Formation of comparable prices for innovative products for the period of their life cycle

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Abstract— the paper considers the issue of comparing the prices for different years and reviews the methods of their comparison. Valuation of products at comparable prices ensures the comparability of data over a number of years. But the issue arises if the task is to compare the prices of goods for the period during which the national currency of the country of origin changed more than once during this period. The paper proposes a formula developed by the authors to compare the prices of different years and bring them to modern ones. The formula takes into account the devaluation of the dollar and resolves the considered issues. The paper also presents the practical use of the recommended formula on the example of comparing the prices for the entire life cycle of an electric motor for the time period of 1982-2019.

Index Terms— innovations, comparable prices, devaluation, rate; currency, life cycle of innovations.

I. INTRODUCTION

One of the means of the statistical analysis of the economic development is the comparison of different indicators for different years. However, the realities of the market economics are such that prices for the same product are constantly rising, so the comparison in absolute terms loses all its sense. This case requires using price comparison. Comparable prices are the prices of a certain year or on a certain date which are conditionally taken as a basis when comparing economic indicators in monetary terms for different periods. The study of comparable prices is important in assessing the efficiency of innovative products and their behaviour in the market since their use eliminates the impact of inflation on the dynamics of production, profits, productivity, capital efficiency and on all indicators which use the cost change of the production volume (Kravchuk and Pererva, 2018; Pererva and Kravchuk, 2018; Kravchuk, 2019).

In economics, there are a large number of original and practically applicable methods of finding price indices, comparing prices and the level of development of countries (Goncharova, Pererva and Yakovlev, 1989, 1998; Grabchenko, Pererva and Smolovik, 1999; Starostina, 2009; Pererva et al., 2012; Pererva et al., 2018). The analysis of macroeconomic indicators of countries using exchange rates, which are formed spontaneously and on the basis of many factors, will not be objective enough, so from the mid-50s of the twentieth century, the conversion of national currencies into a single comparable currency is carried out by calculating purchasing power parity (PPP) of currencies. The issue of international comparisons was carefully studied and revealed in the works (Kravis, Heston and Summers 1978; Summers and Heston, 1988; Sergeev 2011; Kosarev 2014). Interest in the international comparison of macroeconomic indicators is associated with the intensification of foreign economic relations, integration processes and the globalization of international economic cooperation.

International comparisons involve bringing the indicators to some common denominator, measuring them in the same currency or other comparable units. International price comparisons are made in a single currency using exchange rate conversion, or a valuation based on purchasing power parity and the Geary–Khamis dollar, also known as the International Dollar, which appeared in the 1970s as a fictional currency unit. PPP is a ratio of currencies which takes into account the price level in different economies based on the equality of estimates in national prices and currencies of the value of a comparable set of goods and services. And the conversion of the national currency into international dollars is calculated by dividing the value of the national currency by the established rate of PPP. PPP rates are set by several global organizations, such as the World Bank and the International Monetary Fund (IMF).

Also, an interesting analysis allows obtaining one of the key indicators of the system of international comparisons based on PPP – price level index (PLI) which is considered in the article (Kosarev, 2014). This index is the ratio of purchasing power parity to the exchange rate. The higher its value, the higher the price in the economy whose currency is considered.

Thus, the purchasing power parity of currencies is the most important tool of international comparisons. It allows bringing national indicators to a single dimension. The use of PPP is indispensable for the correct answer to questions such as: which country is richer; which are the levels of gross domestic product (GDP) per capita in different countries; where the poverty line

passes in a country (Kosarev, 2014).

But it should be noted that the existing methods of international comparisons have shortcomings that affect the reliability of the results. Thus, the same "basket" of goods and services for different countries depending on their development is different, which calls into question the universality of calculations using PPP, and prices expressed in International dollars are not converted into another country's currency based on current market exchange rates.

The article (Kuznetsov, 2017) demonstrates the application of dimensionless criteria that allow the author to compare the economic development of countries regardless of their size and analyze the dynamic change of economies over time.

Different sources take into account the inflation factor using producer price indices, consumer prices and wage levels for calculating comparable prices (Suvorov and Balashova, 2009; Brintseva, 2016; Shulyatieva, 2016). Due to the fact that the index of wholesale prices of industry had a very high rate of change since 1992 and was equal to 4228.5% and to 9767.5% in Ukraine in 1992 and 1993 respectively (State Statistics Service of Ukraine, 2020), the recalculation compared to the price which takes into account the producer price index can be carried out only very roughly. The method of determining the value of human capital, proposed in the article (Brintseva, 2016), can be used for interstate comparisons, if the cost indicators lead to a single currency (for example, US dollars).

