Mathematical Modelling of Postindustrial Land Use Value in the Big Cities in Ukraine

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Abstract
The research paper deals with theoretical and methodological approaches to rational urban land use. Basing on the international scientific research, the authors offer original interpretation of the term «postindustrial land». Taking into account a drastic rapid dynamics of urbanization in large urban agglomerations worldwide and de-industrialization as a trend of urban land-use exemplified by the city of Kyiv in Ukraine a mathematical model of setting the price of postindustrial land with aimed to prediction the efficiency of industrial land transformation was developed in this study.

Keywords- Land transformation, Postindustrial land, Urban land, Economic and mathematical model.
1. Introduction

Problem of land-use is a complex social, economic, ecological and security problem (Kopachevsky et al., 2016; Shevchenko et al., 2017; Openko et al., 2017; Ievsiukov et al., 2018). A major task of modern urban land use is the release of great areas, used before for industrial production, which due to ineffectiveness of industries are being shifted now out of cities or transformed into highly profitable, green enterprises and territories (Mishenin and Koblyanska, 2012). Because now the major part of labor resources is employed in service sector, operation management and data processing, the employment rate of economically active population in material production is decreasing (Tsvyakh and Openko, 2017). Therefore, management decision concerning enterprises placement is more depends of logistics, the use of adjacent land, eco-economic factors and value of land (Mishenin and Koblyanska, 2012). At the same time, there are some important issues which are still not well-developed. In particular, streamlining the use of big city spaces, elaborating the system of economic liability of real estate developers in urban land-use, rational decision-making system based on eco-economic ground should be developed in view of industrial land transformation (Guo et al., 2018). The current land use structure in big cities with extensive postindustrial areas should be transformed according to the tendencies of industries decentralization and balanced urban use of resources (Guo et al., 2018). That is why the development of scientifically-grounded basis for rational use of postindustrial land is a topical task. According to (Voronina, 2012), the context of urban land use deindustrialization is quite ambiguous, since it is a deep transformation of a big city space. Beyond the positive effect of the release of urban territories from negative consequences of industrial period, the process of deindustrialization may be accompanied with negative social processes, because deindustrialization may be caused by an economic and social crisis, enterprises shutting down and the production decreasing. Researchers found (Guo and Xiong, 2014; Silva et al., 2014) that the decreasing of the industrial sector in the big city is connected with economy restructuring and growing a share of service sectors. This, in turn, is made possible by effective industrial development, with productivity level allowing to meet people’s material needs at a high level and, in doing so, releasing ever more resources for service industries development. Deindustrialization may be viewed in this case as a so-called by-product of industrial society evolution, based on knowledge and geo-information technologies. On the base of analysis of theoretical and methodological justification of transformation, deindustrialization, re-development of industrial facilities in a big city proposed in publications of Loures, Burley, Panagopoulos (Loures and Panagopoulos, 2007; Loures, 2008; Loures et al., 2008; Loures and Panagopoulos, 2010; Loures and Burley, 2012), Brandt et al. (2000), Berger (2006), Shevchenko et al. (2017) and others, the term of post-industrial lands was proposed. As the particularly interesting example of rational use of urban lands of non-functional industrial facilities, the Battersea power station may be examined. This station was constructed in the 1930s on the South Bank of the River Thames in the area of Nine Elms. Reconstruction of the station and adjacent area is going to become the greatest construction in the history of modern London. The construction is scheduled to be completed in 2026. According to the plans of Battersea Power Station Development Company (BPSDC), which was set up by the investors for overseeing the project, renovation will affect not only the former power station, but also the adjacent territory of 16 ha. The industrial monument of the first half of XX century will be transformed into leisure and cultural and business center of the city district (Five most promising areas of Europe under construction, 2015).

In our research, we use term “postindustrial lands” to denote destroyed by human activities landscapes, empty and non-functional industrial facilities on deserted (not used for purposes intended) industrial territories, damaging adjacent settlements, having negative effect on mental
condition of population, shaping unfavorable environment and resulting geo-ecological imbalances in urban system.

