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Influence of Underutilization of Production Capacities on the Dynamics of Russian GDP: An Assessment on the Basis of Production Functions

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Abstract: Sustainable development of the state implies a proportional change in the key macroeconomic indicators described by standard models, one of which is the exponential production function (a special case of the Cobb-Douglas function), where the number of employees (labor) and the value of fixed assets (capital) acts as factor inputs, and GDP becomes the output, and output elasticities of production factors are estimated. This function is successfully used to analyze and predict macroeconomic processes in both developed and developing economies. The purpose of the study is to use econometric modeling—applying the exponential Cobb-Douglas production function—to identify the presence or absence of dependencies of production factors (labor, capital, etc.) on the final product output in Russia. The study shows that in Russia, GDP does not significantly depend on fixed assets. The authors hypothesized that this discrepancy is due to underutilization of production capacities and proved that to reveal the real dependence of Russian GDP production on the value of fixed assets it is necessary to adjust the indicators published by Rosstat for utilization of production capacities, which made it possible to fully use the methodological capabilities of production functions for the analysis and forecasting of macroeconomic processes in Russia.

Keywords: production function; Russian GDP; fixed assets; number of people employed in the economy; underutilization of production capacities

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1. Introduction

In worldwide macroeconomic research and in the practice of forecasting and planning the economies of countries and regions, the traditional tool for modeling the production of the surplus product is production functions (PF), which are nonlinear regression models that demonstrate the relationships between the volume of the product and the key production factors (labor, capital, etc.). The standard model is an exponential PF (a special case of the Cobb-Douglas function), where the factor inputs are the number of employees (labor) and the value of fixed assets (capital), and GDP or GRP is taken as output; estimated parameters are output elasticities of production factors. In our previous studies, we have repeatedly drawn attention to the absence or weakness of the relationship between the GRP of Russian regions—and the GDP of Russia—and the value of fixed assets (Baranov and Skufina 2021; Skufina et al. 2020). This is consistent with the data of other researchers on the economy of Russia and its regions (Kirilyuk 2013). In fact, this indicates a violation of fundamental laws that are objective and operate in both capitalist and socialist formations. The question arises—what is the cause of this violation? Is it a consequence of some uniqueness of the economy of Russia and its regions? Then what is this uniqueness? Or is there some kind of statistical bias? An answer to this question is of fundamental importance because it determines the choice between two completely different research directions. The first approach is to search for the essence of the fundamental difference between the Russian economy and other economies of the world, which will explain the discrepancy between the behavior of macroeconomic indicators in Russia and the standard

PF models. The second approach is to use statistical methods to adjust the standard Rosstat indicators, which will enable fruitful use of the PF for analyzing the dependence of GDP production in Russia on such production factors as a labor (number of people employed in the economy) and capital (fixed production assets). We believe that before using the first approach, it is necessary to assess the influence of the phenomenon of underutilization of production capacities on the dynamics of Russian GDP. Perhaps this is exactly the factor that will allow us to judiciously adjust the Rosstat data for use in the practice of econometric modeling of the interaction of key production factors in Russia. The relevance of the study is dictated by the obvious insufficiency of the application of econometric models in Russian practice. At the same time, ensuring conditions for sustainable development should be based on accurate knowledge of the dependencies of the main production factors that ensure economic growth.

Thus, the purpose of the study is to use econometric modeling—applying the exponential Cobb-Douglas PF—to identify the presence or absence of dependencies of the key factors of production (labor, capital, etc.) on the final product output in Russia.

