SCALAR PARAMETERS BEHAVIOR DYNAMICS OF ECONOMIC GROWTH MODEL

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The modern economic system is influenced by factors like technological innovation, globalization, and demographic shifts. Dynamic models are essential for analyzing economic growth, but understanding their internal mechanisms is crucial to avoid errors that could compromise results on new data. Adapting these models to address challenges like financial crises, climate change, and technological transformation is increasingly important. This study examines the dynamics of economic growth models, focusing on investments, human capital, and innovation, to identify key patterns over time and their alignment with significant events.

As a model, we will use the endogenous model of economic growth with foreign trade and investment and its modification with the division of the economy into sectors in the context of their interaction, which is described in detail in [1-3].

In the model, the main factors of production are private capital Kpr, public capital Kgov, human capital (knowledge) H, labor L and the variable factor R. Variable factor R in a single-sector production model is responsible for the land factor N. A modified Cobb-Douglas function of the form:

$$Yp=AKprKgovH\ N\ L\ 1-\alpha-\beta-\gamma-\varphi, \qquad 1)$$

where α – is the coefficient of elasticity of private capital, β – public capital elasticity coefficient, γ – human capital elasticity coefficient, φ – elasticity of the variable factor, in this case, land [2,3].

In the multisectoral model, the factor R depends on the sector. For the primary sector Yagr land is a factor, similar to the single-sector model. For the secondary sector Yind factor is the output of the primary sector Yagr. For the tertiary sector Yserv factor is the output of the secondary sector Yind.

For a multi-sector model, the production function takes the form:

$$Yp=A1Kagr\alpha1Kgov\beta1Hagr\gamma1\ \ N\ \varphi1Lagr\ 1-\alpha1-\beta1-\gamma1-\varphi1\ +A2Kind\alpha2Kgov\beta2Hind\gamma2\ \ Yagr\ \varphi2Lind\ 1-\alpha2-\beta2-\gamma2-\varphi2\ +A3Kserv\alpha3Kgov\beta3Hserv\gamma3\ \ Yind\ \varphi3Lserv\ 1-\alpha3-\beta3-\gamma3-\varphi3\ , \qquad 2)$$

wherein Yp=Yagr+Yind+Yserv, similarly Kpr=Kagr+Kind+Kserv and H=Hagr+Hind+Hserv, L =Lagr+Lind+Lserv.

The innovation sector generates new knowledge by the production function:

$$\Delta H=BKrdLrd\ 1-\upsilon\ , \qquad 3)$$

where Krd – capital raised in the innovation sector, Lrd – labor involved in the innovation sector, – capital elasticity in the innovation sector. Total capital in the economy Kfull can be found by the formula: Kfull=Krd+Kpr+Kgov, similar to labor: Lfull=Lrd+L .

Capital has been divided into private and public, and investment is made through aggregate savings, so capital dynamics can be expressed through three indicators: private sector capital intensity, public sector capital intensity, and aggregate savings per unit of labor [2,3].

The capital stock of the private sector grows through investment (domestic and foreign) and decreases through depreciation of fixed capital. In equation form, this can be written as:

$$kpr\bullet=iin+if-dpr+nkpr, \quad 4)$$

where kpr=KprL – capital intensity of the private sector, dpr – depreciation ratio of private capital, n – average growth rate of the employed labor force, iin=IinL – domestic investment per unit of labor, if=IfL – foreign investment per unit of labor.

The growth of public capital comes from taxes paid to the state budget, and the decrease, similar to the private sector, comes from capital disposals (depreciation). The equation for the capital intensity of the public sector is as follows:

$$kgov\bullet=g-dgov+nkgov+tx, \quad 5)$$

where kgov=KgovL – capital intensity of the public sector, g=GL – taxes per unit of labor, dgov – depreciation ratio for public capital, tx – net government international transfers. Whereby dpr+dgov=d.

Aggregate savings are increased by productive activity, taking into account their distribution between consumption and savings, and decreased by investment and tax payments. In mathematical terms, this is reflected in:

$$m\bullet=sAkprkgovhnN-(g+nm+iin+iout), \quad 6)$$

where m=ML – total savings per unit of labor, s – accumulation rate, nN=NL – land factor per unit of labor, iout=IoutL – external investment per unit of labor.