Therefore, the purpose of this research is to propose a mathematical model for setting the prices of postindustrial lands in big cities in the context of predicting the efficiency of industrial land transformation. The object of the research is the process of improving postindustrial land use.

2. Methodology of Modeling
According to the United Nations data since 2008, for the first time in history half the world’s population will live in urban areas. However, urbanization rate significantly varies by countries and regions (see Table 1).

Table 1. Dynamics of urban and rural population, 1950-2050

| Year   | Urban population (mln people) | Rate of urban population change (%) |
|--------|------------------------------|-------------------------------------|
| 1950   | 737                          | 2.9                                 |
| 1975   | 1519                         | 2.4                                 |
| 2000   | 4084                         | 1.8                                 |
| 2025   | 6398                         | 1.3                                 |

*according to «World Urbanization Prospects: The 2007 Revision» (UN, 2008)

Transformational effect of urbanization became first visible in the developed regions of the world, with the rate exceeding 80% in Australia, New Zealand and North America. In the developed world Europe is the least urbanized, with 72% of population living in urban areas. Among developing countries particularly high urbanization rate (78%) has been reached in Latin America and the Caribbean, where it is higher than the same rate for Europe as a whole (UN, 2008). Urbanization rate is expected to rise in the decade to come in all key regions of the world, with the process in Africa and Asia proceeding faster, than in other key regions, even if the anticipated pace of urbanization drops compared to that, observed in the past decades (see Table 2). However, till the middle of the century urbanization rate in developing countries of Africa, Asia, Oceania is expected to be lower than that of developed countries, Latin America and the Caribbean. In general, the world’s population is likely to be 70% urban by 2050. The greatest number of urban dwellers is forecast to live in Asia (54%) and Africa (19%) (UN, 2008).
As it was pointed by Percyk (Voronina, 2012), the “urban giants” of 21st century – countries with population more than 100 mln – will include in 2025: China (832 mln), India (630 mln), the US (281 mln.), Brazil (205 mln), Indonesia (167 mln.), Nigeria (147 mln), Pakistan (142 mln), Russia (119 mln), Mexico (117 mln), and Japan (103 mln). At the same time, this data is slightly different than that set presented in the report of the UN Social and Economic Council (Table 3).

Table 2. Dynamics of urbanization, 1950–2050*

| Year | Worldwide | Developed countries | Developing countries | Least developed countries | Africa | Asia | Latin America and the Caribbean | North America | Europe | Oceania |
|------|-----------|---------------------|---------------------|--------------------------|--------|------|-----------------------------|-------------|--------|---------|
| 1950 | 29.1      | 52.5                | 18.0                | 7.5                      | 14.5   | 16.8 | 41.4                        | 63.9        | 51.2   | 62.0    |
| 1975 | 37.3      | 67.0                | 27.0                | 14.8                     | 25.7   | 24.0 | 61.1                        | 73.8        | 65.7   | 71.5    |
| 2007 | 49.4      | 74.4                | 43.6                | 27.9                     | 38.7   | 40.8 | 78.3                        | 81.3        | 72.2   | 70.5    |
| 2025 | 57.2      | 79.0                | 53.2                | 38.1                     | 47.2   | 51.1 | 83.5                        | 85.7        | 76.2   | 71.9    |
| 2050 | 69.6      | 86.0                | 67.0                | 55.5                     | 61.8   | 66.2 | 88.7                        | 90.2        | 83.8   | 76.4    |

The data are presented in Table 2, which shows the percentage of the world population living in urban areas and the rate of urbanization for different regions of the world. The data is presented for the years 1950, 1975, 2007, and 2025. The rate of urbanization is calculated as the percentage of the urban population in relation to the world population. The data is based on the United Nations’ International Centre for Human Settlements-Water (UN-Habitat) (2014).

