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PATTERNS IDENTIFICATION IN THE DYNAMICS OF COUNTRIES' TECHNOLOGICAL DEVELOPMENT IN THE CONTEXT OF MILITARY CONFLICT

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A comparative assessment of the dynamics of technological development of Ukraine and Russia for 2014–2019 has been carried out in the context of the Russian-Ukrainian war. A method for assessing the economic losses of the conflicting parties due to a slowdown in their technological development, under the influence of militarization, based on the parameter of technological progress of the Solow-Tinbergen production function, built according to the World Bank 1991–2019 data, was proposed and tested. It is substantiated that during the Russian-Ukrainian war, starting from 2015, the technological development of the Russian Federation was curtailed and the economy transitioned to an extensive basis, when the parameter of technological progress acquired a negative value. In the case of Ukraine, a deterioration in technological development was detected due to a decrease in the values of the parameter of technological progress during 2014–2019. It has been proven that the economic recession of the aggressor is the worst in comparison with the victim country, but the relative losses of GDP due to the curtailment of technological development caused by the war are much less. In the case of the Russian Federation as an aggressor country, it is substantiated that the main catalyst for the economic recession was the curtailment of the participation of the real sector of the economy in the international transfer of technologies under the influence of international economic sanctions. In the case of Ukraine, as a country-victim of military intervention, it is justified that the replacement of international partnership in the field of technological cooperation ensured a slowdown in the economic recession. The results of the development of methodological support for the process of assessing GDP losses of the parties to a military conflict are universal for use in international comparisons. The proposed methods are relevant in assessing the technological development of countries that are or were in a state of military confrontation, which significantly expands the basis for future research by the authors

***Keywords:** production function, technological progress, technological development, economic losses, military conflict*

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1. Introduction

Since the industrial revolution in Great Britain (late 18^{th}–early 19^{th} centuries), the role of technological progress in economic growth has become increasingly important. Since then, the country's position in the world economy and its political weight in the world are largely based on innovative and technological advantages. The concept of "technology" is understood as a resource that has economic value and can give the country political and technological advantages, and also becomes a new factor of national security. The practice of developed countries shows that technologies are becoming a decisive factor in socio-economic development, a factor in the quality of life, an area of strategic interests, an object of international politics. At the same time, technologies and international transfer within the framework of cooperation models are influenced by the political factor. Therefore, countries are trying to reduce the technological gap, create conditions for interaction with others through international innovation and technological cooperation and technology transfer mechanisms, which in turn leads to technological interdependence between them.

Since the second half of the twentieth century, the Ukrainian economy has been characterized by a high level of historically established production, cooperation and technological ties with Russia. However, starting from February 20, 2014 (the date of the annexation of the Autonomous Republic of Crimea), the Ukrainian economy is developing under the conditions of Russian intervention, which creates significant obstacles to its real growth. It is clear that Ukraine, as a victim country, suffers an absolute loss of the economic potential of the temporarily occupied territories in the context of militarization and direct hostilities. It can be assumed that the costs of the aggressor on the war are incomparable with the economic benefits obtained.

The relevance of the research lies in the fact that an attempt has been made to assess the macroeconomic impact of factors slowing down technological progress and curtailing the processes of international technology transfer and innovative technological cooperation on the economic development of the parties to a military conflict. Also, the problem of assessing the level of absolute losses of GDP of countries due to the deterioration of their technological development in the context of a military conflict has been updated. All this will ensure the allocation of the technological component of the economic development of the country-victim of military aggression for the development of effective measures to resist the aggressor.

2. Literature review and problem statement

The study [1] noted that the globalization of innovation does not mean competition between states: it makes it difficult for the state to influence profit from innovation, but does not deter countries from trying to regulate. It is shown that countries can become more successful in the case of cooperation rather than competition. Indeed, regardless of the political aspects, states are increasingly cooperating even if they compete to occupy a certain economic niche. This principle successfully operates in the context of geopolitics and therefore can naturally be projected for global innovation policy. Let's also assume that innovation cooperation is a powerful factor in the technological development of countries at war. Thus, the review of recent studies and publications on the impact of the 2014 war on technological development and technology transfer processes in Ukraine and the Russian Federation is divided into 2 areas:

1) scientific works devoted to the analysis of the causes and consequences of the Russian-Ukrainian war, including economic ones;

2) scientific research of the peculiarities of the technological development of countries.

Within the framework of the first direction of research, the works [2–11] should be highlighted.