2. Literature Review

Sustainable development of the state implies a proportional change in the key macroeconomic indicators, primarily the key factors of production and the economic result of the functioning of the national economy, described by standard models (Doughan 2020; Colino et al. 2014; Baranov and Skufina 2018). PF is the traditional modeling tool for production processes, usually at the microeconomic level or the industry level (Ramani et al. 2008; Hu and Hu and Hu 2013). A thorough critical account of the PF development dynamics is given by the classic work of M. Blaug, Economic Thought in Retrospect (Blaug 1997). Recourse to this intellectual heritage is important for at least two reasons. Firstly, the scientific achievements of the period of development of the essence of the problem of production functions are still remarkably relevant and are used in this study. Secondly, comprehensive treatises of the best scientific achievements of the economic theory of 1890–1940 at present, as a rule, do not attract much interest from the modern scientific community, focused more on solving narrower and more specific problems, despite their fundamentality and relevance. In this book, M. Blaug recounts fruitless attempts to prove P. H. Wicksteed ("An Essay on the Co-ordination of the Laws of Distribution"), that the aggregate product is exactly reduced to reimbursing the costs of each of the production factors according to their marginal productivity (Wicksteed 1894). A successful proof of this statement is given in the works of A.W. Flux. His discussion of the designated connection between P.H. Wicksteed's reasoning and L. Euler's theorem on homogeneous functions—that the total product will be exhausted provided that all factors of production are paid according to their marginal products only if the production function is linearly homogeneous—is doubtlessly relevant for the knowledge of the essence of production functions (Groenewegen 2008). Summarizing the formal properties, we can list argumentative fundamental statements valid for the Cobb-Douglas-type functions: (1) the marginal product of a factor varies only when the relative quantities of factors applied change; (2) the factors have complementarity, i.e., an increase in the quantity of a variable factor reduces its marginal productivity, but increases the marginal productivity of a fixed production factor; (3) the total product consists exactly of the outputs of the production factors used according to their marginal productivity (Cobb and Douglas 1928; Douglas 1948; Blaug 1997; Brown 1957; Heathfield and Wibe 1987). However, as E. Miller rightly points out, the practice of application of Cobb-Douglas-type PFs shows that they agree well with real data even in cases where fundamental assumptions are violated (Miller 2008). These paradoxes are noted over a long period of time in the development of the PF theory. For example, there is a well-known controversy called the "two Cambridges debate". At its core, this dispute contains different views of the economic theory on the essence and role of capital, the substance of capital goods, etc., and focuses on the criticism of the neoclassical concept of aggregate production and distribution (Cohen and Harcourt 2003; Sraffa 1961; Schefold 2000; Vasiliev 2006).

This discussion gave rise to many fundamental works that reveal and clarify the role and features of capital measurement in the PF, among which J. Felipe and F. Fisher's works stand out (Fisher 1971; Felipe and Fisher 2003). In these works, J. Felipe and F. Fisher demonstrated, actively polemicizing, the processes of capital accumulation and growth. At the same time, the authors emphasize: "The most important conclusion is that the conditions under which a well-behaved aggregate production function can be derived from micro production functions are so stringent that it is difficult to believe that actual economies satisfy them. Therefore, aggregate production functions do not have a sound theoretical foundation». In fact, the debate on the theoretical foundations of the PF has not yet been completed, but the intensity of the discussion of the theoretical foundations of the PF, in particular, has significantly reduced over the last couple of decades, which, in our opinion, is explained by two reasons. Firstly, the main classics, J. Robinson and P. Sraffa, the destroyers of the neoclassical theory died in 1983. Secondly, economic theory is doomed to theoretical and methodological pluralism due to objective reasons—the need for the significant simplifying abstractions that lead away from the real economy, capable of describing the relationships of people in the process of production, consumption, and distribution. Therefore, the paradoxes of neoclassical theory speak not so much about the limitations of the use of PF, but about the insufficiency of the theory, which should be refined to explain statistically significant patterns of production.

