Overcoming the Inadequacy of Economic Dynamics Models

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Abstract. Known models of economic dynamics are too aggregate, so inadequate to the real economy. The analyst will not be able to identify the real dynamics of the economy among the big mistakes. They have no connection between investments, their efficiency, and the rate of economic growth. There is no transition from the optimal share of savings in the country to the agents' optimal shares, managing investment sources.

To link investment and the pace of economic growth, the author introduced the concept of technical productivity of investments, which measures their ability to change the rate of material or labor costs.

Based on the technical productivity of investment, the author has derived the equation (not identity) of economic dynamics.

Instead of the highly aggregated models, the author developed an adequate causal simulation model, reflecting the economy as a closed system with positive feedback of the investment from incomes and economic growth from investment. The author determined the dynamics of the Ukrainian economy with different technical productivity of investment on this model.

Keywords: inadequacy of high aggregated models of economic dynamics, technical productivity of investments, causal simulation model of economic dynamics, shadow economy, forecast

1. Introduction

The author defines his position in economic modeling in general and in models of economic dynamics in particular. He identifies shortcomings of the latter and offers a comprehensive approach to overcoming them. The illustrative calculations were performed for Ukraine, but the conclusions are largely valid for many other countries and hopefully for economic dynamics modeling.

At that time, when scientists began to build economic science on principles of physics, they discussed its nature, roles of mathematical methods, and the very possibility of such a building. Here is what J. von Neumann and O. Morgenstern wrote in 1944:

"To illuminate the concepts that we will apply to economics, we present and will continue to present some illustrations from physics. Many sociologists object to drawing such parallels for 48 different reasons, among which they usually cite the statement that economic theories cannot be modeled on the model of physical ones, since economic theories take into account social, economic phenomena, since they have to take into account psychological factors, etc. Such claims are immature, to say the least. Undoubtedly, it seems reasonable to uncover what led to progress in other sciences and investigate why the application of these principles cannot lead to progress in economics. If there really is a need to apply some other principles to economics, this can only be revealed in economic theory's actual development. This, in itself, will be a revolution in science. But since, almost certainly, we have not yet reached such a state and it is in no way clear that there is a need to use completely new scientific principles, it would be unreasonable to consider anything other than the interpretation of problems in the way that has already led to the creation of physical science" (I quote from the Russian edition (Neumann, Morgenstern, 1970, pp. 29-30)).

So far, no consistent economic theory based on the principles of physics has been created. Moreover, many economists have spoken of the crisis of economics. Paul Samuelson (1947, p.4) wrote:

"The economist comforts himself ... with the thought that he is forging tools that will eventually lead to results. This promise is always for the future; we are like well-trained athletes who do not participate in competitions and therefore lose shape."

E. Malinvaud (1995) says:

"Honestly, we underestimated the complexity of the problem: the detection of these (economic) laws is much more difficult than we thought."

There are many such opinions: for example, (Blaug, 1994, Preface to the third edition), (Lawson, 1995), etc.

Moreover, the very definition of economics is changing. In the first half of the 19th century, economics was seen as a study of the "nature and causes of the wealth of nations" (Smith), "the laws governing the distribution of what is produced on earth" (Ricardo), and "the laws of the movement of capitalism" (Marx). After 1870, it was believed that the economy analyzed human behavior in different markets. Mark Blaug (1994, p. 4) wittily remarked that many early studies then lost the right to be called economics.

We are more inclined to believe Alexander Gray:

"Economic science if this is different from other sciences that there is no imminent transition from least to most credibility, there is no inexorable desire to go all the way, the truth, which, as once revealed, will be true for all time, until the complete eradication of any opposite teaching" (quoted by (Blaug, 1994, p. 3)).

As a result of this approach, Paul Krugman's (2009) produced devastating critique of economic models that cannot predict anything.

When creating our model of economic dynamics of Ukraine (Vasylenko, 2016), we sought **to achieve the greatest adequacy**.

All this applies to the theory of economic growth.

2. Drawbacks of the models of economic growth

One of the fathers of economic dynamics, Roy Harrod (1973), submitted the fundamental equation of economic dynamics which determines the growth rate: the amount of savings, expressed as a share of net income divided by the capital ratio. The capital ratio is the ratio of net (rather than gross) investment to the increase in output or income over the same period.

We should note that the output growth (which stands in the denominator of the Harrod's capital ratio) to its base value – this is the rate of economic growth. Thus, Harrod's fundamental equation of economic dynamics is not an equation – it is nothing more than some identity where the output indicator is determined by itself. If we solve it, we get the known identity: savings equal the capital increase.

Roy Harrod himself understood this perfectly; moreover, he emphasized that this equation is a truism because it is easily deduced from the standard definitions of macroeconomic variables included in this equation.

However, he called this identity an equation. Varieties of this equation (equations of guaranteed and natural growth rate) were used to calculate recommendations to the governments of different countries to forecast and regulate the rate of economic growth in the 60s of the twentieth century. But only in 6 of the 88 countries where they were used were the expected results obtained (Easterly, 1997). Attempts to predict economic growth based on the Harrod-Domar model have failed. The researchers concluded that the model does not explain the main determinants of economic growth. And how could it explain if it is not an **equation** but **identity**? **The rate of output growth does not follow from this identity.** What the increase in the output in the capital ratio we set, the same increase in output we get at the output of the Harrod's fundamental equation of economic dynamics.

Robert Solow (1956) turned this identity into the equation by replacing the capital ratio with a labor efficiency indicator.