The work [2] is devoted to the reasons for the so-called "displacement effect", when governments increase government spending during the war, but in peacetime does not reduce them to the pre-war level. Regarding the Russian-Ukrainian war, in [3] it is proved that economic war has become a permanent unchanging component of bilateral Russian-Ukrainian relations, regardless of the political situation. At the same time, the analysis of the impact of international economic sanctions on the Russian Federation and Ukraine is carried out in [4]. But, as in article [5], we are talking about the ineffectiveness of economic sanctions in 2014–2016, since there was a violation by Russia of international legal norms and increased participation in other military conflicts. The article [6] substantiates the invasion of Russia due to a shortage of resources in the military-industrial sphere, the replenishment of which occurs through the control of Ukrainian resources. Calculation of economic losses of Ukraine as a result of military intervention carried out in [7]. In the article [8] it is proved that in Ukraine there was a decrease in the financial well-being of the population along with deterioration in the state of health throughout the territory, and in Russia – only in the border region. The methodological and applied foundations of security analysis of the aspect of "hybrid wars" of Russia against Ukraine, including against Georgia, are studied in [9–11].

Within the framework of the second direction of research, the works [12–18] should be highlighted.

In [12], some extensions of neoclassical growth models are investigated, taking into account the heterogeneity of development and the evolution of technological progress over time. This is supplemented by work [13], in which, on the basis of the Bayesian approach, the parameters of the normalized production function with constant elasticity of substitution (CES) for Finland were estimated, taking into account the factor of "capital-augmenting technological progress". The validity of using the CES model at the micro level has also been proven [14]. The article [15] carried out a statistical analysis of the relationship between the primary and dual total factor productivity (TFP) on the basis of medium-sized industrial Malaysian companies to study the impact of technological progress. [16] assessed the role of technological progress in the structure of aggregate production to determine the real exchange rate Study of the feasibility and optimality of the initial capital in the Ramsey vintage capital model, taking into account the level of technological progress, is devoted to work [17]. It is also important to study the basic problems of technological progress in conditions of limited natural resources [18]. However, the described scientific works relate exclusively to the technological development of economic entities that are not in conditions of a military conflict.

All this gives grounds to state the absence of studies that would combine the analysis of the technological development of the parties to military conflicts and their macroeconomic assessment. In this regard, the problem of assessing the economic losses of the conflicting parties as a result of a slowdown in technological development in the context of the Russian-Ukrainian war, which began in 2014, remains without the attention of scientists. The proposed study is dedicated to the solution of this actual problem.

3. The aim and objectives of research

The aim of research is to identify the main patterns of the dynamics of technological development of Ukraine and the Russian Federation in 2014-2019 during the Russian-Ukrainian military conflict.

To achieve the aim, it is necessary to solve the following objectives:

– calculate the parameter of technological progress for Ukraine and the Russian Federation by modeling the production function of Solow-Tinbergen and reflect its dynamics;

– to estimate the volume of GDP losses of the conflicting parties due to the deterioration of technological development as a result of the Russian-Ukrainian war in 2014–2019.

4. Materials and methods of research

Technological progress is an objective factor in the country's macroeconomic development on an innovative basis [19]. The basic methodological foundations for assessing technological development are laid down in works [20–24].

The subject of research is to identify trends in technological development and their impact on the dynamics of GDP of the parties to the Russian-Ukrainian conflict.

The study of the patterns of technological development of the countries participating in the military conflict was carried out in compliance with a number of requirements. First, it was based on real (official) statistical data available in the public domain. Secondly, it covered a significant time lag and reflected real dynamics. Thirdly, the object of assessment is at the same time a subject of technological development [25–27].

To identify the patterns of technological development of countries in the context of a military conflict, a model of a dynamic multiplicative production function of the form was used:

$$GDP = A\ GFCF^{\alpha} NE^{(1-\alpha)} e^{\lambda t}, \tag{1}$$

where GDP – the chain index of the country's GDP growth in actual prices (the ratio of the value of the indicator of the current year to the indicator of the previous year) is the resulting sign;

$GFCF$ – chain growth index of gross fixed capital formation – physical capital factor;

NE – chain index of growth in the total number of employed people – human capital factor;

A – free term (the numerical value of GDP with the remaining parameters equal to 0);

α – GDP elasticity coefficient by the factor of physical capital (by how many % will GDP increase with an increase in GFCF by 1 %);

$(1-\alpha)$ – GDP elasticity coefficient by the factor of human capital (by how much % GDP will increase with an increase in NE by 1 %);

λ – technological progress parameter – GDP elasticity coefficient for technological progress;

t – ordinal number of the year – a factor of technological progress;

e – Euler's number, the base of the natural logarithm [20, 23].

The use of the model of the Solow-Tinbergen multiplicative production function is due to the revealed requirements for the regularities of the study of the technological development of the countries participating in the military conflict. The main advantage offered in the models is, among other things, as fundamental industrial instruments, which can be reflected in the parameters of technological progress – something in electrical progress.

So, in order to change the rules for processing the technological process of configuration, the methodological apparatus of the Solow-Tinbergen production function is fixed for achieving technological progress. Verification of this indicator allows to estimate the amount of losses (or benefits) as a result of deterioration (or improvement) of technological deployment and the rupture of technological ties at warring stages in conditions of military confrontation. At the same time, the influence of other factors was not taken into account, since it is not the subject of research.