Therefore, despite the rather harsh and not always fair criticism of the PF (Robinson 1953), they are a fruitful means of understanding the laws of production. Mainly the microeconomic and sectoral level of application of PF is explained not by the factor of certain restrictions on their use at the macro level, but rather by the smaller quantity of macroeconomic objects, and respectively, research tasks. In macroeconomic research, PF is the most widely known and applied model. This is usually due to the good correspondence of PF models to real data and the simplicity of interpretation of the results obtained, which allows to use them not only for analysis, but also for forecasting at the macro and micro levels (Thompson 2016; Samarina et al. 2021; Abdullaev 2011; Skufina et al. 2022). However, studies of macroeconomic processes in Russia employing the PF apparatus are relatively rare. As we noted in the introduction of this article, this is explained by an artifact: the absence of a significant relationship between Russian GDP and the value of fixed assets. In the work of E. Chesnokov, an attempt is made to reveal a dependence of Russian GDP on the volume of fixed production using PF, and he establishes such a dependence (Chesnokov 2021). However, this dependence is false, as his work has significant methodological errors. For example, the values of variables were taken not in indices, but in millions of rubles, which is unacceptable in studies of economies, especially mining economies, when the same volume of output costs differently during different periods of time. The authors of this article in their research focusing on the GDP or GRP of the Russian economy did not use the value of fixed assets as capital, but rather the investments in fixed assets (Skufina et al. 2019; Baranov and Skufina 2021). This approach is also present in foreign studies (García-Belenguer and Santos 2013) However, the economic meaning of such models is different as they do not consider the accumulated capital, and fixed assets, in the production of GDP or GRP.

Thus, despite the wide prevalence of PF application for the analysis and forecasting of production processes—of direct importance for ensuring the goals of sustainable economic development—we expect to supplement the possibility of studying the Russian economy using the exponential Cobb-Douglas production function. To this end, the authors' hypothesis will be tested, which states that the discrepancy between the production of Russian GDP and the standard model of the exponential Cobb-Douglas PF is due to the phenomenon of underutilization of production capacities.

3. Materials and Methods

The methodological tools of the study include econometric modeling, comparison, description, generalization, and correlation analysis. The following initial data were used in the work:

- the index of the physical volume of Russian GDP in constant prices in % relative to the previous year, which we have reduced to the 2000 values;
- the index of the physical volume of investments in fixed assets (IFA) in comparable prices in % relative to the previous year, which we have reduced to the 2000 values;
- the value of fixed assets (VFA) at the end of the year at the full accounting value, which we have reduced to the 2000 values using the GDP deflator index;
    - GDP deflator indices;
    - average annual number of people employed in the economy of Russia (EN);
    - degree of depreciation of fixed assets (at the end of the year, %);
    - coefficient of the efficiency of the use of fixed assets (%) (Rosstat 2022).

The weak dependence of GDP on VFA and fairly strong dependence of GDP on IFA and EN (Figure 1) stand out. Below, using econometric modeling, we will demonstrate the absence (or presence) of these dependencies.

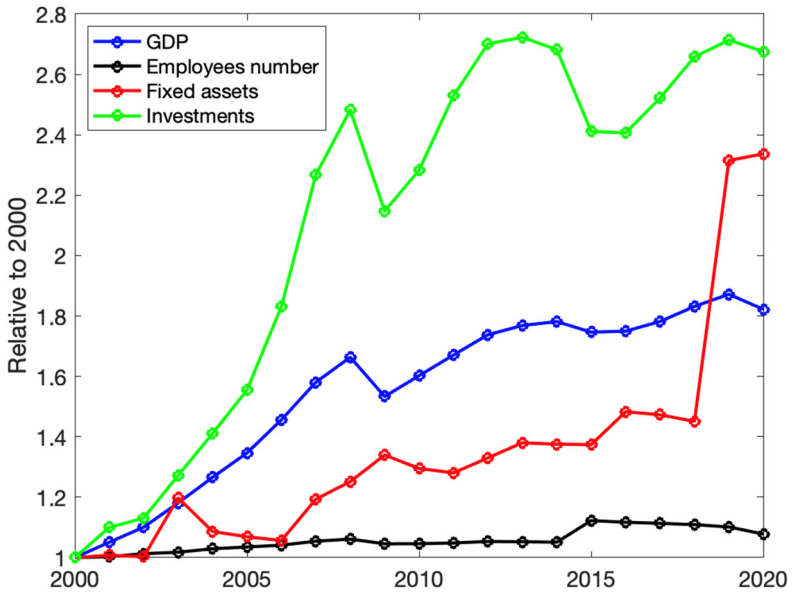

Figure 1. Dynamics of the indicators used for 2000–2020.