Table 3. Population Forecast for Key Countries of the World in 2025*

| No. | Name of country     | Rural population (mln people) | Urban population (mln people) | Proportion of urban population, % | Proportion of urban population in relation to world population, % | Population growth rate for 2007-2025, % | Urban population in 2025 (mln people) |
|-----|---------------------|-------------------------------|-------------------------------|----------------------------------|---------------------------------------------------------------|----------------------------------------|--------------------------------------|
| 1   | China               | 767                           | 3294                          | 49.4                             | 100.0                                                         | 1.8                                    | 4584                                 |
| 2   | India               | 828                           | 341                           | 29.2                             | 10.4                                                          | 2.5                                    | 538                                  |
| 3   | USA                 | 57                            | 249                           | 81.4                             | 7.6                                                           | 1.1                                    | 305                                  |
| 4   | Brazil              | 28                            | 163                           | 85.2                             | 5.0                                                           | 1.3                                    | 207                                  |
| 5   | Indonesia           | 115                           | 117                           | 50.4                             | 3.5                                                           | 2.4                                    | 179                                  |
| 6   | Russian Federation  | 39                            | 104                           | 72.4                             | 3.2                                                           | 0.4                                    | 96                                   |
| 7   | Japan               | 43                            | 85                            | 66.3                             | 2.6                                                           | 0.1                                    | 86                                   |
| 8   | Mexico              | 25                            | 82                            | 76.9                             | 2.5                                                           | 1.2                                    | 102                                  |
| 9   | Nigeria             | 78                            | 71                            | 47.6                             | 2.1                                                           | 3.3                                    | 127                                  |
| 10  | Germany             | 22                            | 61                            | 73.5                             | 1.8                                                           | 0.1                                    | 62                                   |
| 11  | Pakistan            | 105                           | 58                            | 35.7                             | 1.8                                                           | 3.2                                    | 104                                  |
| 12  | The Philippines     | 31                            | 57                            | 64.2                             | 1.7                                                           | 2.4                                    | 86                                   |
| 13  | The United Kingdom  | 6                             | 55                            | 89.9                             | 1.7                                                           | 0.5                                    | 60                                   |
| 14  | Turkey              | 24                            | 51                            | 68.2                             | 1.6                                                           | 1.6                                    | 68                                   |
| 15  | Iran                | 23                            | 48                            | 68.0                             | 1.5                                                           | 1.8                                    | 67                                   |
| 16  | France              | 14                            | 48                            | 77.1                             | 1.4                                                           | 0.7                                    | 54                                   |
| 17  | Bangladesh          | 116                           | 42                            | 26.6                             | 1.3                                                           | 3.3                                    | 77                                   |
| 18  | Italy               | 19                            | 40                            | 67.9                             | 1.2                                                           | 0.3                                    | 42                                   |
| 19  | The Republic of Korea | 9                             | 39                            | 81.3                             | 1.2                                                           | 0.4                                    | 42                                   |
| 20  | Argentina           | 3                             | 36                            | 91.8                             | 1.1                                                           | 1.0                                    | 43                                   |
| 21  | Columbia            | 12                            | 34                            | 74.2                             | 1.0                                                           | 1.4                                    | 44                                   |
| 22  | Spain               | 10                            | 34                            | 77.0                             | 1.0                                                           | 0.5                                    | 38                                   |
| 23  | Egypt               | 43                            | 32                            | 42.6                             | 1.0                                                           | 2.0                                    | 46                                   |
| 24  | Ukraine             | 15                            | 31                            | 67.9                             | 1.0                                                           | 0.5                                    | 28                                   |
| 25  | South Africa        | 19                            | 29                            | 60.2                             | 0.9                                                           | 1.2                                    | 36                                   |