In formulas (1), the most appropriate for assessing losses or GDP growth of a country under the influence of technological progress, the multiplier $e^{\lambda t}$, to display the influence of technological progress for the flow dynamics of GDP for 3 areas:

1) $\lambda=0$, then $e^{\lambda t}=1$, and formula (1) took the form of a two-factor multiplicative Cobb-Douglas production function [28]. The influence of progress is technology, that is, simple reproduction takes place in the economy, since the production function of Cobb-Douglas is characterized by a constant return to production. Therefore, a decrease in the volume of factors of physical and human capital by 1 % leads to an increase in the volume of GDP by 1 %;

2) $\lambda<0$, that is, $e^{\lambda t}<1$, characterize the situation where the economy chooses from technological progress, in connection with which the country suffers losses $(100e^{\lambda t}-100)$ % of GDP. Accordingly, the total growth of the factor of physical and human capital by 1 % due to the increase in GDP, less than 1 %, can lead to my pro-economic nature of economic development;

3) $\lambda>0$, then $e^{\lambda t}>1$, this means, that is, through the allocation of the economy of technological progress, the country gaining a priest $(100e^{\lambda t}-100)$ % of GDP. Accordingly, the simultaneous growth of the factors of physical and human capital by 1 % leads to an increase in GDP by more than 1 %. Therefore, it is possible to behave depending on the nature of economic development and economic development.

For further transformation, formula (1) should be written in logarithmic form:

$$\ln GDP = \ln \mathrm{A} + \alpha \ln GFCF + (1-\alpha)\ln NE + \lambda t. \tag{2}$$

After performing a number of algebraic transformations, the Solow-Tinbergen production function is written as follows [29]:

$$\ln GDP - \ln NE = \ln \mathrm{A} + \alpha\left(\ln GFCF - \ln NE\right) + \lambda t. \tag{3}$$

Based on the above formulas (1)–(3), in Table 1, the initial data were formed for the parties to the Russian-Ukrainian war – Ukraine as a victim country and the Russian Federation as an aggressor country according to World Bank data [30].

The data given in Table 1 are public, freely available, built between 1991 and 2019, and the countries under study are subjects of technological development. That is why this data is used in the Solow-Tinbergen production function simulation to derive the technological progress parameter.

Table 1

Output data of the Solow-Tinbergen production function modeling for Ukraine and the Russian Federation for 1991–2019

Year	GDP at actual prices (GDP), million USD		Gross fixed capital formation (GFCF), million USD		Total number of employed people (NE), thousand people	
	Ukraine	Russian Federation	Ukraine	Russian Federation	Ukraine	Russian Federation
1991	77,464.6	517,963.0	15,521.9	120,518.5	30,676.7	93,203.4
1992	73,942.2	460,290.6	20,066.6	110,169.5	30,632.1	92,867.6
1993	65,648.6	435,083.7	15,946.7	88,711.3	30,519.6	89,545.9
1994	52,549.6	395,077.3	12,367.5	86,169.9	30,390.6	84,683.0
1995	48,213.9	395,537.2	11,224.3	83,370.3	29,073.3	82,634.9
1996	44,558.1	391,724.9	9,232.6	78,351.8	27,849.0	80,865.8
1997	50,150.4	404,929.0	9,946.3	74,070.9	26,813.6	76,941.1
1998	41,883.2	270,955.5	8,204.1	43,760.9	25,460.9	74,393.6
1999	31,580.6	195,907.1	6,084.3	28,184.4	24,620.4	78,383.0
2000	31,261.5	259,710.1	6,144.4	43,796.7	24,738.2	80,280.8
2001	37,972.3	306,602.1	7,096.3	57,912.2	24,225.1	79,675.4
2002	42,351.6	345,470.5	7,704.7	61,859.6	24,146.1	81,011.3
2003	50,084.2	430,347.8	9,791.1	79,248.7	24,138.8	79,888.0
2004	64,819.7	591,016.7	13,870.5	108,660.2	23,962.6	80,473.1
2005	86,057.9	764,017.1	17,937.8	135,654.3	24,092.4	81,225.9
2006	107,648.0	989,930.5	25,132.5	183,170.9	23,964.2	81,355.2
2007	142,580.0	1,299,705.8	37,235.8	272,876.5	23,900.7	83,244.0
2008	179,817.0	1,660,846.4	45,025.6	370,210.3	23,759.6	83,604.2
2009	117,113.0	1,222,644.3	20,399.0	268,922.3	23,064.4	81,817.4
2010	136,013.0	1,524,917.5	23,169.9	329,769.3	23,185.8	82,629.8
2011	163,160.0	2,045,925.6	28,792.0	436,225.2	23,273.1	83,765.1
2012	175,781.0	2,208,295.8	33,386.9	476,134.7	23,175.1	84,894.3
2013	183,310.0	2,292,473.2	30,908.8	502,972.9	23,491.3	84,908.8
2014	133,503.0	2,059,242.0	18,872.1	441,031.6	22,350.9	85,414.5
2015	91,031.0	1,363,481.1	12,333.5	281,034.6	22,458.7	85,218.9
2016	93,356.0	1,276,787.0	14,429.4	279,377.4	22,248.5	85,570.5
2017	112,190.0	1,574,199.4	17,683.7	346,042.7	22,104.9	85,373.0
2018	130,902.0	1,669,583.1	23,098.7	339,780.5	22,134.1	85,578.6
2019	153,781.0	1,699,876.6	27,710.2	357,047.0	21,900.1	85,134.2