For this he received the Nobel Prize in 1987. This was, in my opinion, a rather strange decision, because:

1) His labor efficiency was exogenous and not related to investment.
2) It is the exogenousness of economic growth according to Solow was the object of criticism №1, and less than 10 years later, the Ramsey-Cass-Koopmans model appeared in which the saving rate changed in each period (Koopmans, 1963; Cass, 1965), due to which this model became endogenous. However, it was later recognized as exogenous because, as in the Solow model, scientific and technological progress in the Ramsey-Kass-Kupmans model is not the result of decision-making by economic agents but is set exogenously (Acemoglu, 2008; 2012). F. Ramsey

(Ramsey, 1928) studied the problem of determining the norm of conservation in the 1920s with differential equations.

That is, R. Solow took two steps back at once: in time and in terms of abandoning the endogenous nature of economic growth.

3) In choosing the model, R. Solow was behind K. Marx who divided the economy into two sectors: the production of consumer goods and means of production.

4) Solow's model is not his own model, but the Cobb-Douglas model, the adequacy of which to the real economy is in great doubt – deviations of the actual data of the production of the USA manufacturing industry from the Cobb-Douglas function was more than 15 percent, which does not provide sufficient reason to believe this power function adequate to the existing economy. And this is for one homogeneous industry where companies have approximately the same levels of capital intensity. The mistake for the whole economy, where there are capital-intensive and labor-intensive industries, will be rather more prominent. We will not be able to identify the real dynamics of the economy in these deviations at the analysis. Mark Blaug (1994, p. 653) expressed a more general idea:

"In itself, the concept of production function - a set of all known production technologies – is so general that it can not be called meaningful."

5) So all studies of R. Solow of various modifications of the Cobb-Douglas model (with constant elasticity of substitution (CES), with constant return on a scale, with decreasing return on a scale, etc.) are, in fact, the study of mathematical properties of the power function, but whether this function reflects the real economy is a big question.

6) In the Solow model, investments make up a fixed share of production. In fact, all production is not a source of investment. There are three investment sources: gross profit, wages, and taxes (in public sector investment), which together account for GDP. The volume of production also contains material costs that are not proportional to GDP: in industries and countries with higher production efficiency, they are smaller, with lower efficiency – higher (this is why it is necessary to take the output as a result indicator of the economy, not GDP). Therefore, an investment cannot be taken as a share of output.

One cannot take investment as a share of GDP because the shares of savings in gross profit, wages, and the share of investment in the budget, formed from taxes, are significantly different. Non-financial corporations in Ukraine direct all gross adjusted disposable income to gross savings. Financial corporations of Ukraine, for example, in 2018 – 99.4%. The general government sector directed 8.1% of gross adjusted disposable income to gross savings. Households are unlikely to use social benefits to save as cash, much less in kind. They save from three sources: gross profit (mixed-income), which amounted to 2018 25.7% of the gross balance of primary incomes, wages of employees (71.9% of the gross balance of primary incomes), and property income (2.5%). The share of gross savings in

the gross balance of primary household income was 3.9%. Non-profit institutions serving households directed 8.6% of their gross adjusted disposable income to gross savings (Accounts of institutional sectors of the economy for 2018, 2020).

Thus, the average share of gross savings in gross adjusted disposable income in Ukraine of 14.4% does not contain any useful information. Because if we determine the optimal share of gross savings in the country's gross adjusted disposable income, and even more so in production, then there is no economic agent who can use it, there is no source of investment from which to take this share. From this optimal share, it is impossible to move to the optimal shares for agents who own or manage investment sources: for households, for non-profit organizations serving households, and for the general government sector.

We should note also that to determine the exact optimal share of savings is not simple. As R. Pindyck (2013) stated, there is great uncertainty in Nordhaus model's input indicators and the like ones, particularly regarding the discount factor, small changes of which strongly affect the value of the optimum, and there is no justification for these small differences. W. Nordhaus and E. Moffat (2017) themselves note the poor reproducibility of their results.

Modern economists rightly believe that economic development should be carried out at the expense of some endogenous resources. Thus, Agion-Howitt (1992) modeled economic growth as a consequence of individuals' decisions, not an exogenously given variable. But they focused on the norm of saving and did not study the sources of development, i.e., sources of investment.

All these and similar models had the amount of capital as one of the main determinants of growth, which is uninformative without its productivity. The productivity depends on the nature of the investment. Economic growth models did not address either the nature of investment or investment effectiveness. But one needs to consider this because the pace of technological progress and economic growth depends on it.

None of the economic dynamics models reflects the shadow economy, although, in many countries, it significantly affects economic dynamics. For Ukraine, we showed this in (Vasylenko, 2015b).

The general conclusion of this analysis is as follows: **it is impractical to study the economic dynamics on the highly aggregated models, such as mentioned above, where the main determinant of growth is the uninformative amount of capital, regardless of its productivity.** They are inadequate to the real economy, especially in those countries where the shadow economy is significant. Deviations from the real economy are so great that **any economic dynamics become indistinguishable in them**. It is impossible to draw constructive conclusions appropriate for a particular economy or group of similar economies on such models. The conclusions that have been obtained have either already turned out to be wrong (Harrod-Domar model) or will turn out to be such, or they cannot be applied in a particular economy (Solow model).

3. Research methodology

Based on these shortcomings, what should be the model of economic dynamics?

If we look at the economic development problem from the point of view of control theory, we see clearly that the economy is a typical closed system with feedback, and this connection is positive. At the end of one cycle, we have three components of GDP: gross profit, wages, and taxes, which return to the entrance of the system in the form of investment in capital and technology, additional material costs, and additional hired labor (as a physical number of people (it may decrease) and their higher qualification) in the next cycle and some later cycles.