But what to do if the task is to compare the prices of goods whose production currency has changed more than once? To solve this problem, the current paper proposes a formula developed by the authors to compare prices of different years and bring them to modern ones. On the basis of this formula, prices in different currencies are not only reduced to a single currency, namely the US dollar, but also take into account the devaluation of the dollar which also lost its value relative to gold.

The use of the recommended method of price comparison, free from exchange rate fluctuations and the influence of various economic factors, allows economists to objectively compare not only the price of goods, but also other indicators that use the cost change in production.

The aim of the current paper is to solve the comparability issues and bring together the scattered prices of an innovative product during the period of its life cycle to the nowadays ones, excluding inflation, currency and other economic factors.

II. THE PRICE COMPARISON MODEL

The paper uses the methods of statistics, comparisons, analysis and synthesis in order to create a modern approach to comparing the prices of innovative products over the period of their life cycle. The study is based on the analysis of scientific sources, data from the State Statistical Service of Ukraine, the Ministry of Finance of Ukraine, and the Bank of Russia (Average rate of the national currency of Ukraine to foreign currencies (1992-1999), 2013; State Statistics Service of Ukraine, 2020; Currency rates for the period up to 01.07.1992, 2020).

The paper hypothesizes the need to convert prices to a single currency – the United States (US) dollar (USD), taking into account its devaluation against gold in order to compare the prices of products over a long period of time. Figure 1 presents the dynamics of the US dollar price for the ounce of gold from 1980 to 2019 which will be used for further analyses.

Figure 1 indicates the slight fluctuations of the US dollar since 1980, its gradual fall from 1996 and reaching 260 dollars per ounce by 2000 year. As a result of destabilization of major world currencies and fluctuations in stock prices, the debt crisis in Europe and accelerating inflation in various countries in 2011, the price of gold set a new record and for the first time exceeded 1700 dollars per ounce. After 2011, the growth of the value of gold stopped, followed by a downward trend that lasted until 2015. Since the beginning of 2016, gold prices have shown steady growth, and in 2019 the price of gold was 1390 US dollars per ounce, almost reaching the level of 2013. Thus, the dynamics of the US dollar is an important economic indicator that allows assessing not only the risks of investors, but also helps to objectively reflect the changes in prices of products in any other currency.

FIGURE 1. DYNAMICS OF THE US DOLLAR PRICE FOR THE OUNCE OF GOLD, 1980-2019
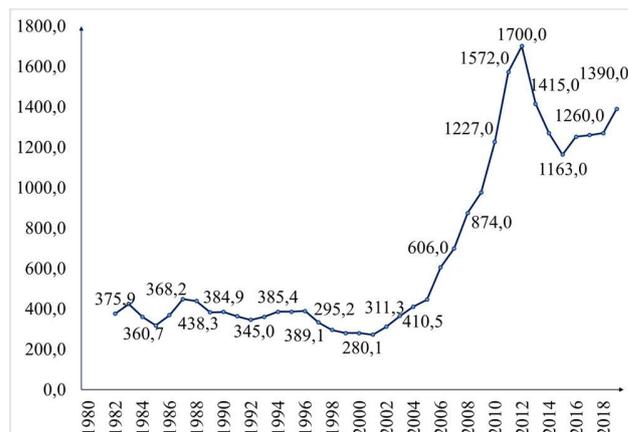
Source: built by the authors on the basis of (Officer and Williamson, 2020)

To transfer the prices of goods and converge them with nowadays ones, the first step is to convert prices into hard currency, namely the US dollar. The second step is to bring the prices of different years to current prices taking into account the devaluation of the dollar. The formula derived in the article for bringing prices to modern ones has the following form:

$$PC_i = \frac{P_i}{R_{\text{USD}\,i}} \times k_{\text{d USD i}} \times R_c \qquad (1)$$

Where:
PC_i is the comparable price of the i-th year;
P_i is the price of the i-th year;
R_{USDi} is the exchange rate of the corresponding currency of the i-th year to the US dollar;
$k_{d\,USDi}$ is the devaluation rate of the US dollar of the i-th year (the devaluation rate of the last year of the study is equal to 1);
R_c is the base exchange rate of the relevant currency to the US dollar.