To demonstrate the absence or existence of a relationship between GDP and factors of production, we calculated the squares of correlation coefficients (Table 1) that characterize the share of GDP variance explained by one or another factor of production. In this manner, VFA explains only 46% of the GDP variance, while IFA explains 97% and EN 70%. Thus, the dependence of Russian GDP on VFA is much weaker than on IFA and EN.

Table 1. Values of the square of the Pearson correlation coefficient between GDP and production factors.

	VFA	**IFA**	**EN**
GDP	0.46	0.97	0.70
VFA		0.41	0.37
IFA			0.57

To clarify the relationship between GDP and production factors, we used the following PF (Cobb and Douglas 1928):

$$Y = AC^p L^q, \; A, p, q > 0, \tag{1}$$

where Y is GDP, C is capital, and L is labor. A, p, and q are estimated parameters. Parameters p and q are elasticities of capital and labor, respectively; A is the total factor performance, characterizing the influence of intangible factors, such as features of technology and knowledge.

The estimation of the Cobb-Douglas PF parameters was performed using the least squares method after the logarithmation of the formula (1) using VFA and IFA as capital (C). The results of the assessment are shown in Table 2, and a graph of the correspondence of the models to the initial data is shown in Figures 2 and 3. According to calculations, despite the fact that both models are significant, the parameter p in (1), which characterizes the elasticity of VFA, is insignificant at the 5% level: the p-value is 0.07, and the 95% confidence interval contains positive and negative values. If the degree of depreciation is not taken into account in the VFA, the p-value will even increase and become equal to 0.16. Thus, $p = 0$ and the GDP production is independent of VFA. In fact, according to this model, it turns out that GDP depends only on labor (L).

Table 2. Estimates of Cobb-Douglas PF parameters (1), F-statistics (F), adjusted coefficients of determination (r^2), values of the Akaike information criterion for small samples ($AICc$), 95% confidence intervals (ci), p-values (p-value) calculated based on the data for 2000–2020 using VFA and IFA as capital.

	Estimate	***ci***	***p*-Value**
Capital $C = VFA$, $F = 26.7$, p-value $= 4.1 \times 10^{-6}$, $r^2 = 0.72$, $AICc = -30.7$			
$\log(A)$	0.155	0.064, 0.247	0.002
p	0.27	−0.02, 0.57	0.07
q	3.51	1.54, 5.43	0.001
Capital $C = IFA$, $F = 1.5 \times 10^3$, p-value $= 7.9 \times 10^{-21}$, $r^2 = 0.99$, $AICc = -109.8$			
$\log(A)$	0.018	0.001, 0.03	0.04
p	0.50	0.46, 0.53	4.4×10^{-17}
q	0.98	0.65, 1.31	6.9×10^{-6}