The fact that the share of savings is optimal does not make economic development endogenous. **The use of any part of GDP for investments makes it endogenous.**

Continuous development is an inherent property of the economy as a closed system with positive feedback. If exogenous factors (war, foreign trade restrictions, sanctions, etc.) do not affect, it can grow exponentially or go into a mode of fluctuations (rise – crisis) with an amplitude that increases or decreases according to the oscillation theory.

One can influence the development of the economy and endogenously. For example, households, non-profit institutions serving households, and the general government sector can choose different savings rates. The devaluation of the national currency, inflation may be, and so on.

So, one has to link the investment, the source of which is the income of previous cycles (and the investment from other sources), with the economic growth in the next cycles in the economic dynamics models.

The second point is **the change of the main determinant of economic growth,** which was used in traditional models: instead of the **amount of capital, regardless of its productivity,** you must study the impact of the **investment of different productivity** on economic growth.

The third point – one has to disaggregate the economic dynamics model strongly to enrich the possibilities of analysis, which are extremely poor in traditional economic dynamics models (as already mentioned, all studies of R. Solow of various modifications of the Cobb-Douglas model are in fact the study of mathematical properties of the power function, but not the real economy).

The fourth point – the authors of all known disaggregated models based them on various macroeconomic theories and hypotheses (hypotheses of monetarists, Keynes, of equilibrium, and so on) that *a priori* rigidly predefine the economy's behavior and make a model inadequate real economy. Sometimes these hypotheses are implicit. For example, the use of GDP as the model output automatically introduces the hypothesis of the constancy of economic efficiency (GDP per unit of intermediate consumption). In contrast, the simulation of output and costs reflects its changes. In the language of control theory, all these hypotheses relate to the management of the economy, but not to the economy itself as a control object. Introduction of them into the model of an object means to mix object and control system that makes impossible an analysis of 'pure' economy (economy

as a system with internal positive feedback is unstable) and correct synthesis of a control system. We used *a priori* more appropriate path (long known in the theory of control systems but have never been used in economics): displays only the object of control but not control actions, that is, the existing economy, not the ideas. By the way, it is much easier than to create and apply different theories, although more cumbersome.

The fifth point – one has to reflect the shadow economy, and not separately from the legal one (as, for example, in (Giles, 1997; Lalitha, 2000; Lasko, 2000)), but in connection with it, which is not in any known model (not only dynamic).

So we believe that for studying the economy's dynamics under exogenous and endogenous influences, one has to build a sufficiently detailed causal model of a particular economy or group of similar economies, reflecting the economy as a **closed system with positive feedback of the investment from incomes of a previous cycle and economic growth in the next cycle from investment**.

We have built such a model of economic dynamics. It can be considered a development of the ASPEN model (Basu N., Pryor R. and Quint T., 1998). True, the author found out about her in 2018. It is of simulating type. The model features that ensure the Ukraine economy's adequacy are given in (Vasylenko, 2016). To make the model suitable for other countries, you need to change its parameters and sometimes some of its parts according to their economic otherness. However, the general principles of our model building are valid for all countries.

The model reflects the positive feedback mentioned above. It reflects all three sources of investment: gross income, wages and taxes. One can set or optimize on one (maximum consumption for the period) or several criteria (according to the algorithm developed earlier (Vasylenko, 1983)) the propensity to accumulate at each of these sources in the production of any separate or all goods for each or several playback cycles. You can set any period. Currently, the model was set up for 15 years. It hardly makes sense to have more because in 15 years, technological progress will change the economy so much that further forecasting will lose its meaning.

Such a short forecast corridor makes the two-generation models of Peter Diamond (1965) unsuitable and generally calls into question the problem of finding the optimal share of savings for a long or infinite period.

Our model can study the economic dynamics under the influence of both endogenous and exogenous factors, both one by one and groups of factors.

Investment can be from both endogenous (from own GDP) and exogenous sources (foreign investment or loans).

The model groups all the diversity of investment activity into four types:

a) On one year to reduce material or labor costs per unit of traditional produce; on average such investments give a profit through one year;
b) on three years to create new varieties of goods that will have higher demand and sell at higher prices; their cost will be less or more (the rate of change in price and value can be adjusted); they give a profit on the fourth year; one can channel both types of investment into one or more products;
c) for housing construction; in Ukraine, buyers pay in advance;
d) to recover worn-out or obsolete fixed capital.

Investment can be more or less effective; can have more or less impact on economic development. Therefore, it is necessary to invent some general characteristic of investment, regardless of their technical content.

Investments are mostly explored for their payback, which is mainly a microeconomic approach. One has to characterize investment in macroeconomic terms. Besides payback is an **economic** indicator of their performance. No one measured the direct result of active investment, namely the **ability of an investment to reduce the rate of material or labor costs**. This characteristic is a direct factor in increasing the competitiveness of the enterprise and an input indicator for the generalized economic effect of investment. The economist, having such an input characteristic of investment, will quantify the potential of the totality of any investment, regardless of their specific nature. That is, the economist will be able to move from the microeconomic level to macroeconomic analysis.

To fill this gap and link investment to GDP growth, we have introduced such an indicator and called it the **technical productivity of investment**. We accepted that the technical productivity of investment is equal to 1 if the rate of decrease in the rate of expenditure (per unit of output) is equal to the increase of the active part of fixed assets through investment. If technical productivity is 2, then the reduction is twice as much.

