of the function is similar to the Greek letter σ or the Latin letter ‘S’. To describe a smooth transition in mathematics, various types of sigmoid functions are used, depending on the nature of the process. For example, the following sigmoid functions of the following form are often used (formulas (1)-(4)).

Hyperbolic tangent \[11\]:
\[
\sigma(x) = \tanh\frac{x}{\alpha} = \frac{e^x - e^{-x}}{e^x + e^{-x}}
\] (1)

Logistic sigmoid \[12\]:
\[
\sigma(x) = \frac{1}{1 + e^{-x}}
\] (2)

Fermi function:
\[
\sigma(x) = \frac{1}{1 + e^{-2\alpha x}}
\] (3)

The sigmoid of rationality \[13\]:
\[
\sigma(x) = \frac{x}{|x| + \alpha}
\] (4)

In the above functions, \(\alpha\) is a parameter that sets the duration of passage from one level to another.

3. Results and discussion
In the course of two interconnected processes of prevention and extinguishing of forest fires with the subsequent renewal of forest resources using the innovative IN VITRO approach, it is advisable to develop a multisigmoidal model of innovative development of forestry enterprises, reflecting the following relationship (formula (5)):
where \( P_1 \) – initial value \( E \); \( P_2 \) – Final change in value \( E \) after the first process (prevention and suppression of forest fires); \( P_3 \) – Value of quantity \( E \) after the second process (renewal of forest resources using the innovative IN VITRO approach) [14]; \( t_{S1} \) and \( t_{S2} \) – Initial time of primary and secondary processes; \( t_f \) and \( t_{f2} \) – End time of primary and secondary processes; \( \Delta t_1 \) and \( \Delta t_2 \) – Duration of primary and secondary processes.

The application of the multisigmoidal model based on multisigmoidal functions in the form of a function of activation and normalization of the sigmoid at the output level is carried out so that the entire layer is added to one whole unit. If there is an arbitrary set of sigmoid terms, then in the case we represent the multisigmoidal function \( E(t) \) as follows (formula (6)) [15]:

\[
E(t) = P_1 + \sum_{i=1}^{n} \frac{P_{i+1} - P_i}{1 + \exp \left( \frac{6t - 3(t_{i+1} + t_{i})}{\Delta t_i} \right)}
\]

(6)

where \( P_{i+1} - P_i \) – increment of economic indicator \( E \) in the process of the \( i \)-th transition; \( t_{S1} \), \( t_f \) and \( \Delta t_i \) – initial, final time and duration of the \( i \)-th transition process [16,17].

The multisigmoidal model of innovative development of forestry enterprises describes several simultaneously occurring production, economic, innovation, and technical processes. The method of its construction allows to graphically analyze the time dependences of such economic indicators as the volume of shipped products, the volume of the domestic market, exports and imports in the production structure of timber industry enterprises, to analyze the efficiency of the production of innovative products by type of economic activity, to assess the financial result and to compile all this through superposition of sigmoid functions.

Figure 2 shows the results of the analysis of the time dependences of the above indicators: under the letter a) sigmoid functions were superimposed on each other when describing the transition from in the time interval from 2015 to 2016 and further transition from to 2016 to 2017, then until the end of 2018 the transition was from.

Let us express this dependence in the following form (formula (7)):

\[
E(t) = 1 + \frac{2 - 1}{1 + \exp \left( \frac{6t - 3(2015 + 2016)}{6} \right)} + \frac{4 - 2}{1 + \exp \left( \frac{6t - 3(2016 + 2018)}{6} \right)}
\]

(7)

The graph in figure 2a reflects 4 transients of various degrees and directions of the process.

The first decline \( E \) in 2015 is characterized by a decline from 4 to 2, then there is an increase in 2016 from 2 to 3, after some stagnation there is a sharp decline from 3 to 1 in 2018, and during 2018 there is an increase until the middle of the year, and then- stable stagnation.

The following figure 2c) reflects a gradual growth, starting from 1 in 2015 and at the end of 2018 it had already reached the ‘4’ mark: rise 1: with \( E=1 \) before \( E=2 \) during the period with \( t_{f1}=2015.6 \) on \( t_{f2}=2016.5 \) years; rise 2: with \( E=2 \) before \( E=3 \) during the period with \( t_{f2}=2016.5 \) on \( t_{f2}=2017.5 \) years; rise 3: with \( E=3 \) before \( E=4 \) during the period with \( t_{f3}=2017.5 \) on \( t_{f4}=2018.5 \) years.

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Figure 2. Graphical results of time analysis by means of a combination of sigmoidal functions, strong growth (a), significant decline (b) and significant growth (c), long-term transition process (d).

The imposition of a short-term transient on a long-term transient occurred in the graphical time dependencies shown in figure 2b, 2c and 2d. We see that in both cases the long-term process provides an increase in the value $E$ by three points and in the short-term period on the graph under the letter c an additional an increase by one, and under the letter r by 0.7.