*according to «World Urbanization Prospects: The 2007 Revision» (UN, 2008)
In Ukraine the process of urbanization as a complex economic phenomenon has resulted to expansion of the urban areas and, consequently, to growth of proportion of urban dwellers, basically due to reduction of the number of rural population. Urban population in Ukraine is about 69.12% (29,673 mln people), while rural population stands at 30.88% (13,256 mln people). Expansion of the Dynamics of urban population in Ukraine was studied on the example of Kyiv capital city. Results of the study of processes of deindustrialization in the context of urban land use were tested on the model city of Kyiv, as one of the most densely populated industrial centers of Ukraine (Tsvyakh and Openko, 2017). According to the Kyiv City Development Strategy - 2025, the following key projected figures of demographic change of the city were accepted as a basis for Kyiv master plan calculations: resident population – 3.15 mln people, actual – 3.68 mln people, daytime – up to 4.0 mln people (The general plan of the city of Kyiv for the period till 2020, 2001). It was found that historically local industrial areas, enterprises, storages, factories are located within valuable for urban development sites such as coastal areas, health protection zones or near the residential buildings. According to data of the Main Department of the State Statistics Service of Ukraine in Kyiv, at the moment of January 01, 2016 the total area of Kyiv covered 83.6 k ha, including 4.6 k ha agricultural lands; 35.1 k ha of woods and other forested areas; 6.7 k ha of residential areas; and 3.3 k ha of industrial lands. Analysis of dynamics of land use in Kyiv during 1995–2016 demonstrates a tendency of expanding of the building sites: from 34.0 k ha in 1995 to 37.0 k ha in 2016. At the same time, total area of industrial lands decreased during this period from 5.9 to 3.3 k ha. In our opinion, the long-term economic development of Kyiv should be based on rational urban land-use, including deindustrialization, modernization and restructuring of productive capacities, reduction its resource consumption, and improving its competitiveness.

In general, in big developing cities there is an acute lack of lands of residential and civil use, especially in downtown. In this context, the question of territory choice for real estate construction became a topical: most convenient and optimal on technical indicators and town-planning conditions areas turn out to be occupied with industrial facilities, many of which eventually become unprofitable, environmentally hazardous or non-functional. This situation is caused by the following factors: historically formed urban infrastructure, lack of systematic approach to the process of zoning and overall city planning, as well as its rapid and eventually chaotic development, when radically different zones, e.g. industrial and residential zones become mixed.

Development of mathematical model for setting the price of postindustrial lands in a big city requires determination of factors directly affecting to market land value. In our opinion, among the key factors, affecting the market value of postindustrial land (Y), the following are distinguished:

- inflation rate in Ukraine (X₁), %;
- inflation rate in Ukraine (progressive total) (X₂), %;
- average US dollar rate for the respective assessment period (X₃), UAH;
- existence of a subway station nearby (X₄), m;
- distance from downtown (X₅), m;
- existence of water bodies (X₆), m;
- distance from recreation areas – parks, squares, woodlands etc.) (X₇), m;
- existence of residential areas nearby (X₈), m;
existence of railway nearby \((X_3)\), m;
- distance to city center (city center – site of the main post office) \((X_{10})\), km;
- total area of land \((X_{11})\), ha;
- proportion of the land, belonging to industrial zones as per the master plan \((X_{12})\), %;
- dynamics of the average monthly wage of those, employed in industries \((X_{13})\), UAH;
- average income of the population of Kyiv \((X_{14})\), mln UAH;
- fixed investments in the city \((X_{15})\), mln UAH.

Before constructing a mathematical dependence, the impact of factors \((X_1, X_2, X_3, \ldots, X_{15})\) to the final outcome – postindustrial land value \((Y)\) – was assessed. To that effect, possible combinations of pair coefficients of correlation between resultant figure \((Y)\) and factors \((X_1, X_2, X_3, \ldots, X_{15})\) were determined.

Adhering to the scheme of the least-squares method, we have to find \(\min F(b, c)\), which is formulated as the following optimization problem:

\[
\sum_{j=1}^{m} R\left[y_j, bX_j + c\right] \rightarrow \min.
\]  
(1)

Which in fuzzy numbers becomes:

\[
\sum_{j=1}^{m} \left[ \frac{1}{2} (bX_{0j} + c - aX_{0j})^2 + \frac{1}{2} (bX_{1j} + c - aX_{1j})^2 \right] da \rightarrow \min.
\]  
(2)

where \( aX_{0j} \) and \( aX_{0j} \) – left limits of ranges \(\alpha\)-cuts of the fuzzy numbers \(X\) and \(Y\); \( aX_{1j} \) and \( aY_{1j} \) – respective right limits of ranges.