In our model, we can change the investment technical productivity and analyze the results. Thanks to introducing the concept of the technical productivity of investment, one can obtain some results analytically. For example, we have derived the equation (not identity as R. Harrod) of economic dynamics to the first type of investing (Vasylenko, 2021). For other types of investment, this cannot be done since a complex nonlinear system of equations describing direct, reverse and cross-connections in the economy is recurrent. It is not easy to solve them explicitly. Our model solves them by sequential approximations implemented in Excel using macros developed by the author.

From this, it follows a proposal for the lazy: even if the method of solution of any system of equations is known but is hard enough, you can not spend time on it, but easy to implement this iterative algorithm in Excel and get a solution quickly and without errors, that often encountered in the 'manual' decision in the "quadrature". Even for experienced mathematicians, it may be easier to use iteration than 1) to identify the appropriate method's suitability for this problem (i.e., to check the scope of application), and 2) to use it. If a method is not yet developed, the more so. The convergence of the process is also easier to identify every time than to prove it.

4. Application of the causal simulation model to determine the dynamics of the Ukrainian economy

To accurately determine the Ukrainian economy dynamics in the conditions of existence of all types of investments, we applied our model, reflecting all the main direct, reverse, and cross-links in the economy, including the links between the shadow and legal sectors.

Using our model, we are confident that we forecast Ukraine's economic dynamics indeed rather than study the Solow power function's mathematical properties, which is unlikely to reflect the real economy.

Assume that all input variables in 2020-2032 do not change and are equal to the value of 2019.

Table 1 presents the economic dynamics of Ukraine for 2020-2032 at constant input variables of 2019.

Table 1. The economic dynamics of Ukraine for 2020-2032 at constant input variables 2019 at different investments' technical productivity obtained on our model

Years	Real increase in GDP at constant input variables 2019, %					
	Investment's technical productivity 0.2		Investment's technical productivity 0.5		Investment's technical productivity 1	
	total	legal	total	legal	total	legal
2020	-5.50	-5.50	-5.26	-5.41	-5.24	-5.24
2021	-1.34	-1.28	-0.96	-1.14	-0.41	-0.88
2022	0.41	0.27	0.75	0.40	1.22	0.67
2023	0.42	0.18	0.73	0.31	1.13	0.58
2024	0.40	0.16	0.69	0.29	1.03	0.57
2025	0.39	0.15	0.66	0.28	0.95	0.56
2026	0.38	0.15	0.63	0.26	0.88	0.55
2027	0.37	0.14	0.60	0.26	0.82	0.53
2028	0.36	0.13	0.57	0.25	0.76	0.52
2029	0.35	0.13	0.55	0.24	0.71	0.51
2030	0.34	0.12	0.52	0.24	0.67	0.50
2031	0.33	0.11	0.50	0.23	0.63	0.49
2032	0.33	0.12	0.48	0.23	0.60	0.48

Although we have set constant input variables since 2019, the prehistory influenced Ukraine's economic dynamics until 2022. Only since 2023, the economic dynamics has been almost free of prehistory.

Table 1 shows that the real increase in total (legal + shadow) GDP in 2023-2032 under the influence of active investment only due to own savings with their technical productivity 0.2 averaged 0.35%, gradually decreasing from 0.42% to 0.33%. The real increase in the legal GDP in these years averaged 0.13%, decreasing from 0.18% to 0.12%. Why did these reductions occur? Because Ukraine's fixed assets were growing every year due to investment, and investment remained constant. Consequently, their shares relative to fixed assets were declining.

We should note that all known equations of economic dynamics give only the increase in legal GDP. The real total GDP grew by 2.5% over these years, the real legal GDP – by 0.9%. The difference is huge. The investments increased Ukraine's fixed assets by 33% over these years.

At investments' technical productivity 0.5, the real increases in the total and legal GDP become are much higher: 0.55% and 0.24%, and for the whole period – 3.9% and 1.7%. At investments' technical productivity 1, they become bigger: 0.72% and 0.51%, and for the whole period – 5.2% and 3.6%.

Our model gives not only the pace of development, but also the dynamics of almost all result indicators: cost, gross and net profit, amounts of wages, value-added, output, GDP, share of GDP in output, share of wages in cost, rising unemployment, pensions, tax and non-tax revenues, salaries of public sector employees, issues and revenues of the general government sector, physical volume and foreign exchange earnings from exports of final and intermediate consumption goods, physical volumes and currency expenditures on imports of final, intermediate goods and investment consumption, foreign trade balance, the share of imports in final and intermediate consumption, prices, GDP per unit of intermediate consumption goods and services, which characterizes the efficiency of the economy from a national point of view, production efficiency of a single product from the point of view of other economic entities (owner of production – the ratio of gross or net profit to capital or cost; employee – wages for working time, etc.), and so on. For example, in the first case (with investments' technical productivity 0.2), the real wages decreased over the whole period by 1.6%, the real total gross profit increased by 8%, final consumption by 2.3%, gross capital accumulation – by 20.5%, taxes – by 1.4%, bribes – by 1%, imports – by 1.7%, legal exports-imports balance – by 5.2%, total exports-imports balance – by 4.5% and so forth.

By using our model, we can predict Ukraine's economic dynamics under the influence of many factors that are not in the models of economic dynamics.

The most influential factors are exports and imports. Let exports grow by 1% every year due to the increase in physical volume at constant price. The results for different technical productivity of investment are summarized in Table 2.