Let’s write a multisigmoidal expression for this case (formula (8)):

$$E(t) = 1 + \frac{2.5 - 1.2}{1 + \exp \left( \frac{6t - 3(2015 + 2017)}{4} \right)} + \frac{4.7 - 3}{1 + \exp \left( \frac{6t - 3(2017.5 + 2018.9)}{0.6} \right)}$$

(8)

The value of the multisigmoidal model is very significant in terms of describing a wide range of innovation processes associated with the development of industrial enterprises in the field of the timber industry. The use of multisigmoidal functions in solving the problems of building a model of priority directions of the policy of innovative development of enterprises of the timber industry complex is sufficiently justified in view of the high degree of complexity and consistency of the approaches used when studying changes in the processes of complex systems filled with economic meaning and mathematical description.

In order to optimize the innovative development of forestry enterprises, we will forecast the transformation of each value and indicator on the basis of an analytically constructed formula for multisigmoidal approximation of the obtained statistical data for the last 10 years, starting from 2002 to 2009 and from 2012 to 2018.

The results obtained in the approximation process (table 1) allow us to quantitatively characterize the ongoing economic process: 1) The beginning of the transition process in 2013.59 years, and its end in 2018.73 years (total time 5.32 years); 2) Indicators smoothly change from 0.55 to 1.19 and generally increase by 0.64 points).
Table 1. The obtained results of the approximating dependence $D(t)$.

| Sigmoid quantity | Smooth transition number | Growth indicators, $\Delta P_i$ | Transition from level, $P_i$ | Go to level, $P_{i+1}$ | Transition duration, $\Delta t$ | The beginning of the transition $t_s$, years | End of transition $t_f$, years |
|------------------|--------------------------|---------------------------------|-------------------------------|--------------------------|-------------------------------|---------------------------------|---------------------------------|
| 1                | 1                        | 1.166                           | 0.5609                        | 1.1932                   | 0.017767                      | 2014.25                         | 2016.90                         |
|                  | 2                        | 0.650                           | 1.2228                        | 0.8970                   | 0.015748                      | 2017.53                         | 2017.97                         |
|                  | 3                        | 0.529                           | 3.6800                        | 2.2136                   | 0.067435                      | 2018.20                         | 2018.71                         |
| 2                | 1                        | 2.075                           | 0.5589                        | 0.5888                   | 0.025678                      | 2013.59                         | 2018.73                         |
|                  | 3                        | 3.400                           | 3.4934                        | 1.0860                   | 0.056181                      | 2015.62                         | 2016.64                         |
|                  | 2                        | 0.204                           | 5.6507                        | 2.3181                   | 0.003494                      | 2017.61                         | 2018.22                         |

The result of the approximation function for options – single, double and triple sigmoid can be represented in the form of formulas (9)-(11):

$$D_1(t) = 0.56 + \frac{1.19 - 0.56}{1 + \exp\left(\frac{6t - 3(2014.25 + 2016.90)}{0.01}\right)} + \frac{0.89 - 1.22}{1 + \exp\left(\frac{6t - 3(2017.53 + 2017.97)}{0.01}\right)} + \frac{2.21 - 3.68}{1 + \exp\left(\frac{6t - 3(2018.20 + 2018.71)}{0.06}\right)} \tag{9}$$

$$D_2(t) = 0.55 + \frac{0.58 - 0.55}{1 + \exp\left(\frac{6t - 3(2013.59 + 2013.73)}{0.01}\right)} \tag{10}$$

$$D_3(t) = 3.49 + \frac{1.08 - 3.49}{1 + \exp\left(\frac{6t - 3(2015.62 + 2016.64)}{0.05}\right)} + \frac{2.3 - 5.65}{1 + \exp\left(\frac{6t - 3(2017.61 + 2018.22)}{0.03}\right)} \tag{11}$$

Figure 3 shows the calculation results. The use of the multisigmoidal model and the use of the results of the multisigmoidal approximation function allow the most detailed examination of the original graph of statistical points. The double sigmoid makes it possible to take into account the bending of the schedule that fell for 2015 (figure 3a). When approximated, when one sigmoid is used, the main transition remains almost unchanged. When like the second sigmoid, it is possible to pay attention to the second process, which has a short duration and smaller amplitude.
Figure 3. Function approximation results $D(t)$: single (a), double (b), triple (c) sigmoid.

On the basis of the characteristics obtained, the economic essence of these investigated processes was established by means of a more detailed analysis of the innovative development of the timber industry enterprise and the rate of transformation of the economy in the future period.

4. Conclusion

The use of three sigmoid for the approximation significantly worsened the resulting relationships due to the large set of parameters. So the triple sigmoid function has a passage through each point of statistics, repeating its shape feature, which is reflected in figure 3c. However, it is the triple sigmoid in the consideration of random fluctuations of the dependences that completely repeats them, and in contrast to it, the double and single sigmoid, in general, restored the real dependence and the fluctuations were smoothed. In the future, based on the assessments of experts and succumbing to logical thinking, the increase in dependence will continue, and then gradually slow down, which is reflected in figure 3b.

Acknowledgments

The reported study was founded by RFBR according to research project No. 18-010-00318.

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