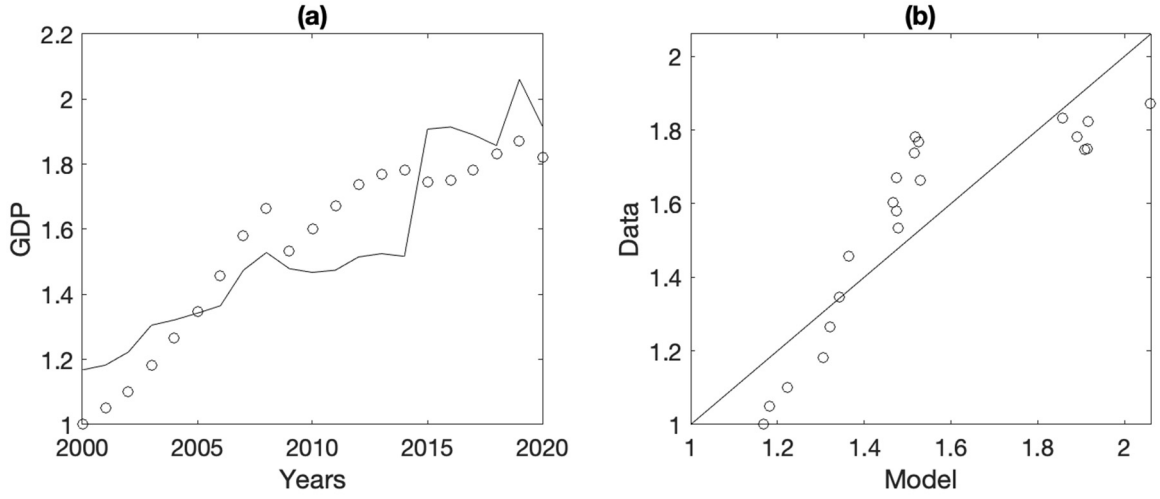

Figure 2. Dynamics of the GDP physical volume index (**a**) and actual data and model values (**b**). Circles denote actual data, black line is values obtained according to the Cobb-Douglas PF (1) with parameters from Table 1, where VFA is taken as the capital C.

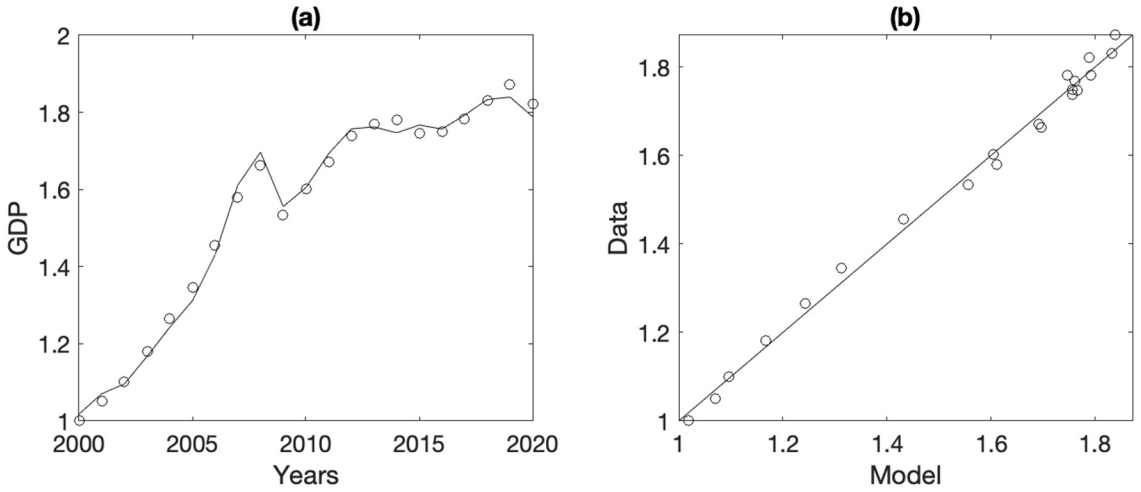

Figure 3. Dynamics of the GDP physical volume index (**a**) and actual data and model values (**b**). Circles denote actual data, black line is values obtained according to the Cobb-Douglas PF (1) with parameters from Table 1, where IFA is taken as the capital *C*.

If the Cobb-Douglas PF adopts the IFA as capital *C*, then the estimates of the elasticities of capital (p) and labor (q) become significant (Table 1) and this model is much more preferable to the model, where *C* = VFA (large values of F-statistics and the coefficient of determination r^2 and the lower values of the Akaike criterion *AICc*). A better correspondence of the model to the initial data at *C* = IFA than at *C* = VFA is also visually noticeable (refer to Figures 2 and 3, respectively). Estimates of elasticities (Table 1) for capital ($p = 0.50$) and labor ($q = 0.98$) show that an increase in IFA by 1% will lead to GDP growth of 0.5%, and an increase in the number of employed by 1% will lead to GDP growth of 0.98%. The sum of elasticities ($p + q = 1.48$) is greater than 1, hence the production of GDP in Russia is characterized by increasing returns.