Table 2. The economic dynamics of Ukraine for 2020-2032 at constant input variables of 2019; exports grow annually by 1% due to an increase in the physical volume, with different investments' technical productivity obtained on our model

Years	Real increase in GDP, %					
	Investment's technical productivity 0.2		Investment's technical productivity 0.5		Investment's technical productivity 1	
	total	legal	total	legal	total	legal
2020	-5.49	-5.50	-5.40	-5.40	-5.24	-5.24
2021	-0.62	-0.56	-0.25	-0.42	0.31	-0.16
2022	1.15	0.97	1.50	1.10	1.97	1.38
2023	1.16	0.88	1.48	1.01	1.89	1.30
2024	1.15	0.87	1.45	1.00	1.80	1.29
2025	1.14	0.87	1.42	0.99	1.72	1.29
2026	1.14	0.86	1.39	0.99	1.66	1.29
2027	1.13	0.86	1.37	0.98	1.59	1.29
2028	1.12	0.85	1.34	0.98	1.54	1.28
2029	1.12	0.85	1.32	0.98	1.49	1.28
2030	1.11	0.85	1.30	0.98	1.45	1.28
2031	1.10	0.85	1.28	0.98	1.41	1.27
2032	1.10	0.85	1.26	0.98	1.80	1.27

The average real increases in the total and the legal GDP become much higher than at constant exports: 1.12% and 0.85%, for the whole period - 8.1% and 6.1% (at investments' technical productivity 0.2).

At investment's technical productivity 0.5, the average real increases in the total and legal GDP become else higher: 1.32% and 0.98%, for the whole period – 9.6% and 7.1%. At investment's technical productivity 1, they become one and a half times bigger: 1.56% and 1.28%; 11.5% and 9.3% for the whole period.

Now, let exports grow by 1% every year due to price increases. The results for different investments' technical productivity are summarized in Table 3.

Table 3. The economic dynamics of Ukraine for 2020-2032 at constant input variables of 2019, exports grow annually by 1% due to price increases, with different investments' technical productivity obtained on our model

Years	Real increase in GDP, %					
	Investment's technical productivity 0.2		Investment's technical productivity 0.5		Investment's technical productivity 1	
	total	legal	total	legal	total	legal
2020	-5.50	-5.50	-5.40	-5.40	-5.24	-5.24
2021	-0.62	-0.56	-0.13	-0.31	0.42	-0.05
2022	1.15	0.97	1.61	1.23	2.08	1.51
2023	1.16	0.88	1.59	1.14	2.00	1.43
2024	1.15	0.87	1.56	1.13	1.90	1.43
2025	1.14	0.87	1.53	1.13	1.82	1.43
2026	1.14	0.86	1.50	1.12	1.74	1.43
2027	1.13	0.86	1.47	1.12	1.67	1.42
2028	1.12	0.85	1.44	1.12	1.61	1.41
2029	1.12	0.85	1.41	1.11	1.56	1.40
2030	1.11	0.85	1.39	1.11	1.51	1.39
2031	1.10	0.85	1.36	1.11	1.47	1.38
2032	1.10	0.85	1.34	1.11	1.43	1.38

The average real increases in the total and legal GDP become much higher than at constant exports: 1.12% and 0.85%, for the whole period – 8.1% and 6.1% (at investments' technical productivity 0.2).

At investments' technical productivity 0.5, the real increases in the total and legal GDP are else higher: 1.42% and 1.11%, for the whole period – 10.3% and 8.1%. At investments' technical productivity 1, they become even bigger: 1.57% and 1.4%, 11.5% and 10.2% for the whole period.

The generalized results are summarized in Table 4.

What conclusions can we draw from the analysis of Tables 1-4?

1) As expected, the real increases in total and legal GDP at higher investments' technical productivity are higher both at constant exports and when it grows.

2) When exports grow, the real increases in the total and in the legal GDP are much larger than with constant exports.
3) The real increases in the total and in the legal GDP are greater when exports increase due to price increases than when they increase due to increased physical volume. That is, the price of exports has a greater impact on GDP growth than its physical volume.

Table 4. Average real increases in the total and legal GDP of Ukraine for 2023-2032 obtained in our model

Real increase in GDP, %					
Investment' technical productivity 0.2		Investment' technical productivity 0.5		Investment' technical productivity 1	
total	legal	total	legal	total	legal
Exports are unchanged					
0.35	0.13	0.55	0.24	0.72	0.51
Exports grow by 1% annually due to the volume					
1,12	0,85	1.32	0.98	1.56	1.28
Exports grow by 1% annually due to the price					
1,12	0,85	1.42	1.11	1.57	1.40

These are accurate conclusions for Ukraine. For other countries, it is necessary to modify the model according to their economic differences. But even without modification, we can use the conclusions obtained for Ukraine. For developed countries, the conclusions obtained for high investments' technical productivity are applicable, for retarded – for low technical productivity of investments. In countries less open to the outside world, the impact of exports is expected to be smaller.

If the model is good, one can use it for many tasks. We used our model both for retrospective analysis of the dynamics of the Ukrainian economy and for specific forecasts. Thus, we identified the most influential factors for the development of Ukraine (Vasylenko, 2015), we studied the Ukrainian economy behavior during inflation and devaluation (Vasylenko, 2016). Keynes's hypothesis about the usefullness of low inflation in Ukraine does not work – any inflation and devaluation is harmful. We identified the conditions for successful investment in Ukraine in terms of government and far-sighted business interests (Vasylenko, 2020), we appreciated the impact of the shadow activity on the economic development of Ukraine (Vasylenko, 2015b) etc. In the near future, we are going to use it to solve problems: to analyze the reasons for the decline of the Ukrainian economy in 2012-2019, to find the limits of economic development lending without a financial crisis, etc.