In the determination of regression coefficients \(b, c\) we have two equations, expressed in the derivatives:

\[
\frac{dF(b, c)}{db} = 0; \quad \frac{dF(b, c)}{dc} = 0.
\]  
(3)

Since derivatives of the function (3) equal:

\[
\frac{dF}{db} = \sum_{j=1}^{m} \left[ \int_0^1 (bX_{0j} + c - aX_{0j}) X_{0j} da + \int_0^1 (bX_{1j} + c - aX_{1j}) X_{1j} da \right],
\]

\[
\frac{dF}{dc} = \sum_{j=1}^{m} \left[ \int_0^1 (bX_{0j} + c - aX_{0j}) da + \int_0^1 (bX_{1j} + c - aX_{1j}) da \right].
\]  
(4)

To do the sum we get a system of equations:

\[
\begin{align*}
X^2 \times b + X \times c &= XY \\
X \times b + 2m \times c &= Y.
\end{align*}
\]  
(5)

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In which the following symbols are accepted:
\[
\bar{X} = \sum_{j=1}^{m} \left[ \int_{0}^{1} a_{X_{ij}} da \right], \quad \bar{Y} = \sum_{j=1}^{m} \left[ \int_{0}^{1} a_{Y_{ij}} da \right],
\]
\[
\bar{XY} = \sum_{j=1}^{m} \left[ \int_{0}^{1} a_{X_{ij}} \times a_{Y_{ij}} da \right],
\]
\[
\bar{X}^2 = \sum_{j=1}^{m} \left[ \int_{0}^{1} a_{X_{ij}}^2 da \right].
\]

Doing the system of equations, we get the value of regression coefficients:

\[
b = \frac{\bar{XY} \bar{X} - \bar{X} \bar{Y}}{\Delta}, \quad c = \frac{\bar{X}^2 \bar{Y} - \bar{X} \bar{XY}}{\Delta},
\]

where: \( \Delta = \left| \begin{array}{cc} \bar{X}^2 & \bar{X} \\ \bar{X} & 2m \end{array} \right| \) – determinant of the system of equations (5).

Consequently, having done the system of equations, (5) we get the following values of coefficients:

\[
b = \frac{2m \bar{XY} - \bar{X} \bar{Y}}{2m \bar{X^2} - \bar{X}^2}; \quad c = \frac{\bar{X}^2 \bar{Y} - \bar{X} \bar{XY}}{2m \bar{X^2} - \bar{X}^2} \quad \text{that is an analogue of formulas for calculating coefficients of two-dimensional regression for exact numbers.}
\]

3. Results of the Modeling
The findings allow extending methods of regressive analysis of fuzzy numbers from a relatively narrow range of triangular fuzzy numbers to the whole range of fuzzy arbitrary numbers (Table 4).

To create the mathematical model, stepwise multiple regression was used, which is applicable when the resultant figure (Y) depends on multiple factors (X), in our case – on \( X_1, X_2, X_3, X_4, X_{10}, X_{13}, X_{14}, X_{15} \) (7):

\[
Y = a_0 x_1^{a_1} \times x_2^{a_2} \times \ldots \times x_m^{a_m} = a_0 \prod_{j=1}^{m} x_j^{a_j},
\]

\( x_1, x_2, \ldots, x_m \) – factors, affecting the result figure \( Y \);
\( a_0, a_1, a_2, \ldots, a_m \) – unknown regression parameters.

Using the least-square method, we can found the unknown parameters \( a \) of the searched mathematical model by means of Microsoft Excel software, namely, built-in LINEST function. To obtain a form of linear dependence (eq. 8) it is necessary to turn the stepwise regression into a linear form by taken the logarithms of the regression equation and make a replacement of variables.

\[
\ln y = \ln a_0 + a_1 \ln x_1 + a_2 \ln x_2 + \ldots + a_n \ln x_n,
\]