4. Discussion of Results

The main result of the study is the absence of a significant dependence of the production of Russian GDP on VFA during 2000–2020. This contradicts the standard model in the form of the Cobb-Douglas PF (1). If IFA is taken as capital, then GDP production demonstrates a clear dependence on this factor. Here the question arises—what is the reason for the lack of dependence of Russian GDP production on the VFA? We believe that the main reason is the underutilization of production facilities in Russia. That is, the value of fixed assets is a monetary expression of production capacities (considering depreciation), which are not fully used. We should note that this fact is considered by a number of researchers as a kind of opportunity to ensure the economic growth of Russia (Glazyev 2018). That very paper also provides data according to which in a number of sectors of the economy of Russia production capacities are used by 50–70%. In fact, this indicates that not the entire value of fixed assets published by Rosstat is used in the production of GDP, but only a part of it. This fact is also confirmed by the dynamics of capacity utilization in Russia (Figure 4), according to which for 2000–2022 production capacities were used by 48–64%.

Thus, in model (1), it is methodologically more correct to use VFA adjusted to consider the utilization of production capacity. That is, the values of the VFA indicator should be reduced by the % of underutilization for the corresponding year. For example, in 2019, VFA amounted to 349,731,105 million rubles, and the use of production capacity was 64% (Figure 4a), which means that the corrected VFA (CVFA) is 223,827,907.2 (CVFA = VFA $\times$ 0.64) million rubles. The dynamics of the CVFA and GDP are shown in Figure 4b. Calculations show that the correlation coefficient of CVFA and GDP is 0.78, which is higher than the same value for the VFA (0.68).

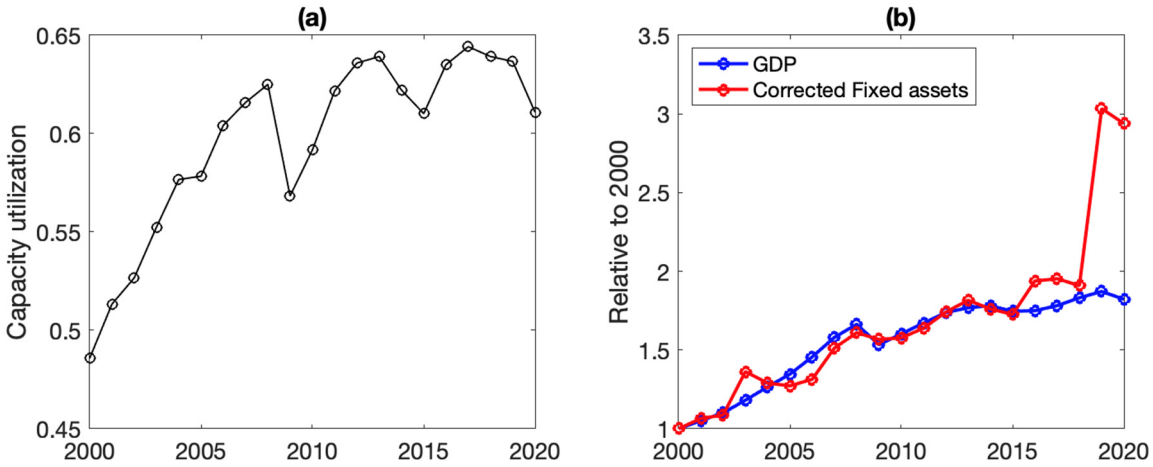

Figure 4. (**a**)—Dynamics of capacity utilization (https://macrovar.com/russia/capacity-utilization/ (accessed on 21 January 2023)); (**b**)—GDP and utilization-adjusted value of fixed assets (CVFA, Corrected Fixed assets).