5. The results of a macroeconomic assessment of the dynamics of technological development of Ukraine and the Russian Federation in the context of military confrontation

Data of Table 1 shows that during 1991–2019. In terms of the dynamics of the studied indicators, the Russian Federation surpassed Ukraine. Thus, GDP (in actual prices) in Ukraine has doubled, and in the Russian Federation – 3.3 times. The growth in gross fixed capital formation amounted to +80 % (Ukraine) and +196 % (Russian Federation), respectively. The total number of employed people in Ukraine decreased by –29 %, and in the Russian Federation by – 9 %.

At the same time, the volume of GDP (in actual prices) of Ukraine in 2019 is 11 times less than the volume of GDP of the Russian Federation, and the labor productivity of the employed population in terms of GDP/person (efficiency of using human capital) is 2.8 times lower. The rate of return on capital or the efficiency of using physical capital (the ratio of GDP to gross fixed capital formation) in Ukraine is 15 % higher than in the Russian Federation. Table 2 analyzes the dynamics of indicators of the effectiveness of the development of the studied countries during the Russian-Ukrainian war, taking into account the technological component according to the World Bank [30].

Table 2

Dynamics of indicators of the effectiveness of the use of physical and human capital, innovations in Ukraine and the Russian Federation for 2013–2019

Year	Physical capital efficiency		Efficiency of using human capital, USD/person		Share of spending on innovation activities in GDP, %	
	Ukraine	Russian Federation	Ukraine	Russian Federation	Ukraine	Russian Federation
2013	5.93	4.56	1.32	5.92	0.67	1.52
2014	7.07	4.67	0.84	5.16	0.60	1.53
2015	7.38	4.85	0.55	3.30	0.55	1.44
2016	6.47	4.57	0.65	3.26	0.48	1.50
2017	6.34	4.55	0.80	4.05	0.45	1.53
2018	5.67	4.91	1.04	3.97	0.47	1.42
2019	5.26	4.64	1.44	5.61	0.43	1.79

Data in the Table 2 reflected the multi-vector dynamics of efficiency indicators of Ukraine and the Russian Federation during the Russian-Ukrainian war in comparison with the pre-war 2013. At the same time, the maximum gap between the efficiency of using physical capital (1.5:1) and the efficiency of using human capital (1:6) between Ukraine and the Russian Federation was recorded in 2015–2016. The share of spending on innovation in GDP is critically low in both countries. Comparative dynamics of GDP in the studied countries was comparable (Fig. 1).

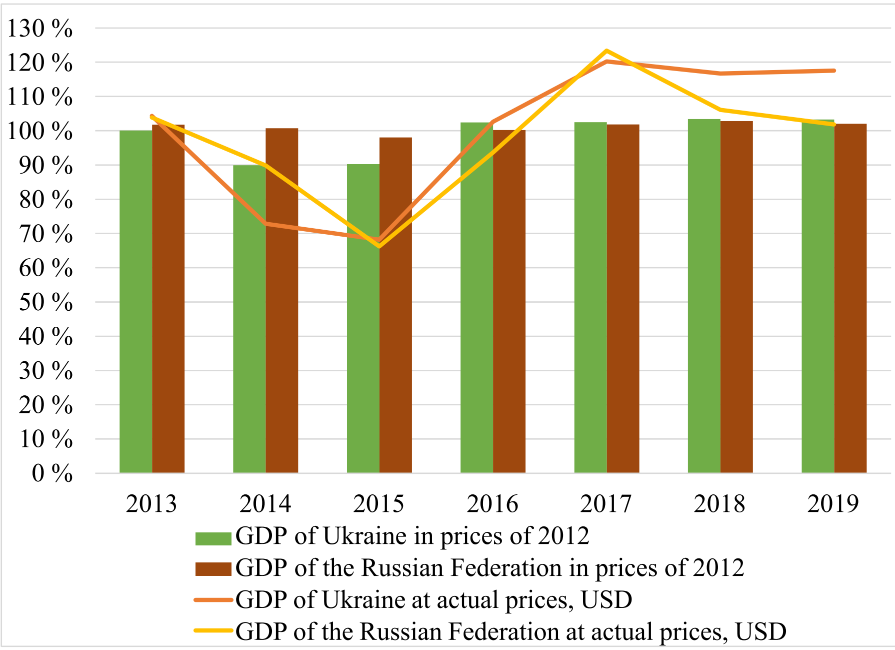

Fig. 1. Comparative dynamics of the GDP of the parties to the Russian-Ukrainian war

Fig. 1 shows the period of economic recession (2014–2015), the period of accelerated growth (2016–2017) and the period of slower growth (2018–2019) of Ukraine and the Russian Federation, formed on the basis of the dynamics of real GDP in 2012 prices and the dynamics GDP at actual prices (USD). At the same time, as of the end of 2019, compared to 2012, the real GDP of Ukraine amounted to 91 %, and the nominal GDP in USD – 87.5 %; the real GDP of the Russian Federation amounted to 107.6 %, and the nominal GDP in USD – 77 %.