In turn, the devaluation rate of the US dollar in the *i*-th year is calculated by the following formula:

$$k_{\text{d USDi}} = \frac{D_{USD\Sigma}}{D_{USD\Sigma i}} \qquad (2)$$

Where:
$D_{USD\,\Sigma}$ is the growing sum of the devaluation of the last year of the study;
$D_{USD\,\Sigma i}$ is the growing result of the devaluation of the i-th year of study.

III.   III. RESULTS AND DISCUSSION

As an example of the practical use of the recommended formula, it can be applied for calculations of comparable prices of the three-phase electric motor of the AIR 80 model for its entire life cycle for the period 1982-2019. Figure 2 presents the volumes of production of electric motors of the AIR 80 model from the moment of their development in 1983 till 2019.

FIGURE 2. LIFE CYCLE OF ELECTRIC MOTORS OF THE AIR 80 MODEL
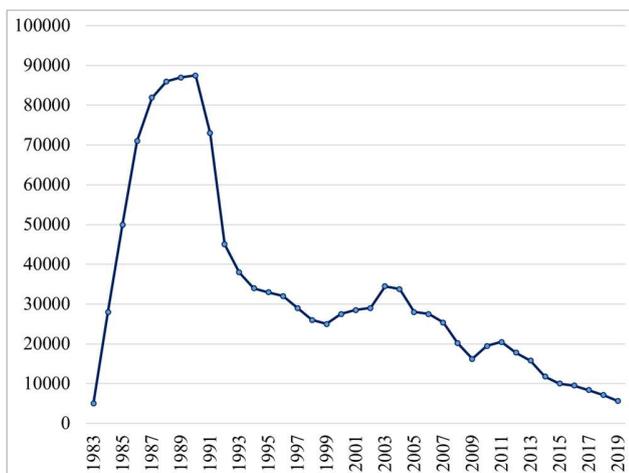
Source: built by the authors on the basis of their own investigations of the production activity of the enterprise (Kharkiv electrical engineering plant "Ukrelectomash", 2020)

Analyzing the life cycle of the electric motor of the AIR 80 model indicates that it significantly depends on the dynamics of the world and national economies, while improvements and declines in production corresponds to those processes that occur in the world and Ukrainian industries. For example, production volumes decreased significantly due to the global crisis in 2008 and due to hostilities in eastern Ukraine in 2013-2014. Table 1 and Figure 3 present the dynamics of changes in indices of inflation, devaluation and producer prices in Ukraine in recent years, which confirm the previous statements.

TABLE 1.
SUMMARY TABLE OF PRODUCER PRICE INDICES, INFLATION AND DEVALUATION IN UKRAINE FROM 1991 TO 2020

Year	Inflation index [a], %	Producer price index [b], %	Devaluation [c], %
1991	390	263,4	-
1992	2100	4228,5	-
1993	10256	9767,5	-
1994	501	874	-
1995	281,7	272,1	-
1996[d]	139,7	117,3	100,00
1997	110,1	105	105,00

TABLE 1.
SUMMARY TABLE OF PRODUCER PRICE INDICES, INFLATION AND DEVALUATION IN UKRAINE FROM 1991 TO 2020

Year	Inflation index [a], %	Producer price index [b], %	Devaluation [c], %
1998	120	135,3	181,48
1999	119,2	115,7	152,19
2000	125,8	120,8	104,02
2001	106,1	100,9	97,61
2002	99,4	105,7	100,57
2003	108,2	111,1	100,00
2004	112,3	124,1	99,62
2005	110,3	109,5	95,10
2006	111,6	114,1	100,00
2007	116,6	123,3	100,00
2008	122,3	123	152,48
2009	112,3	114,3	103,77
2010	109,1	118,7	99,62
2011	104,6	114,2	100,38
2012	99,8	100,3	100,00
2013	100,5	101,7	100,00
2014	124,9	131,8	197,37
2015	143,3	125,4	152,19
2016	112,4	135,7	113,29
2017	113,7	116,5	103,20
2018	109,8	114,2	98,61
2019	104,1	92,6	85,54
2020	102,0	101,8	117,03

a. Inflation index, or consumer price index - an indicator that characterizes changes in the general level of prices for goods and services purchased by the population for non-productive consumption.
b. Producer price index is an indicator of the average level of change in wholesale prices for raw materials, stuff and intermediate goods, at which domestic producers sell their goods.
c. Devaluation - the depreciation of the national currency against other currencies.
d. On September 2, 1996, the national currency, the hryvnia, was introduced in Ukraine.
Source: built by the authors on the basis of (State Statistics Service of Ukraine, 2020; Ministry of Finance of Ukraine, 2020)