An assessment of the Cobb-Douglas PF parameters (1), where the CVFA is used as capital (Table 3), shows that the elasticity of capital ($p = 0.37$) is statistically significant (p-value is 0.004); the values of the determination coefficient ($r^2 = 0.79$) of F-statistics ($F = 38.8$) and the Akaike information criterion ($AICc$) = −36.9 indicate that the model with CVFA better corresponds to the initial data than the model with VFA (Table 1, $AICc = -30.7$, $r^2 = 0.72$, $F = 26.7$). The graphical correspondence between the models and the source data is shown in Figure 5.

Table 3. Estimates of Cobb-Douglas PF parameters (1), F-statistics (F), adjusted coefficient of determination (r^2), Akaike information criterion value for small samples ($AICc$), 95% confidence intervals (ci), p-values (p-value), calculated on the basis of data for 2000–2020 using the utilization-adjusted value of fixed assets (CVFA) as capital.

	Estimate	***ci***	***p*-Value**
Capital $C = CVFA$, $F = 38.8$, p-value $= 2.95 \times 10^{-7}$, $r^2 = 0.79$, $AICc = -36.9$			
$\log(A)$	0.11	0.03, 0. 197	0.01
p	0.38	0.14, 0. 61	0.004
q	2.36	0. 43, 4. 30	0.02

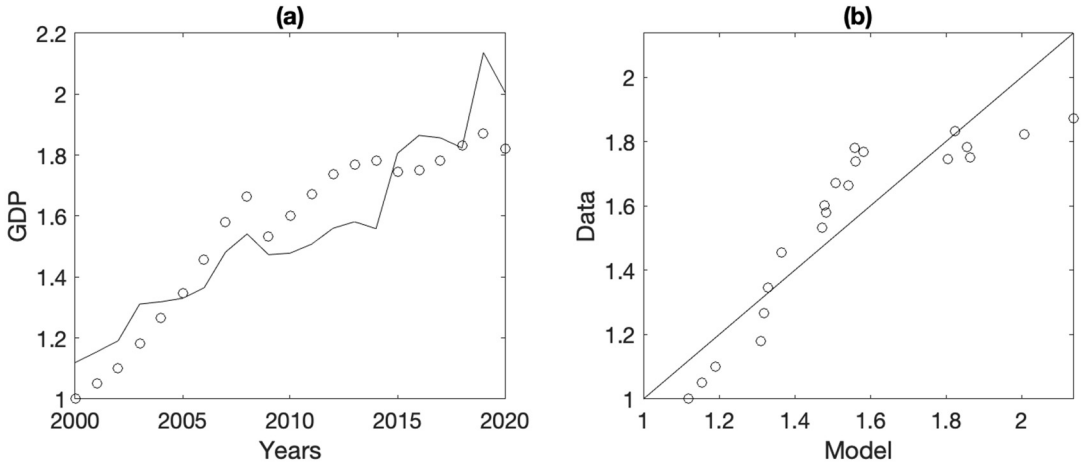

Figure 5. Dynamics of the physical GDP volume index (**a**) and actual data and model values (**b**). Circles denote actual data, black line is values obtained according to the Cobb-Douglas PF (1) with parameters from Table 1, where the utilization-adjusted value of fixed assets (CVFA) is used as capital C.

The results draw attention to two important circumstances. First, the importance of considering the utilization of production capacities as a factor of influence on GDP production. This is confirmed not only by the results of our study, but by a discussion formed in recent years about the essence and problems of using the SSM model, with F. Serrano (1995), H. Bortis (1997), O. Dejuan (2005) considered as its founders. An analysis of the disagreements on the applicability of these models suggests that the origins of this criticism lie in the unresolved "two Cambridges debate" on the essence of the processes and factors of economic growth, including the essence of capital. For example, M. Nikiforos (2018) believes that one of the fundamental problems of the SSM model approach is that the normal degree of capacity utilization is treated as an exogenous variable. The current debate on the weaknesses and strengths of the applicability of the SSM model confirms the problematic nature of this initial assumption (da Costa Oreiro et al. 2020). In particular, it shows that if the economy operates with increasing returns (as we have shown, this is typical for the Russian economy), then the level of capacity utilization becomes an endogenous variable, that is, an increase in aggregate demand will lead to an increase in the level of use of production capacities.