The conducted comparative analysis shows that during the war, the macroeconomic dynamics of Ukraine's development was worse than in the Russian Federation, but the impact of the devaluation of the national currency was not so destructive. At the same time, the issue of the contribution of technological progress to the innovative development of the sides of the Russian-Ukrainian war requires careful research.

5. 1. Calculation of the parameter of technological progress for the parties to the Russian-Ukrainian war

The methodology for assessing the GDP losses of the conflicting parties due to the deterioration of technological development as a result of the Russian-Ukrainian war in 2014–2019. The calculation of the parameter of technological progress is provided. This parameter is a key criterion for technological development, calculated by formulas (1)–(3). At the same time, the chain growth indices of the indicators given in Table 1 were taken as a basis. Their calculation is carried out in Table 3 according to the World Bank [30].

Data in Table 3 is an important empirical material that made it possible to assess the level of technological development of countries based on the parameter of technological progress without standardizing indicators, since the initial data were taken in the form of chain growth indices. Also, the calculations were based on the principle that in a war, the technological development of both conflicting parties slows down, as a result of which the countries suffer absolute losses of GDP. For example, in Ukraine, the occupied territory is 4.3 % of the territory within the Autonomous Republic of Crimea and 6.9 % of the territory is part of the Donetsk and Luhansk regions [31], the economic potential of which is not used for objective reasons, that is, there is no contribution to GDP.

The economy of the Russian Federation is under international economic sanctions, in connection with which the GDP-forming sectors are in international isolation regarding technology transfer. Of course, the technological development of both countries was negatively affected by the militarization of the economy. Therefore, the technological development of Ukraine and the Russian Federation as of the end of pre-war 2013 was taken as a basis. To formalize technological development, the Solow-Tinbergen production function was modeled in order to obtain the parameters of the function, primarily the parameter of technological progress (3). To do this, preliminarily logarithmized chain indices of GDP growth (in actual prices), gross capital formation, and the number of the entire employed population for 1992–2013.

The calculation of the parameters of the Solow-Tinbergen production function for 2014 was based on the values of indicators for 1992–2014, for 2015 – 1992–2015 etc. [29]. According to the obtained results of modeling the production function of Solow-Tinbergen in Ukraine and the Russian Federation, Table 4.

Table 4 shows the dynamics of changes in the parameters of the Solow-Tinbergen production function for the period of the Russian-Ukrainian war from 2014 to 2019, where the baseline pre-war 2013 is taken. The characteristics of the technological development of Ukraine for 1991–2013 as of the end of 2013 (Table 4) are as follows. The share of physical capital in the economy was 63.7 %, and human capital was 36.3 %. A decrease in physical capital by 1 % was offset by an additional attraction of 1.8 % of human capital, and a decrease of 1 % in human capital was offset by an additional attraction of 0.6 % of physical capital. The parameter of technological progress λ=0.006 means that the additional GDP growth as a result of the positive impact of technological progress, according to the data in Table 4, amounted to $(100e^{0.001*22}–100)$=+13.3 %.

Table 3

Chain growth indices of the dependent and predictor variables of the Solow-Tinbergen production function for Ukraine and the Russian Federation