FIGURE 3. DYNAMICS OF CHANGES IN INDICES OF INFLATION AND PRODUCER PRICES IN UKRAINE (INCREASING SUM), 1997-2020
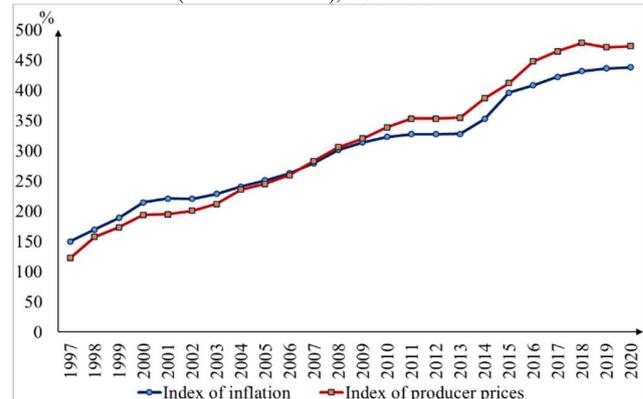
Source: built by the authors on the basis of Table 1

It should be noted that the total producer price index exceeds the inflation index, however, without reaching the significant gap. The growth of the producer price index may be a harbinger of higher consumer inflation, i.e. its changes are an early

inflation indicator. In addition, the producer price index shows how much the purchasing power of the national currency has changed.

Summarizing the previous statements indicates that the life cycle of the electric motors of the AIR 80 model has undergone a change of three currencies from the beginning of their development until now: since 1982 – Soviet ruble, since 1992 – Ukrainian ruble, or coupon-ruble, and since 1996 – Ukrainian hryvnia (UAH). Thus, the calculation of the economic efficiency of AIR 80 motors in three different currencies is not correct, and it requires transferring the prices in individual currencies to comparable current prices in UAH using the proposed formula, which in this case is as follows:

$$PC_i = \frac{P_i}{R_{\text{USD}\,i}} \times k_{d\,\text{USD}\,i} \times R_{\text{UAH}} \qquad (3)$$

Where:
PC_i is the comparable price of the electric motor of the i-th year in modern hryvnias;
P_i is the price of the electric motor of the i-th year;
R_{USDi} is the exchange rate of the corresponding currency of the i-th year to the US dollar;
$k_{d\,USDi}$ is the devaluation rate of the US dollar of the i-th year (the devaluation rate of the last year of the study kd USD 2019 = 1);
R_c is the current exchange rate of the Ukrainian hryvnia to the US dollar (the rate of 2019 equal to 23,67 UAH/USD is accepted).

The Ukrainian ruble or the coupon-ruble became a temporary currency introduced in Ukraine in 1992 and intended for a transient period. It was this currency that suffered from hyperinflation during 1992-1995. Figure 4-6 present the dynamics of the Soviet ruble, the Ukrainian ruble and the hryvnia to the US dollar respectively which are used for calculations of comparable prices. The exchange rate of the US dollar to gold is shown above in Figure 1.

FIGURE 4. DYNAMICS OF THE EXCHANGE RATE OF THE SOVIET RUBLE (RUBLE) TO THE US DOLLAR, 1973-1992
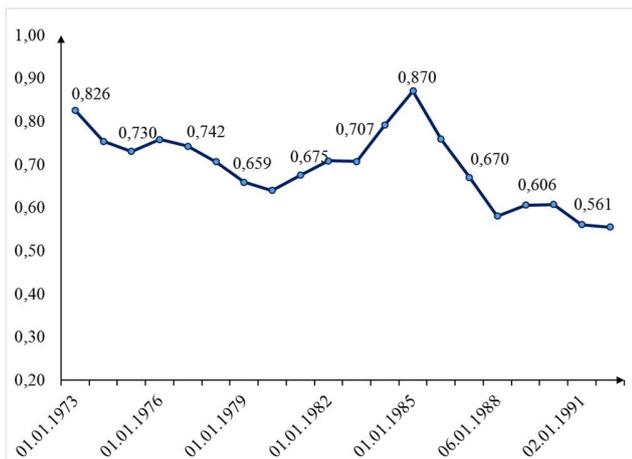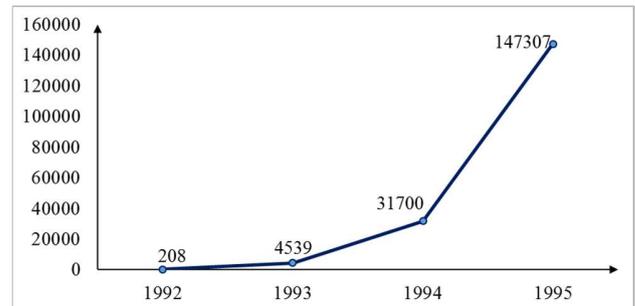