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Table 4. Determination of various combinations of pair correlation coefficients (R) along the main diagonal*

|     | Y   | X1  | X2  | X3  | X4  | X5  | X6  | X7  | X8  | X9  | X10 | X11 | X12 | X13 | X14 | X15 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Y   | 0.35| 0.49| 0.31| 0.27| 0.06| -0.13| -0.05| 0.18| -0.07| -0.41| -0.07| -0.12| 0.45| 0.44| 0.28|
| X1  | 0.57| 0.49| 0.31| 0.27| -0.01| -0.04| 0.16| -0.11| -0.03| -0.12| 0.09| -0.02| 0.02| 0.49| 0.50| 0.36|
| X2  | 0.87| 0.49| 0.31| 0.27| -0.02| 0.11| -0.14| -0.02| -0.05| -0.13| 0.86| 0.86| 0.90|     |     |     |
| X3  | 0.32| -0.13| 0.10| 0.07| -0.16| -0.49| -0.09| -0.06| -0.09| -0.09| 0.03|     |     |     |     |     |
| X4  | -0.20| -0.04| 0.09| 0.01| -0.26| -0.08| 0.06| -0.14| -0.14| -0.02|     |     |     |     |     |     |
| X5  | -0.23| -0.08| 0.04| 0.23| 0.15| 0.09| 0.13| 0.13| 0.04|     |     |     |     |     |     |     |
| X6  | -0.30| -0.19| -0.13| 0.03| -0.12| 0.09| -0.02| 0.02| 0.49| 0.50| 0.36|     |     |     |     |     |
| X7  | 0.05| 0.36| -0.12| 0.14| -0.13| 0.86| 0.86| 0.90|     |     |     |     |     |     |     |     |
| X8  | 0.01| 0.01| 0.17|     |     |     |     |     |     |     |     |     |     |     |     |     |
| X9  | 0.13| 0.06| 0.07| 0.05| 0.01| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05|     |     |     |     |     |
| X10 | 0.13| 0.06| 0.07| 0.05| 0.01| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05|     |     |     |     |     |
| X11 | 0.15| 0.05| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05|     |     |     |     |     |
| X12 | 0.01| 0.01| 0.17|     |     |     |     |     |     |     |     |     |     |     |     |     |
| X13 | 1.00| 0.66|     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| X14 | 0.65|     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

*Calculated by the authors

Having regard to the scale of interpretation of the correlation coefficient, eight factors (X1, X2, X3, X4, X10, X13, X14, X15) were singled out, which to a certain extent affect the market value of postindustrial land (Y), from among X1, X2, X3, X4, X10, X13, X14 – having a mean effect; factors X4, X15 – a low effect, a X5, X6, X7, X8, X9, X11, X12, do not affect the land value at all (Table 5).

Table 5. Choice of factors, affecting the market value of land underlying industrial facilities by correlation coefficient*

|     | Y   | X1  | X2  | X3  | X4  | X5  | X6  | X7  | X8  | X9  | X10 | X11 | X12 | X13 | X14 | X15 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Y   | 0.35| 0.49| 0.31| 0.27| 0.06| -0.13| -0.05| 0.18| -0.07| -0.41| -0.07| -0.12| 0.45| 0.44| 0.28|
| X1  | 0.57| 0.49| 0.31| 0.27| -0.01| -0.04| 0.16| -0.11| -0.03| -0.12| 0.09| -0.02| 0.02| 0.49| 0.50| 0.36|
| X2  | 0.87| 0.49| 0.31| 0.27| -0.02| 0.11| -0.14| -0.02| -0.05| -0.13| 0.86| 0.86| 0.90|     |     |     |
| X3  | 0.32| -0.13| 0.10| 0.07| -0.16| -0.49| -0.09| -0.06| -0.09| -0.09| 0.03|     |     |     |     |     |
| X4  | -0.20| -0.04| 0.09| 0.01| -0.26| -0.08| 0.06| -0.14| -0.14| -0.02|     |     |     |     |     |     |
| X5  | -0.23| -0.08| 0.04| 0.23| 0.15| 0.09| 0.13| 0.13| 0.04|     |     |     |     |     |     |     |
| X6  | -0.30| -0.19| -0.13| 0.03| -0.12| 0.09| -0.02| 0.02| 0.49| 0.50| 0.36|     |     |     |     |     |
| X7  | 0.05| 0.36| -0.12| 0.14| -0.13| 0.86| 0.86| 0.90|     |     |     |     |     |     |     |     |
| X8  | 0.01| 0.01| 0.17|     |     |     |     |     |     |     |     |     |     |     |     |     |
| X9  | 0.13| 0.06| 0.07| 0.05| 0.01| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05|     |     |     |     |     |
| X10 | 0.13| 0.06| 0.07| 0.05| 0.01| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05|     |     |     |     |     |
| X11 | 0.15| 0.05| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05| 0.06| 0.07| 0.05|     |     |     |     |     |
| X12 | 0.01| 0.01| 0.17|     |     |     |     |     |     |     |     |     |     |     |     |     |
| X13 | 1.00| 0.66|     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| X14 | 0.65|     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