5. Forecast for 2021-2025

In our forecast for 2020, the legal GDP should have decreased by 10.6%. In fact, it fell by only 4%. Why were we so wrong? Because the forecast was based on a 13.2% decrease

in exports provided for in Consensus Forecast (Impact of COVID-19 on the economy and society – Post-pandemic development. Forecast, 2020). In fact, it decreased by only 4.5%, so GDP in 2020 decreased by 4%.

Considering this discrepancy, we will increase the volume of exports and imports at the median level of the Consensus Forecast (Impact of COVID-19 on the economy and society – Post-pandemic development. Forecast, 2020) by 10% in the forecast for 2021-2025.

We took the rest of the values of input variables (hryvnia exchange rate, devaluation, inflation, etc.) at the median level of the Consensus Forecast (Impact of COVID-19 on the economy and society – Post-pandemic development. Forecast, 2020). The Consensus Forecast does not specify how exports and imports will change. Let us assume that their prices will grow by 1% annually, and the rest of their changes will occur due to changes in their physical volumes so that, starting in 2021, as stated in the Consensus Forecast, exports grew by 7%, 7.3%, 7.1%, 5.5%, 3.7%, and imports – by 20.5%, 10.5%, 5.3%, 5.7%, 4.1%, 7.83%. All four types of investment are taken into account in the ratios that were in Ukraine in 2019. Similarly, loans are taken into account.

Our result does not coincide with the Consensus Forecast (Impact of COVID-19 on the economy and society – (Post-pandemic development. Consensus forecast, 2020) (Table 5).

Table 5. The forecast of economic dynamics of Ukraine for 2021-2025 at median input variables but exports and imports 10% more median obtained on our model

| Years | Real increase at median input variables but exports and imports 10% more, % | | | | | | | | |
| | in GDP | | | wages | | total gross profit | | foreign trade balance, USD billion | |
	total	legal	Consensus	total	legal	total	legal	total	legal
2021	3.4	3.3	3.2	-1.9	-2.2	5.3	3.7	-3.2	-10.5
2022	4.7	4.2	3.5	2.9	2.6	6.1	6.8	-6.5	-13.8
2023	6.4	5.7	4.1	4.2	3.9	8.7	7.8	-5.1	-13.3
2024	2.8	1.5	4.5	2.2	2.0	4.1	2.1	-5.6	-14.3
2025	6.5	5.5	-	4.9	4.7	8.4	7.2	-6.4	-15.4

There are two main reasons for the inconsistency with the Consensus Forecast. The first is because the Consensus forecast does not account for the shadow reduction in exports and overall because it does not account for the shadow at all. Due to the Covid-19 pandemic, there will be a significant reduction in the cash flow from abroad from our 'earners', and possibly some other shadow dealings, thus significantly reducing the shadow portion of exports. Reducing the shadows also reduces the legal part.

Accounting for shadow flows is most important in the foreign trade. The legal foreign trade balance of Ukraine is highly negative – USD 10-15 billion. However, the whole export volume, as determined by the model, is a little less than the volume of imports, so we expect a rather less negative balance of USD 3-6 billion. This is explained by the fact that our model defines intermediate consumption as strictly necessary to produce

all goods (including intermediate goods themselves). Technical progress is constantly reducing the need for them. So the shadow import of the necessary intermediate goods is increasing less than the shadow exports, and sometimes even decreases. And since these goods constitute the lion's share of Ukraine's exports and imports, the foreign trade balance substantially improves, that is, its deficit decreases. If, at the same time, prices are exaggerated at public procurement, then the physical volume of these purchases decreases, and, consequently, the import of intermediate consumption goods, which is necessary for production, is further reduced. Therefore, the balance improves even more. Thus, **taking into account shadow transactions significantly improves the foreign trade balance.** This is very important for the National Bank.

The second reason is that the Consensus forecast is obtained by averaging several different forecasts across different models. Even if all the individual models are systemic, averaging the outputs makes the consensus forecast non systemic, because, for specific values of exogenous indicators, endogenous indicators take values that do not match any model. An example of this is in the Consensus forecast itself: the product of real GDP growth and the GDP deflator is not equal to the nominal GDP change each year. For example, the GDP in 2022 is 3,964x1.032x1.07 = 4377 billion UAH, and the Consensus forecast gives 4391.4.

As we can see, the rate of economic growth according to the median Consensus forecast is growing steadily. But, because it is not systemic, this growth does not correspond to the dynamics of input variables. The model calculates it according to this dynamic. With the median level of input variables accepted in the Consensus Forecast, the real increase in total and legal GDP increases to 6.4% and 5.7% respectively in 2023, fall to 2.8% and 1.5% in 2024. In 2025, while maintaining the trend of changes in the median input variables, the real increases will be 6.5% and 5.5%.

6. Optimization of the propensity to accumulate in the production of consumer goods when investing the first type

A) According to the criterion of the minimum payback period of investment in this product for an average of 15 years

The payback function of the first type of investment in consumer goods from the propensity to accumulate has a minimum with a propensity of 0.2. The minimum payback period is 0.216 years, while with a minimum possible propensity to accumulate 0.01, it is equal to 0.292 years, and with a maximum of 0.9 – 0.424 years.

B) According to the criterion of the maximum efficiency of investments of the first type in the production of consumer goods on average for 15 years

This function has a maximum at the same point (with a propensity of 0.2) – 28.4%; with a minimum propensity to accumulate, the efficiency of investments is 22.6%, with a maximum propensity – 15.5%.