Year	Sequential number of the year (t)	GDP at actual prices (GDP), million USD		Gross fixed capital formation (GFCF), million USD		Total employed population (NE), thousand people	
		Ukraine	Russian Federation	Ukraine	Russian Federation	Ukraine	Russian Federation
1992	1	0.9545	0.8887	1.2928	0.9141	0.9985	0.9964
1993	2	0.8878	0.9452	0.7947	0.8052	0.9963	0.9642
1994	3	0.8005	0.9080	0.7756	0.9714	0.9958	0.9457
1995	4	0.9175	1.0012	0.9076	0.9675	0.9567	0.9758
1996	5	0.9242	0.9904	0.8226	0.9398	0.9579	0.9786
1997	6	1.1255	1.0337	1.0773	0.9454	0.9628	0.9515
1998	7	0.8352	0.6691	0.8248	0.5908	0.9495	0.9669
1999	8	0.7540	0.7230	0.7416	0.6441	0.9670	1.0536
2000	9	0.9899	1.3257	1.0099	1.5539	1.0048	1.0242
2001	10	1.2147	1.1806	1.1549	1.3223	0.9793	0.9925
2002	11	1.1153	1.1268	1.0857	1.0682	0.9967	1.0168
2003	12	1.1826	1.2457	1.2708	1.2811	0.9997	0.9861
2004	13	1.2942	1.3733	1.4166	1.3711	0.9927	1.0073
2005	14	1.3277	1.2927	1.2932	1.2484	1.0054	1.0094
2006	15	1.2509	1.2957	1.4011	1.3503	0.9947	1.0016
2007	16	1.3245	1.3129	1.4816	1.4897	0.9973	1.0232
2008	17	1.2612	1.2779	1.2092	1.3567	0.9941	1.0043
2009	18	0.6513	0.7362	0.4531	0.7264	0.9707	0.9786
2010	19	1.1614	1.2472	1.1358	1.2263	1.0053	1.0099
2011	20	1.1996	1.3417	1.2426	1.3228	1.0038	1.0137
2012	21	1.0774	1.0794	1.1596	1.0915	0.9958	1.0135
2013	22	1.0428	1.0381	0.9258	1.0564	1.0136	1.0002
2014	23	0.7283	0.8983	0.6106	0.8768	0.9515	1.0060
2015	24	0.6819	0.6621	0.6535	0.6372	1.0048	0.9977
2016	25	1.0255	0.9364	1.1699	0.9941	0.9906	1.0041
2017	26	1.2017	1.2329	1.2255	1.2386	0.9935	0.9977
2018	27	1.1668	1.0606	1.3062	0.9819	1.0013	1.0024
2019	28	1.1748	1.0181	1.1996	1.0508	0.9894	0.9948

Table 4

The results of modeling the Solow-Tinbergen production function for Ukraine and the Russian Federation according to 1991—2019 data

Parameter of the function*	2013	2014	2015	2016	2017	2018	2019
Ukraine							
A	0.9562	0.9635	0.9748	0.9861	0.9847	0.9906	0.9895
α	0.6373	0.6648	0.7026	0.6928	0.6943	0.6858	0.6865
$1-\alpha$	0.3627	0.3352	0.2974	0.3072	0.3057	0.3142	0.3135
MRTS**	–1.7571	–1.9833	–2.3625	–2.2552	–2.2712	–2.1827	–2.1898
λ	0.0057	0.0046	0.0030	0.0017	0.0018	0.0012	0.0013
R^2***	0.8540	0.8615	0.8611	0.8442	0.8481	0.8448	0.8471
The Russian Federation							
A	1.0056	1.0096	1.0164	1.0215	1.0173	1.0117	1.0139
α	0.7468	0.7572	0.7823	0.7873	0.7904	0.7839	0.7851
$1-\alpha$	0.2532	0.2428	0.2177	0.2127	0.2096	0.2161	0.2149
MRTS	–2.9494	–3.1186	–3.5935	–3.7015	–3.7710	–3.6275	–3.6533
λ	0.0010	0.0005	–0.0005	–0.0011	–0.0007	–0.0001	–0.0003
R^2	0.9113	0.9137	0.9227	0.9209	0.9208	0.9166	0.9161

*Note: * – designation of parameters are taken from formula (1); ** – marginal rate of technical substitution; *** – R^2 – multiple determination coefficient*

In the pre-war period, the technological development of the Russian Federation (Table 4) had the following characteristics. The proportionality of the economy is 3:1, that is, 75 % was the share of physical capital and 25 % was the share of human capital. Accordingly, a 1 % decrease in physical capital was offset by the additional attraction of 2.9 % of human capital, and a 1 % decrease in human capital was offset by an additional attraction of 0.34 % of physical capital. The parameter of technological progress λ=0.001 means that additional GDP growth as a result of the positive impact of technological progress, according to the data in Table 4, amounted to $(100e^{0.001*22}-100)=+2.3$ %.

Over the 6 years of the Russian-Ukrainian war, significant changes have occurred in the technological development of the conflicting parties. Thus, the weight of physical capital was growing, and human capital was decreasing, and as of the end of 2019, their ratio was 7:3 for Ukraine, and 4:1 for the Russian Federation. That is, the militarization and curtailment of technology transfer between the belligerents transformed the proportionality of their national economies towards material production, increasing the role of physical capital (Table 4). Another consequence of the war was the reduction in the parameter of technological progress of Ukraine in 2013–2019 by –76.3 % – from 0.0057 (+13.3 % of GDP) to 0.0013 (+3.8 % of GDP), and the parameter of technological progress of the Russian Federation by –128.1 % – from 0.001 (+2.3 % of GDP) to –0.0003 (–0.8 % of GDP). Thus, as a result of the temporary occupation of territories and active hostilities in Ukraine, there has been a slowdown in technological development, and in the Russian Federation – its curtailment and transition to extensive grounds since 2015.

