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An Analysis of the Efficiency of Regional Forest Complexes (by the Example of Siberian Federal District)

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In the presented paper we have developed a new method of analysis of efficiency of regional forest complexes. Our method is based on the Data Envelopment Analysis methodology. It allows not only comparison of different regional forest complexes by their level of efficiency, but also produces specific recommendations for improving of "outsiders" forest sector activity. The method was successfully applied to the optimization of efficiency of Siberian forest complexes. The analysis showed that the higher efficiency corresponds to the regions with the richest stocks of forest resources: Krasnoyarsk Krai and Irkutsk Oblast. We determined the values of necessary changes in the input (resource expenditure) parameters to be implemented for improving the efficiency of the forest complexes of Siberian Federal District.

Keywords: forest complex, efficiency, Siberian Federal District, Data Envelopment Analysis.

1. Introduction

Forest complex of Russia is subjected to the different kinds of risks, which restrain its development. Between such risks one could mention the low efficiency of regional forest branches. Despite this issue is widely discussed, there is no comprehensive studies of the efficiency of forest complex of Russia on macro economical scale.

The category of economical efficiency is widely considered in the modern literature (Avdasheva, 2003; Bezrukova et al., 2012, 2012a, 2012b; Glazyev, 2009; Gromov et al., 2012; Davydyants, 2005; Davaydyants, 2001; Nikitin, Kuznetsova, 2007; Novikov, 2005; Suvorov, 2008; Suvorova, 2006; Shilov, 2011). At the same time, there is no a sole definition of economical efficiency. This is a reason to thoroughly consider different interpretations of this category.

The classical textbook on modern economics defines the efficiency as expressed below: "Efficiency is always connected to the relation between the result and the costs needed to achieve it… Hence, the efficiency of any process could change along with the change of estimations, and since everything depends on everything, any change of any subjective preference can change the efficiency of the whole process… It is important to understand that the efficiency is a relative category" (Heyne, 1992, p. 170).

As a matter of fact, the analogical definition is given by V.V. Novozhilov, a representative of the

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soviet school of economics: “Generally spoken, the efficiency is the ratio of effective result to the costs of its gaining… The characteristics of efficiency are usually expressed in reverse form, i.e. as ratio of costs to result” (Novozhilov, 1972, p. 55). Such a basing of the efficiency category was first introduced in the classical works of S.G. Strumilin (1958, pp. 14-15) and L.A. Vaag (1958, p. 36).

Since we stated that the efficiency is always measurable, it is needed to build an uniform index that could describe the efficiency of an economical agent. Representation of the total yield as a result of junction of labor and capital in the production process means the necessity to develop a multifactor model of production. Such a model should establish the tie between costs and yield. Any summarizing parameter is equivalent to some production function. Reasonableness of choosing one or another form of production function is defining by the measure of validity of theoretical concept of the efficiency being used. From the theoretical point-of-view, production function characterizing some production process includes multiple factors representing means and objects of labor and parameters describing natural conditions of production process.

2. Theoretical Framework

The methodology of Data Envelopment Analysis (DEA) has been developed by A. Charnes, W. Cooper and E. Rhodes in 1978 (Charnes et al., 1978; Banker et al., 1984). The DEA gives the opportunity to estimate the efficiency of decision-making units (DMUs). The efficiency is defined as a ratio of resources spent on production output to the achieved result, usually expressed in a total yield of goods and services. Originally, the DEA methodology has been developed to assess the efficiency of non-commercial organizations in the United Stated of America. However, due to its universality, the Data Envelopment Analysis has been recognized in different spheres of economics, including for assessment of forest complex industries (see, e.g. (Limaei, 2013; Kao and Yang, 1991)).

Mathematical model lying under the DEA methodology is a problem of linear programming. It is assumed that one maximizes the efficiency of decision-making unit subject to fulfillment of restrictions on resource use. Let us consider this problem in general form for the basic model.

We study the relative efficiency ε_k of a set consisting of k decision-making units. It is assumed that the scale elasticity is constant. Some quantities of resources X_{ik}, $i = 1,2,\ldots,m$ come on the conditional input of a DMU. Then they are combined within the production process and yield the outputs, or the elements of total output Y_{rk}, $r = 1,2,\ldots,s$. The relative efficiency ε_k of the k-th DMU is expressed through the ratio of total output to the total consumption of resources:

$$\varepsilon_k = \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}}.$$

Here u_r and v_i are the weights of corresponding inputs and outputs, which act as variables for the optimization problems. It is obvious that all the weights are non-negative:

$$u_1, u_2, \ldots, u_s \geq 0;\ v_1, v, \ldots, v_m \geq 0.$$

It is natural to represent the restrictions of a model in the following way, assuming that efficiency of specific economical agent should not exceed 1:

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1, j = 1,2, \ldots, n.$$

To apply the method of solving of the linear programming problems, one should convert the current system of restrictions from fractional notation to the linear considering system of the following form:

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, j = 1,2, \dots, n;$$

$$\sum_{r=1}^{s} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ik} = 1.$$

Then, the basic problem of determining of efficiency of a DMU could be written as following:

$$\varepsilon_k = \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} \to max,$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, j = 1,2, \dots, n;$$

$$\sum_{r=1}^{s} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ik} = 1.$$

$$u_1, u_2, \dots, u_s \geq 0;\ v_1, v, \dots, v_m \geq 0.$$

Solving this problem for every k-th DMU, we find the optimum plan and values ε_k that reflect relative efficiency of corresponding DMUs. The more value of ε_k is close to 1, the higher the efficiency of k-th DMU is. Those decision-making units that have the efficiency parameter strictly equal to 1 is the most efficient. It is important to understand that, by its definition, the parameter ε_k cannot exceed 1, so the lower this parameter is, the more resources are consumed by the decision-making unit and the less output it has (or the production is of a lower quality, hence it costs less than similar products of competitors).

In some literature DMUs that have the efficiency parameter equal to 1 are called “leaders”, and all the others–“outsiders”.

The practical outcome of the DEA methodology includes not only a possibility to make a comparative analysis of decision-making units by their level of efficiency, but also a powerful instrument for producing the specific recommendations of how to optimize the activity of “outsiders” so they could achieve the optimal trajectories. The optimal values of input parameters are defined as a product of efficiency parameter and the value of particular indicator of input:

$$X_{ik}^{recommended} = \varepsilon_k X_{ik}.$$

Thus, one could suggest some policy decisions for the management of “outsiders” based on calculated recommended values of input resources amounts.

Interpretation of parameter ε_k may be different and depends on the object and content of study. In our opinion, R.M. Mel’nikov suggested the most correct interpretation (Mel’nikov, 2007):

- if $\varepsilon_k > 0.75$, then the DMU could be considered as normally effective;
- if $0.5 \leq \varepsilon_k < 0.75$, then the DMU is weakly effective;
- if $\varepsilon_k < 0.5$, then the DMU is inefficient.

As mentioned above, the DEA methodology is widely applied through the world for assessment of the forest complexes efficiencies. Let us consider the most interesting studies. K. Karo and Y. Young studied the efficiency of forest land management (Kao and Young, 1991), S. Lebel and W. Stuart considered only the forest lumbering sector (Lebel and Stuart, 1998), the work of S. Fotiou has dedicated his study to the saw-mill production (Fotiou, 2000). It is worth to notice the recent work of M. Limaei (2013), where the efficiency of Iranian forest companies of full cycle of processing is considered. All the studies mentioned above are united with a common micro economical object–a forest company.

Despite so widespread application of the DEA methodology in the world practice, they had never been used in Russia for the assessment of the efficiency or for sets of forest industries, neither for regional forest complexes. Moreover, as we stated earlier, even the Western literature has no experience of applying of the DEA methodology to the analysis of regional production formation efficiency.

In the present work we suggest to apply the DEA methodology for the analysis of regional forest complexes for the first time. In order to implement this point, one should introduce the DEA model of abstract firm.

We use the model of production output, which became traditional for the nature resources economics:

$$Y = F(K,L,N)$$

Herein:

Y is a total production output,

K is a cost of capital,

L is a cost of labour.

N represents a cost of natural resources factor (in our case, a total cost of extracted round wood). The DEA model for this case is written as follows:

$$\varepsilon_k = \frac{uY_k}{v_1K_k + v_2L_k + v_3N_k} \to max,$$
$$uY_j - (v_1K_j + v_2L_j + v_3N_j) \leq 0, j = 1,2,\dots,n;$$
$$uY_k - (v_1K_k + v_2L_k + v_3N_k) = 1,$$
$$u \geq 0;\ v_1, v_2, v_3 \geq 0.$$

So, we have just formulated the common problem of data envelopment analysis for the regional forest complexes. Let us define the particular approaches to the assessment of independent parts of suggested model.

First, we consider the approach to the assessment of efficiency of forest complex as a whole, not dividing it on separate sectors. For the parameters that characterize the activity of the forest complex as a whole the data is summarized through three types of economical activity: forest logging, sawmilling, and pulp production. The period of observation is one year. Variables obtained from the system are denoted as lower-case Latin letters. Units of measure for all the cost parameters are thousands of rubles. Salaries are nominated in rubles.