Source: built by the authors on the basis of (Currency rates for the period up to 01.07.1992, 2020)

Since its introduction in 1996, the hryvnia was a fairly strong currency – its official exchange rate to the US dollar was 1,8 hryvnias. However, the hryvnia experienced serious

devaluations in 1998, 2008 and 2014. In August 1998, the hryvnia depreciated almost threefold, after which the exchange rate became more than 5 hryvnias per dollar and remained at that level for 10 years.

FIGURE 5. DYNAMICS OF THE EXCHANGE RATE OF THE UKRAINIAN RUBLE (COUPON-RUBLE) TO THE US DOLLAR, 1992-1995

Source: built by the authors on the basis of (Average rate of the national currency of Ukraine to foreign currencies (1992-1999), 2013)

FIGURE 6. DYNAMICS OF THE HRYVNIA EXCHANGE RATE TO THE US DOLLAR, 1996-2020
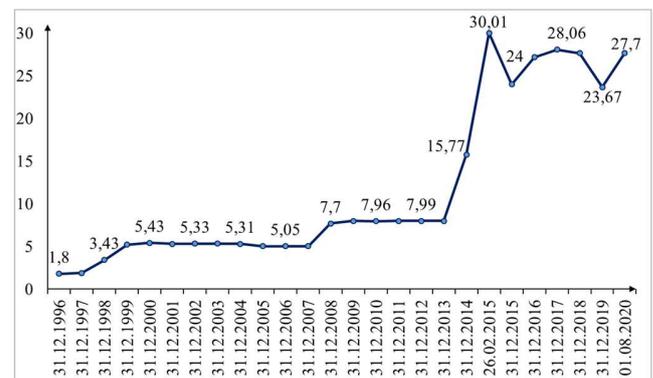
Source: built by the authors on the basis of (Ministry of Finance of Ukraine, 2020)

Due to the global financial crisis in 2008, the hryvnia exchange rate fell from 5,1 to 8 hryvnia per dollar and remained at that level until the winter of 2014. On February 26, 2015, the hryvnia exchange rate reached an all-time low of more than 30 hryvnias per dollar, but later the hryvnia strengthened slightly and in 2020 the official exchange rate was 27,7 hryvnias against the US dollar.

The paper considers the example of using the originally developed formula to compare the prices for a certain period and bring them to the current value. Table 2 contains the comparable prices of the electric motor AIR 80, the development of which started in 1982 with the planned sale price of 35 Soviet rubles (rubles). The data in the table were obtained by using the authors' formula.