The second important circumstance is the need to take into account the achievements of scientists in the practice of management, which can strengthen the possibilities of ensuring conditions for sustainable development of the economy. In particular, addressing the results of our research, the results of the debate on the weaknesses and strengths of the applicability of neoclassical models of economic growth, the results of a critical examination by S. Yu. Glazyev of the essence of Russian economic policy (Glazyev 2018) can determine the possibilities of increasing the values of Russian GDP production factors. In particular, in his study, S. Yu. Glazyev clearly demonstrates the possibilities of increasing the labor factor due to the growth of labor productivity, as well as the continuing inflow of labor from the post-Soviet countries of Central Asia (Glazyev 2018). The possibilities of increasing the utilization of production capacities according to neoclassical and political economic models are obvious: this is the intensification of the use of production resources due to STP, increased investment, and increased aggregate demand.

5. Conclusions

Thus, a study of the production of surplus products in Russia was carried out using the traditional tool of macroeconomic research, PF, linking factors of production with output, where the number of employees (labor) and the value of fixed assets (capital) acts as factor inputs, and GDP becomes the output, and output elasticities of production factors are estimated. The results of the study allow us to draw the following conclusions.

1. A weak dependence of Russian GDP on the value of fixed assets has been established. At the same time, a fairly strong dependence of Russian GDP on investments in fixed assets and the number of people employed in the Russian economy has been established. For example, the value of fixed assets explains 46% of the variance of Russian GDP, while investments in fixed assets do 97%, and the number of employees does 70%.
2. The relationship of Russian GDP with the main factors of production based on the use of the PF apparatus has been clarified. The absence of an association between the GDP and the value of fixed assets has been confirmed. The relationship between the production of Russian GDP and the investment in fixed assets and the number of employees has been established: an increase in investment in fixed assets by 1% will ensure Russian GDP growth; an increase in the number of employed by 1% will lead to an increase in GDP by 0.98%; Russian GDP production is characterized by increasing returns.
3. It is proven that insufficient use of production capacities is a significant factor determining the absence of dependence of the Russian GDP production on the value of fixed assets, which confirms the main hypothesis of the study. To reflect the real dependence of the Russian GDP production on the value of fixed assets, it is necessary to adjust the numbers of the values of fixed assets published by Rosstat taking into account the utilization of production capacities.

We believe that the theoretical and methodological significance of the results lies in two components. Firstly, in the proof that the discrepancy between the production of Russian GDP and the standard PF models is explained not by the unique nature of the interaction of the main production factors (the number of employees and the value of fixed assets) of Russian GDP, but by not accounting for the phenomenon of underutilization of production capacities. Secondly, the proposed adjustment of the value of fixed assets in Russia allows us to use the typical PF tools for the study and forecasting of macroeconomic processes in Russia, and also makes it possible to include Russia as an object of study in cross-country comparisons of the specifics of GDP production.

We believe that the practical significance of the results obtained lies in the possibility of using PF models in substantiating the optimal values of factors of production and forecasting the production of Russian GDP in the development, monitoring, and implementation of state forecasts, programs, and projects aimed at ensuring sustainable economic development.

The further direction of research seems to lie in the need to consider the relationship between the added value and factors of production by industry and sphere of activity. Another promising direction is the search for opportunities for economic growth by increasing the utilization of production capacities, which is consistent with the conclusions of the work of S. Yu. Glazyev (2018). Thus, an increase in the use of production capacities in Russia by 20% (which roughly corresponds to the average level for the G20 countries) will lead to an increase in GDP by 7–8%. Obviously, achieving these conditions is significant for ensuring the sustainable growth of the Russian economy.

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Conflicts of Interest: The authors declare no conflict of interest.

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