Gross complex's output Y is estimated through the parameter "Volume of shipped goods produced by domestic manufacture, rendered services by net economic activities" (y), i.e.

$$Y = y$$

Capital costs K are presented as parameter "Fixed assets" in the system of Russian national statistics (k):

$$K = k$$

We suggest evaluating the labour factor L as a sum of total salary of the employees of the forest complex and employees of bodies of regional administration acting in the forest branch. The salary of forest complex employees could be evaluated as "Average monthly wage per one employee, for the whole list of organizations" (w) times "Average count of employees, for the whole list of organizations" times 12 (for getting the salary in the course of year). Salary of employees of bodies of regional administration acting in the forest branch is determined through the parameter "Wages fund of employees of bodies of regional administration acting in the forest branch" (b). Thus, we get:

$$L = 12wl + b.$$

According to our assumption, the factor of natural resources N is composed of three components: volume of logging, costs of forest protection and costs of reforestation. Since we suppose that the timber is the raw material for forest complex, the volume of logged timber may act as an input variable. In the system of national statistics this variable is evaluated as a parameter "Volume of logged timber" (t). Costs of forest protection and reforestation reflect the total cost of resources spent by government and private sector firms on resources renewal. These variables may be approximated by the following parameters obtained from the national statistics: "Costs of forest protection" (p) and "Reforestation costs" (r) respectively. So, the total depreciation of natural resources factor in our model may be written as:

$$N = t + p + r.$$

Let us write the final form of DEA model that make the foundation for our method of assessment of relative efficiency of forest complex as a whole:

$$\varepsilon_k = \frac{uY_k}{v_1K_k + v_2(12wl)_k + v_3b_k + v_4t_k + v_5p_k + v_6r_k} \to max,$$
$$uY_j - (v_1K_j + v_2(12wl)_j + v_3b_j + v_4t_j + v_5p_j + v_6r_j) \le 0, j = 1,2,\dots,n;$$
$$uY_k - (v_1K_k + v_2(12wl)_k + v_3b_k + v_4t_k + v_5p_k + v_6r_k) = 1,$$
$$u \ge 0;\ v_1, v_2, v_3, v_4, v_5, v_6 \ge 0.$$

Unified Interdepartmental Statistical Information System. Undoubtedly, it would be interesting to hold the same evaluation for earlier periods (e.g., during the whole 2000s), but the most part of parameters being used in our model were not observed before 2009, hence they were not included in the statistical databases mentioned above.

The results of assessment of efficiency for the regional forest complexes of Siberian Federal District of Russia in late 2000s–early 2010 are presented in Table 1. The calculations have been carried out in the Microsoft Excel environment using the "Solver" extension.

Every value of efficiency parameter has the short label in parentheses signifying its interpretation according to the scheme we introduced earlier:

- efficient complexes ($\varepsilon_k \ge 0.75$) are denoted as "E";
- weakly effective complexes ($0.5 \le \varepsilon_k < 0.75$) are denoted as "W";
- inefficient complexes ($\varepsilon_k \le 0.75$) are denoted as "N".

3. Results and Discussion

In current section we'll give the assessment of efficiency for the regional forest complexes of Siberian Federal District of Russia in late 2000s–early 2010 using the method developed and set forth above.

The dataset is based upon the official statistics obtained from the Russian Federal State Statistics Service across the regions of Siberian Federal District in 2009–2012 (Promyshlennost' Rossii, 2008, 2009, 2010. 2011, 2012; Regiony Rossii…, 2008, 2009, 2010. 2011, 2012), and the

As one may see from Table 1, Altai Krai has demonstrated maximal efficiency of its forest complex in 2009–2011. However, in 2012 the efficiency parameter has decreased down to 0.72. Zabaikalsky Krai has relatively weak efficient forest complex (the parameter is between 0.49 and 0.79 during the observed period). The most efficient forest complexes act in Irkutsk Oblast and Krasnoyarsk Krai (the value of efficiency parameter is exactly equal to 1 for every year). Forest complexes of Kemerovo and Novosibirsk

Table 1. The results of assessment of efficiency for the regional forest complexes of Siberian Federal District of Russia in late 2000s–early 2010

Region	2009	2010	2011	2012
Altai Krai	1 (E)	1 (E)	1 (E)	0.729 (W)
Zabaikalsky Krai	0.793 (E)	0.560 (W)	0.492 (N)	0.702 (W)
Irkutsk Oblast	1 (E)	1 (E)	1 (E)	1 (E)
Kemerovo Oblast	1 (E)	1 (E)	0.425 (N)	0.980 (E)
Krasnoyarsk Krai	1 (E)	1 (E)	1 (E)	1 (E)
Novosibirsk Oblast	0.995 (E)	1 (E)	1 (E)	1 (E)
Omsk Oblast	0.598 (W)	1 (E)	0.756 (E)	0.562 (W)
Altai Republic	0.279 (N)	0.387 (N)	0.383 (N)	0.438 (N)
Republic of Buryatia	0.635 (W)	0.702 (W)	0.553 (W)	0.531 (W)
Tyva Republic	1 (E)	0.736 (W)	0.211 (N)	0.305 (N)
Republic of Khakassia	0.797 (E)	1 (E)	1 (E)	1 (E)
Tomsk Oblast	0.423 (N)	0.710 (W)	1 (E)	0.558 (W)

Oblasts are relatively efficient, but in particular years the parameter of efficiency deviated from 1. The same conclusion goes for Republic of Khakassia and Omsk Oblast. The forest complexes of Altai and Tyva Republics and Tomsk Oblast are weakly effective.