But GDP growth at this point is 103%, and with the maximum propensity to accumulate – 122%. Therefore, the investor should set some compromise value of the propensity

to accumulate, for example, 0.3. Here, investment efficiency will decrease by 5%, the payback period will increase by 10%, and the growth of the real GDP in this product by 8%. With a propensity of 0.4, the efficiency of investment will decrease by 13%, the payback period will increase by 22%, and the increase in real GDP created in this product's production – by 13%.

Conclusions

1. It is impractical to study the economic dynamics on the highly aggregated models (of Solow, Harrod-Domar, etc.). They are inadequate to the real economy. Deviations from the real economy are so great that any economic dynamics in them become indistinguishable. The inadequacy of such models is proven by practice. The conclusions that have been obtained on them have either already turned out to be wrong (Harrod-Domar model) or will turn out to be such, or they cannot be applied in a particular economy (Solow model).

2. For studying the economy's dynamics under exogenous and endogenous influences, one has to build a sufficiently detailed causal model of a particular economy or group of similar economies, reflecting the economy as a closed system with positive feedback of the investment from incomes and economic growth from investment. The author built such a model of economic dynamics. It is of simulating type, so it is adequate to the Ukraine economy. To make the model suitable for other countries, you need to change its parameters and sometimes some of its parts according to their economic otherness. However, the general principles of our model building are valid for all countries.

3. We have changed the main determinant of economic growth in dynamic models. Instead of the amount of capital, regardless of its productivity, our model studies the impact of the investment of different productivity on economic growth.

4. Representation of investment as a share of production is not correct because production includes material costs that have nothing to do with investment.

5. It does not make sense to measure investment as a share of GDP because the shares of savings in gross profit, wages, and budget, formed from taxes, are significantly different.

6. Even if we determine the optimal share of gross savings in the country's gross adjusted disposable income (GADI), there is no agent who can use it; there is no source from which to select this optimal part. From this optimal share, it is impossible to move to the optimal shares for agents who own or manage investment sources: for households, for non-profit organizations serving households, and for the general government sector. Non-financial corporations direct all GADI to gross savings; financial corporations – about 100%.

7. In principle, it is impossible to determine the exact optimal share of savings due to the discount factor's uncertainty.

8. It is not expedient now, at a very high pace of technical progress, when forecasting for more than 15-20 years loses its meaning to find the optimal share of savings for a long period.

9. The theory of economic growth does not investigate the effectiveness of investment. To link investment to GDP growth, the author introduced the concept of technical productivity of investments, which measures their ability to change the rate of material or labor costs. We accepted that the technical performance of investments is 1 if the reduction of material or labor costs per unit of production equals the rate of increase in the active part of fixed assets. If technical productivity is equal to 2, then the reduction is twice as much.

10. Based on the technical productivity of investment, we derived the equation (not identity) of economic dynamics for investment of the first type.

11. To accurately determine the economic dynamics, the author developed an adequate causal simulation model, reflecting all the main direct, reverse, and cross-links in the economy, including the links between the main types of shadow economic activities and the legal sector. It provides significantly more extensive and interesting results than traditional models of economic growth.

    It allowed to determine the economic dynamics of Ukraine at different investments' technical productivity and at different levels of many factors that are not in the models of economic dynamics: physical volumes and prices of exports of final and intermediate consumption goods and imports of final, intermediate and investment goods, price and salary policy of the manufacturer of each product; price elasticity of supply and demand of export goods; the level of de- or revaluation, in- and deflation and the relationship between them; loan rate; norms of taxes and deductions; exchange rate; the degree of substitution of imports by domestic goods, the degree of over-or underproduction for each product, etc.

12. At higher investments' technical productivity, the real increases in total and legal GDP are higher.

13. When exports grow, the real increases in the total and the legal GDP are much larger than with constant exports.

14. The real increases in the total and the legal GDP are greater when exports increase due to price increases than when they increase due to increases in physical volume. That is, the price of exports has a greater impact on GDP growth than its physical volume.

15. We can use these specific conclusions obtained for Ukraine for other countries. For developed countries, the conclusions obtained for high investments' technical productivity are applicable, for retarded ones – for low investments' technical productivity. In countries less open to the outside world, the impact of exports is expected to be smaller.

16. The forecast of the economic dynamics of Ukraine for 2021-2025 is developed on this model.

17. It does not coincide with the official Consensus Forecast. The first reason - because the Consensus forecast does not account for the shadow reduction in exports Due to the Covid-19 pandemic. The second reason is that the Consensus forecast is obtained by averaging several different forecasts across different models. Averaging the outputs makes the consensus forecast nonsystem because, for specific exogenous indicators, endogenous indicators take values that do not match any model.

18. The biggest and most important difference between legal and shadow indicators is in exports and imports. The legal foreign trade balance of Ukraine is big negative - USD 10-15 billion. However, the whole export volume, as determined by the model, is a little less of the volume of imports, so we expect the rather less negative balance of USD 3-6 billion. **Taking into account shadow transactions significantly improves the foreign trade balance.** This is very important for the National Bank.

19. Our forecast of the economic dynamics of Ukraine for 2021-2025 is as follows: at the median level of input variables accepted in the Consensus Forecast, real increase in total and legal GDP increase respectively to 6.4% and 5.7% respectively in 2023, fall to 2.8% and 1.5% in 2024. In 2025, while maintaining the trend of changes in the median input variables, the real increases will be 6.5% and 5.5%.