So, the main feature of the used traditional model of the Solow-Tinbergen production function is that it made it possible to calculate the parameter of technological progress. It was this indicator that became the basis for the study to identify the main patterns of the dynamics of the technological development of the parties to a military conflict, and not dependent and predictor variables. The very same model of the Solow-Tinbergen production function is traditionally used mainly in macroeconomic research (much less often in microeconomic) to model the results of production, taking into account the influence of technological progress.

5. 2. Macroeconomic assessment of the volume of GDP losses of the parties to the Russian-Ukrainian war due to the deterioration of technological development

The macroeconomic consequence of any military conflict is the economic recession of the warring countries, which is formalized by calculating the difference between the actually received and potential GDP volumes (assuming "no war"). A negative value of such a difference interprets GDP losses. The calculation of the economic losses of the parties to the Russian-Ukrainian war for the deterioration (curtailment) of technological development is presented in Table 5.

Table 5 the annual GDP losses of the conflicting parties due to the deterioration (curtailment) of technological development as a result of the war were calculated using the formula:

$$\Delta GDP_i^{TD} = GDP_i\left(e^{\lambda_i t_i} - e^{\lambda_{2013} t_i}\right), \quad (4)$$

where GDP_i – volume of the country's GDP in actual prices of the i-th year, million USD; λ_i – parameter of technological progress in the i-th year; t_i – serial number of the i-th year; $i \in [2014; 2019]$.

Table 5

Losses of GDP of the conflicting parties due to the deterioration of technological development as a result of the Russian-Ukrainian war in 2014–2019

Calculated indicator *	Indicator value by year:							Total
	2013	2014	2015	2016	2017	2018	2019	
Ukraine								
$e^{\lambda i ti}$**, %	113.26	111.04	107.34	104.27	104.85	103.36	103.83	*x*
$e^{\lambda 2013 ti}$, %	113.26	113.90	114.55	115.20	115.85	116.51	117.17	*x*
$e^{\lambda 2013 ti} - e^{\lambda i ti}$, %	0	–2.86	–7.21	–10.93	–11.00	–13.15	–13.34	–58.49
ΔGDP_i^{TD}, million USD	0	–3,828.3	–6,562.6	–10,199.7	–12,337.2	–17,216.1	–20,522.8	–70,666.7
The Russian Federation								
$e^{\lambda i ti}$**, %	102.26	101.06	98.77	97.24	98.25	99.85	99.20	*x*
$e^{\lambda 2013 ti}$, %	102.26	102.36	102.47	102.57	102.67	102.78	102.88	*x*
$e^{\lambda 2013 ti} - e^{\lambda i ti}$, %	0	–1.30	–3.70	–5.33	–4.42	–2.93	–3.68	–21.36
ΔGDP_i^{TD}, million USD	0	–26,834.1	–50,350.4	–68,050.6	–69,629.0	–48,837.1	–62,511.7	–326,212.9

*Note: * – designation of indicators is taken from formula (4); ** – where* $i \in [2014; 2019]$

In the methodology for calculating GDP losses (4), it is assumed that in the absence of war, the parameter of technological progress does not decrease. Since its dynamics can't be calculated separately, the "no war" conditions are formalized by fixing the parameter of technological progress at the level of the pre-war 2013 for subsequent years ($e^{\lambda 2013ti}$).

When assessing the volume of GDP losses of the conflicting parties due to the deterioration of technological development and the interruption of technological ties due to the Russian-Ukrainian war in 2014–2019. The following results were obtained. The total losses of Ukraine's GDP as a result of a slowdown in technological development in the context of the Russian-Ukrainian war and the occupation of more than 11 % of the territory amounted to 70.7 billion USD, or 38.6 % of the GDP of the pre-war 2013. Moreover, for 2013–2019, there was a reduction in the volume of GDP by 16 %, and in the conditions of "no war" the economic recession would have amounted to only –5 %. The aggregate losses of the aggressor turned out to be 4.6 times more and amounted to 326.2 billion USD, or 14.2 % of GDP in 2013, amid a decrease in the volume of GDP in 2019, compared to 2013, by 26 %. In a "no war" environment, the economic decline of the Russian Federation would have been –23 %.

6. Discussion of the results of a macroeconomic assessment of the state of technological development and innovative cooperation of the parties to the conflict

The revealed patterns of the downward dynamics of technological development and participation in the international transfer of technologies by the parties to the

Russian-Ukrainian war indicate that, in addition to the militarization of the economy, a number of significant factors also influenced. In particular, a common feature of the national economies of Ukraine and the Russian Federation during 2014–2019. Their capital intensity was significant (Table 4). That is, in the sectoral structure of the economy, the sectors of material production prevailed – industry, agriculture, building, where physical capital is dominant in comparison with the IT industry, education, science, where human capital dominates.

It was in material production that more transfers of technologies took place between Ukraine and the Russian Federation in the pre-war period, which undoubtedly had a positive effect on their technological development.