According to our estimation, the Irkutsk Oblast is a leader of forest industry of Siberia. In our opinion, this result may be explained by several reasons. First, this region has the largest share (about 40% in 2011) in the total production of Siberian forest production. It is also important that a lot of highly efficient modern forest industries founded by foreign forest branch leaders act on the territory of the Irkutsk Oblast, e.g. the Ilim Group.

Thus, the leaders of forest industry of Siberian Federal District are Krasnoyarsk Krai and Irkutsk Oblast. These regions possess the richest stocks of forest resources and the most powerful potential of development. Altai krai and Novosibirsk Oblast are also highly developed forest regions, despite that Novosibirsk oblast doesn't have as much forest resources as others do. On the other hand, Novosibirsk has a strong scientific and innovative potential thanks to Siberian Branch of the Russian Academy of Sciences and in fact is the scientific capital of the whole Siberian Federal District. It was expected that the efficiency of forest complexes of Altai and Tyva Republics, Republic of Buryatia, Tomsk Oblast and Zabaykalsky Krai is low.

It is also important to determine the targeted values of input parameters of our model, in order to improve the efficiency of the whole system of regional forest complexes. After calculations, we have the following values to be subtracted from the current levels of corresponding parameters of activity for the regions' forest complexes (Table 2).

4. Conclusion

In the presented paper we have developed a new method of analysis of efficiency of regional forest complexes. Our method is based on the Data Envelopment Analysis methodology. It allows not only comparison of different regional forest complexes by their level of efficiency, but also produces specific recommendations for

Table 2. Values to be subtracted from the current levels of corresponding parameters of activity for the regions' forest complexes

	ΔK	ΔL	Δb	Δt	Δp	Δr
Altai Krai	688 408,93	864 704,59	864 704,59	806,77	1 088,39	7 714,79
Zabaikalsky Krai	31 750,12	88 063,64	88 063,64	704,74	5 192,50	36 897,50
Irkutsk Oblast	0,00	0,00	0,00	0,00	0,00	0,00
Kemerovo Oblast	5 951,27	26 531,73	26 531,73	485,64	531,11	430,52
Krasnoyarsk Krai	0,00	0,00	0,00	0,00	0,00	0,00
Novosibirsk Oblast	0,00	0,00	0,00	0,00	0,00	0,00
Omsk Oblast	661 048,82	922 563,16	922 563,16	859,50	415,62	9 339,08
Altai Republic	20 169,98	80 508,60	80 508,60	352,95	1 039,28	7 854,98
Republic of Buryatia	608 547,50	550 789,28	550 789,28	1 075,42	3 370,19	20 444,63
Tyva Republic	13 487,90	72 749,09	72 749,09	110,90	1 162,69	9 013,94
Republic of Khakassia	0,00	0,00	0,00	0,00	0,00	0,00
Tomsk Oblast	4 802 298,36	986 851,21	986 851,21	2 001,25	168,47	9 845,58

improving of "outsiders" forest sector activity. The method was successfully applied to the optimization of efficiency of Siberian forest complexes. The analysis showed that the higher efficiency corresponds to the regions with the richest stocks of forest resources: Krasnoyarsk Krai and Irkutsk Oblast. Besides the result of assessment, our analysis allowed to determine the values of necessary changes in the input (resource expenditure) parameters to be implemented for improving the efficiency of the forest complexes of Siberian Federal District.

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Анализ эффективности функционирования региональных лесопромышленных комплексов (на примере Сибирского федерального округа)

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В статье разработана новая методика анализа эффективности региональных лесопромышленных комплексов, основанная на методологии анализа свертки данных (DEA). Полученная методика позволяет не только сравнивать различные региональные ЛПК между собой по уровню эффективности, но и вырабатывать практические рекомендации по оптимизации деятельности «отстающих» региональных лесопромышленных комплексов. Методика была применена для анализа эффективности функционирования лесопромышленных комплексов регионов Сибирского федерального округа. Результаты анализа выявили, что наивысшей эффективностью обладают лесопромышленные комплексы Красноярского края и Иркутской области – регионов, являющихся лидерами округа по запасам леса. Сформулированы предложения по оптимизации затрат ресурсов в тех регионах, чьи лесопромышленные комплексы были признаны малоэффективными.

Ключевые слова: лесопромышленный комплекс, эффективность, Сибирский федеральный округ, анализ свертки данных.