20. In our model, one can set or optimize on one (maximum consumption for the period) or several criteria the propensity to accumulate in the production of any goods for any period. For example, the optimal value of the propensity to accumulate when investing the first type in the production of consumer goods, which is a compromise between the criteria for the minimum payback period and the maximum GDP growth per investment unit, on average over 15 years, is 0.4.

References

Accounts of institutional sectors of the economy for 2018. (2020). State Statistics Service of Ukraine. [Data set] http://www.ukrstat.gov.ua/ (In Ukrainian)

Acemoglu, Daron. (2008). Introduction to Modern Economic Growth. Princeton University Press. ISBN 9781400835775.

Acemoglu, Daron & Robinson, James. (2012). Why Nations Fail: The Origins of Power, Prosperity, and Poverty. NY: Crown Publishers.

Aghion, Philippe & Howitt, Peter. (1992). A Model of Growth Through Creative Destruction. Econometrica, No 60(2): p. 323-352.

Basu, N., Pryor R. & Quint T. (1998). ASPEN: A Microsimulation Model of the Economy. Computational Economics, No 12(3): p. 223-241.

Blaug, M. (1975). The Cambridge Revolution: Success or Failure? London: Published by The Institute of Economic Affairs.

Cass, D. (1965). Optimum Growth in an Aggregative Model of Capital Accumulation. Review of Economic Studies, No 32(3): p. 233-240.

Chang, Ha-Yun. (2016). Economics. Instructions for use. Transl. Andriy Lapin. Kyiv: Nash Format. ISBN 978-617-7279-42-5. (In Ukrainian)

Diamond, Peter A. (1965). National Debt in a Neoclassical Growth Model. The American Economic Review, No 55(5, Part 1, Dec): p. 1126-1150.

Easterly, William. (1997). The Ghost of Financing Gap The qhost of a nq-dead arowth model still haunts aid How the Harrod-Domar to developing countries. Growth Model Still Haunts Development Economics. The World Bank Development Research Group, August, http://documents1. worldbank.org/curated/ en/494271468739201862/pdf/multi-page.pdf

Frenkel, J., & Mussa, M. (1985). Asset Markets, Exchange Rates and the Balance of Payments. In R. Jones, & P. Kenen (Eds). Handbook of International Economics (Vol. I, Book 3) Amsterdam, N.Y, Oxford: North-Holland.

Giles, D.E.A. (1997). Causality between the measured and underground economies in New Zealand. Appl. Economics letters, No 4(1): p. 63–67.

Impact of COVID-19 on the economy and society - Post-pandemic development.

Consensus forecast. (2020). Ministry of Economic Development, Trade and Agriculture of Ukraine. https:// www.kmu.gov.ua/news/minekonomiki-oprilyudnilo-novij-konsensus-prognoz-na-2020-2024-roki (In Ukrainian)

Koopmans, T. C. (1963). On the Concept of Optimal Economic Growth, Cowles Foundation Discussion Paper, December.

Krugman, P. (2009). How Did Economists Get It So Wrong? The New York Times, September, Annex.

Lalitha, N. (2000). Unorganized manufacturing sector in the national economy: an analysis of its growth dynamics and contribution to national income. – New Delhi : National Council of Applied Economic Research.

Lasko, M. (2000). Hidden economy – an unknown quantity? Comparative analysis of hidden economies in transition countries, 1989–1995. Economics of transition, Oxford, No 8(1), p. 117–145.

Malinvaud, Edmond. (1995). Why Economists do not make Discoveries. Lecture on Xlth World Congress of the International EconomicAssociation, December, p. 18-22: Tunis-Tunisia.

Neumann, J. fon, Morgenstern, O. (1970). Game theory and economic behavior. - Moscow: Science (In Russian)

Nordhouse, W. & Moffat, E. (2017). A Survey of Global Impacts of Climate Change: Replication, Survey Methods, and a Statistical Analysis. Cowles foundation for research in economics Yale University Box 208281 New Haven, Connecticut 06520-8281. http://cowles.yale.edu/

Pindyck, R. (2013). Climate change policy: What do the models tell us? Journal of Economic Literature, No 51(3), p. 860-872.

Ramsey, F. P. (1928). A Mathematical Theory of Saving, The Economic Journal, No 38, p. 543-559.

Samuelson, P. (1947). Foundations of EconomicAnalysis. Cambridge, Harvard University Press.

Solow, R.M. (1956). A Contribution to the Theory of Economic Growth. Quarterly Journal of Economics, No 70, p. 65-94.

Vasylenko, Y. (1983). Optimization of the distribution of net income in collective farms. Izvestia of the Academy of Sciences of the USSR, Economic series, No 2, p. 86-99. (In Russian)

Vasylenko, Y. (2010). The economy at the devaluation and inflation. Kyiv: Synopsis, 142 p. (In Ukrainian)

Vasylenko, Y. (2014). Forecast of economic development of Ukraine. The Herald of the National Bank, No 12, p. 6-12. (In Ukrainian)

Vasylenko, Y. (2015a). Factors of economic development of Ukraine. The Herald of the National Bank, No 4, p. 24-35. (In Ukrainian)

Vasylenko Y. (2015b). The impact of shadow activities on the development of Ukraine's economy. Economics and forecasting, No 3, p. 89-103. (In Ukrainian)

Vasylenko, Y. (2016). Economic development model. Saarbrücken: Lambert Academic Publishing. 299 p.

Vasylenko, Y. (2021). Conditions for Successful Active Investment in Terms of the State and the Far-sighted Interests of the Business. Ekonomika. Vol. 100, No 1, p. 6-30.

World Economic Outlook Reports. (2020). IMF. [Data set] https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020