TABLE 2.
BRINGING THE PRICE OF THE ELECTRIC MOTOR AIR 80 WITHIN THE RANGE OF 1982-2019 TO THE CURRENT PRICES

Year	Currency	Price in currency, P_i	Exchange rate USD, R_{USDi}	Price in USD, P_{USDi}	The growing result of devaluation USD, $D_{USDi\Sigma}$	Devaluation rate of the USD, $k_{D\,USDi}$	Price in USD taking into account the devaluation	Comparable price in the hryvnia of 2019, PC_i
1982	ruble	35	0,708	49,44	1	3,698	182,80	4326,77
1983	ruble	35	0,707	49,50	1,128	3,278	162,29	3841,46
1984	ruble	35	0,791	44,25	0,959	3,854	170,53	4036,52
1985	ruble	35	0,870	40,23	0,845	4,376	176,04	4166,77
1986	ruble	35	0,759	46,14	0,980	3,775	174,18	4122,82
1987	ruble	35	0,670	52,24	1,192	3,103	162,10	3836,87
1988	ruble	35	0,580	60,30	1,166	3,171	191,24	4526,60
1989	ruble	35	0,606	57,77	1,018	3,633	209,87	4967,73
1990	ruble	35	0,607	57,64	1,024	3,611	208,15	4926,83
1991	ruble	59	0,561	105,26	0,966	3,826	402,75	9533,14
1992	coupon	4450	208,0	21,39	0,918	4,029	86,20	2040,46
1993	coupon	401500	4539,0	88,46	0,960	3,851	340,68	8063,80
1994	coupon	3500500	31700,0	110,43	1,025	3,606	398,25	9426,48
1995	coupon	9650000	147307,0	65,51	1,026	3,606	236,21	5591,04
1996	UAH	114	1,800	63,33	1,035	3,572	226,25	5355,44
1997	UAH	119	1,890	62,96	0,884	4,182	263,30	6232,33
1998	UAH	161	3,430	46,94	0,785	4,708	220,99	5230,82
1999	UAH	185	5,220	35,44	0,745	4,966	175,99	4165,78
2000	UAH	225	5,430	41,44	0,745	4,963	205,63	4867,24
2001	UAH	228	5,300	43,02	0,724	5,106	219,66	5199,39
2002	UAH	240	5,330	45,03	0,828	4,465	201,04	4758,57
2003	UAH	265	5,330	49,72	0,970	3,810	189,44	4484,12
2004	UAH	330	5,310	62,15	1,092	3,386	210,43	4980,79
2005	UAH	360	5,050	71,29	1,186	3,117	222,17	5258,83
2006	UAH	410	5,050	81,19	1,612	2,294	186,22	4407,91
2007	UAH	510	5,050	100,99	1,859	1,989	200,82	4753,51
2008	UAH	625	7,700	81,17	2,325	1,590	129,09	3055,56
2009	UAH	715	7,990	89,49	2,594	1,426	127,58	3019,73
2010	UAH	850	7,960	106,78	3,264	1,133	120,97	2863,35
2011	UAH	970	7,990	121,40	4,182	0,884	107,35	2540,89
2012	UAH	974	7,990	121,90	4,522	0,818	99,67	2359,26
2013	UAH	990	7,990	123,90	3,764	0,982	121,72	2881,01
2014	UAH	1300	15,770	82,44	3,376	1,095	90,30	2137,29
2015	UAH	1630	24,000	67,92	3,094	1,195	81,17	1921,36
2016	UAH	2215	27,190	81,46	3,331	1,110	90,44	2140,79
2017	UAH	2580	28,060	91,95	3,352	1,103	101,43	2400,90
2018	UAH	2940	27,670	106,25	3,378	1,094	116,29	2752,63
2019	UAH	2730	23,670	115,34	3,698	1,000	115,34	2730,00

Source: calculated by the authors on the basis of their own investigations

Table 2 allows concluding that the price of an innovative electric motor was almost twice as high at the implementation stage as at the stage of decline, which is logical because the new industrial product is the most attractive and competitive on the market in the first years of sales and tends to have a significantly reduced price before leaving the market. Table 2 shows that the change in prices during the Soviet period was almost uniform and did not have a sharp jump, in contrast to the post-Soviet period. Comparative prices of electric motors indicate that the transition period with the introduction of new currencies and the transition to a market economy was accompanied by an increase in prices for the studied electric motors, which characterizes the current market situation in the 1990s. Thus,

these conclusions confirm the adequacy of the used price comparison formula, which allows economists to objectively analyze the development of innovative goods and their prices in the market.

The paper proposed a universal formula for comparing prices in any and from any national currency and bringing them to nowadays values, taking into account the devaluation of the dollar. The practical applicability of the developed approach is given in the example of calculating comparable prices for the entire life cycle of the electric motor for the period of 1982-2019.

The use of comparable prices with the help of the approach presented in the article also enables comparisons of production volume, turnover and other indicators in separate periods for the entire life cycle of the product, avoiding distortions caused primarily by inflation and other economic factors.

IV. ACKNOWLEDGEMENTS

V. AUTHORS' CONTRIBUTION

The paper is a part of investigations within the framework of the postgraduate study of Alina V. Martynenko under the scientific supervision of Petro G. Pererva.

Alina V. Martynenko performed investigations and the formal analysis, developed a concept, methodology and the model of comparing the prices and bringing them to the modern ones, visualized the results and composed the paper.

Petro G. Pererva performed the supervision and coordination, review and correction of the data, and approval of the manuscript.

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