Significant absolute losses of the aggressor's GDP in monetary terms, amounting to –326.2 million USD vs. –70.7 million USD. The US losses of the country-victim of aggression due to deterioration of technological development (Table 5) are also explained by other factors, in particular, devaluation processes, negative conditions in energy markets, the effect of international economic sanctions, external economic isolation of key sectors of the economy, etc. That is, the economic recovery in the Russian Federation proceeded more slowly than in Ukraine, but with smaller relative losses of GDP due to the curtailment of technological development caused by the war. At the same time, the real sector of the economy of the Russian Federation, being under economic sanctions, curtailed its participation in the field of international technology transfer, was an additional factor in the country's economic recession. The real sector of the Ukrainian economy (primarily enterprises and research centers of the military-industrial complex) managed to find an alternative to the terminated Russian-Ukrainian technological ties. It is also managed to establish cooperation in the field of international technology transfer with European and North American partners, which contributed to the technological development of the country.

The main advantages of a macroeconomic assessment of the technological development of countries in a state of military conflict, which made it possible to identify its main regularities, were the following:

– use of the official statistics of the World Bank publicly available for 1991–2019. (Table 1);

– the use of a dynamic model of the Solow-Tinbergen multiplicative production function, the key component of which is the parameter of technological progress (1);

– the ability to single out in assessing the depth of the economic recession of the national economy the share of GDP losses due to the deterioration of the technological development of countries (Table 5).

The limitations inherent in the studies carried out include the impossibility of detailing the obtained values of absolute and relative GDP losses, including due to the lack of information from the temporarily occupied territories. As a shortcoming of the study, let's highlight the lack of alternative methods, which does not make it possible to fully verify the reliability of the results obtained, which is confirmed exclusively by statistical estimates.

So, the macroeconomic assessment of technological development and international technology transfer in the context of the Russian-Ukrainian conflict based on the Solow-Tinbergen production function is universal. Therefore, it is quite suitable for use on the basis of other countries that are or were in a state of military confrontation. At the same time, in the course of modeling the parameter of technological progress, one may encounter a number of difficulties. First, statistical estimates can be low, which will indicate low reliability and quality of the model. Second, the GDP elasticity coefficients for physical or human capital factors can be negative numbers (one or all of them), which is unacceptable for further application of the model. Thirdly, there is a risk of lack of publicly available statistics. The above obstacles can be eliminated by adjusting the study period, viewing the initial data. For example, GDP can be replaced by other macroeconomic indicators, gross fixed capital formation – by the value of fixed assets, the number of employed people – by the size of the labor force, the amount of income, and the like.

The prospects for using the identified patterns of technological development of the parties to the Russian-Ukrainian military conflict, including as a result of the curtailment of technology transfer between them, can be used both at the sectoral level and in the development of joint innovative and technological projects to assess the effects of the participating countries.

An important aspect of using the macroeconomic assessment of the state of technological development and international technology transfer is the assessment of the effects of international technology transfer, in particular the effects of the development of the innovation system and socio-economic development.

7. Conclusions

1. Calculation of the technological progress parameter of the dynamic model of the Solow-Tinbergen production function made it possible to carry out international comparisons of the dynamics of technological development of the parties to the Russian-Ukrainian military conflict. It was determined that under the influence of the militarization of the economy, the technological development of Ukraine slowed down, since the value of the parameter of technological progress decreased from 0.0057 in 2014 to 0.0013 in 2019. A decrease in the value of the parameter of technological progress of the Russian Federation from 0.001 in 2014 to –0.0003 in 2019 was revealed, that is, there was a curtailment of technological development and a transition to extensive bases. This is the main negative consequence of the Russian-Ukrainian war for the aggressor, who occupied more than 11 % of the territory of a neighboring country with all available economic potential. This also happened due to the termination of the participation of the real sector of the economy of the Russian Federation in the international transfer of technologies under the influence of international economic sanctions. A return to the pre-war state is possible only after the restoration of the territorial integrity of Ukraine.

2. It has been proven that through the Russian-Ukrainian war the economic decline of the aggressor (26 % of GDP in 2013) is stronger than the decline in the victim of aggression (16 % of GDP in 2013). Similarly, the absolute losses of the GDP of the Russian Federation due to the deterioration of technological development as a result of the Russian-Ukrainian war in 2014–2019. They were 4.6 times more than in Ukraine. However, the relative losses of Ukraine's GDP for 2014–2019 accounted for 38.6 % of GDP in 2013, and the Russian Federation – only 14.2 %. It is substantiated that, in addition to militariza-

tion, the GDP losses were influenced by the devaluation of the national currency, the negative conjuncture of energy markets, international economic sanctions, the external economic isolation of the Russian Federation, etc. The Russian Federation, being under economic sanctions, curtailed its participation in the field of international technology transfer, significantly worsened its technological development. Ukraine managed to find an alternative to the terminated Russian-Ukrainian technological ties and establish innovative cooperation with European and North American partners, which contributed to the country's technological development.

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