*Calculated by the authors
Figure 1. Graphic representation of adequacy of the mathematical model of land deindustrialization in Kyiv, developed on the basis of stepwise multiple regression, UAH/m².

Linear elements were substituted for the nonlinear: 

\[ x_j' = \ln x_j, (j = 1, m); \quad y' = \ln y; \quad a'_0 = \ln a_0. \]

As a result, we got the following transposed equation (9):

\[ y' = a'_0 + a'_1 x_1' + a'_2 x_2' + \ldots + a'_m x_m'. \]

According to our parameters, the general regression equation will be following:

\[ y' = a'_0 + a'_1 x_1 + a'_2 x_2 + a'_3 x_3 + a'_4 x_4 + a'_5 x_5 + a'_6 x_6 + a'_7 x_7 + a'_8 x_8. \]

If we calculate (based on the least squares method) \( y' \) and \( x' \), we can determine the regressors \( a'_0, \ a'_1, a'_2, a'_3, a'_4, a'_5, a'_6, a'_7, a'_8 \). Hence, the mathematical model of stepwise multiple regression, allowing to evaluate postindustrial land in Kyiv, will be presented as follows:

\[ y = 4.58011E-12 \times x_1 \times 0.035 \times x_2 \times 0.011 \times x_3 \times 1.605 \times x_4 \times 0.418 \times x_5 \times 0.300 \times x_6 \times 1.374 \times x_7 \times 2.758 \times x_8 \times x_9 \times x_{10} \times x_{11} \times x_{12} \times x_{13} \times x_{14} \times x_{15} \]

where \( x_1, x_2, x_3, x_4, x_{10}, x_{13}, x_{14}, x_{15} \)— factors, affecting the resultant figure (postindustrial land value).
Thus, we develop the mathematical model, allowing to predict postindustrial land value in Kyiv based on the known factors $x_1, x_2, x_3, x_4, x_{10}, x_{13}, x_{14}, x_{15}$ and, consequently, to model the efficiency of land deindustrialization.

Based on the economic and mathematical model, expert monetary evaluation of the researched land was made ($N = 160$) and depicted graphically (Figure 1), showing that curve $Y$ (estimated) somehow describes curve $Y$ (result).

4. Conclusions
The proposed economic and mathematical model of stepwise multiple regression allowing to predict a postindustrial land value, can be used for analysis of typical big cities. It should also be noted that this model enables to simulate rational land use and determine key directions of transforming postindustrial urban lands into a highly profitable territorial resource. It was found that the prime costs, related to the application of the mathematical model of expert monetary evaluation of postindustrial lands in a big city, cover the maintenance and upkeep the costs of data matrix of an expert monetary evaluation of typical lands. The determined dependency will allow automating the process of expert evaluation of similar lands in a big city based on the model developed. Economic efficiency of its application may be manifested in lower transaction costs related to staffing of immovable property valuators. In addition, positive effects of application of the economic and mathematical model in the field of management were determined, in particular objective and impartial decision-making as to the market postindustrial land value. For this reason, regardless the long-term process of creating, populating and updating an info-base of expert monetary evaluation of postindustrial land, which underlies the development of the model, it is emphasized, that its further application will reduce the subjective impact of valuators to the land evaluation.

Conflict of Interest
The authors confirm that this article contents have no conflict of interest.

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