The complete single-sector model in general form [2,3]:

$$\{kpr\bullet=iin+if-dpr+nkpr,\ kgov\bullet=g-dgov+nkgov+tx,\ m\bullet=sAkprkgovhnN-g+nm+iin+iout,\ h\bullet=Bkrdl-nh. \quad 7)$$

For a multisectoral modification, the formula for the derivative of total savings per unit of labor is as follows:

$$m\bullet=A1LagrLkagr1kgov1hagr1nN1+A2LindLkind2kgov2hind2yarg2+A3LservLkserv3kgov3hserv3yind3-g+nm+iin+iout. \quad 8)$$

The above model allowed us to evaluate in detail the main characteristics of economic growth and establish the relationships between them. We conducted the modeling based on World Bank statistics [4]. The sample of countries amounted to 150 observations out of 217 available observations, excluding observations that did not have all the data necessary for modeling. The period was chosen as long as possible to study the dynamics depending on the length of the period. The analysis of the parameters was conducted in two areas: depending on the length of the period, i.e., models were built for the last 10 years to 62 years (full period) and depending on time (models were built for 10 years starting from 1960 in one-year increments).

Consider the parameter A, responsible for technological progress (Fig. 1).

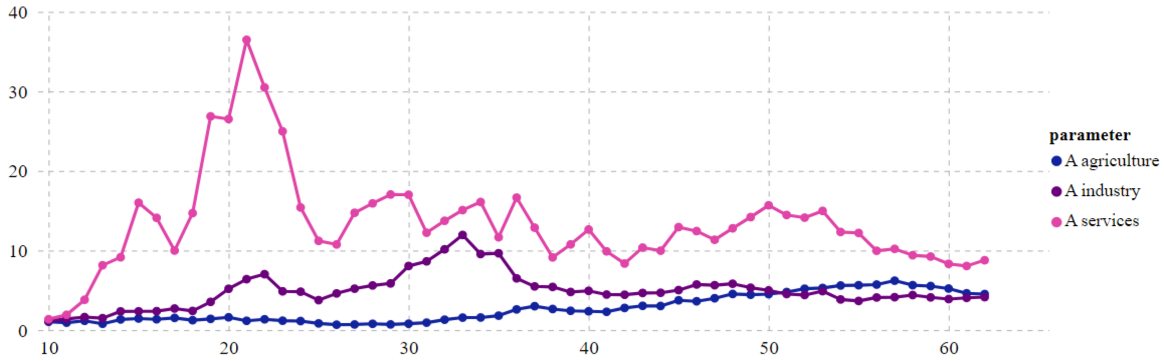

Figure 1 – Average parameter A by economic sector by period length

The value of the parameter *A* decreases and fluctuates less with the length of the period (Fig. 1) due to the effect of gradual adaptation of innovations and saturation of technological processes. In short time intervals, technological breakthroughs can have a significant impact on the economy, causing sharp jumps in productivity and capital intensity. However, over time, the effect of innovation is smoothed out as the economic system adapts to the new technology and the pace of technological progress stabilizes. Longer periods cover the phases of market saturation with new technologies, when growth becomes more uniform and the impact of individual innovation breakthroughs is less.

Parameter *A* is highest for the services sector, lower for industry, and even lower for agriculture (Fig. 1), due to the different nature and speed of technological innovation in these sectors. The services sector is often characterized by a high rate of change and the integration of new technologies, such as information and communication technologies, which contribute to significant shifts in productivity and efficiency. In industry, technological progress, while also important, requires more time to implement new technologies in production processes due to significant capital investment and equipment modernization. In agriculture, despite the gradual impact of new technologies, the pace of progress is usually slower due to the more conservative nature of production practices and the lower intensity of technological innovation.

Countries with lower knowledge growth rates tend to have higher capital elasticities, as their economic development depends more on capital investment than on innovation or technological progress. In such countries, increased investment in infrastructure, equipment, or production capacity has a much greater impact on productivity growth and economic output, as new knowledge and technologies are adopted more slowly. The lack of rapid accumulation of knowledge means that capital becomes the main driver of development, and each additional capital investment has a stronger effect on the economy compared to countries where growth is based on technology and knowledge.

Capital elasticities fluctuate much more in the period 1960-1990 (see Fig. 2 and 3) than in later periods, due to the economic and structural changes that characterized this era. After the Second World War, the world economy experienced a rapid recovery and industrialization, accompanied by rapid changes in investment and productivity. Additionally, this period included the oil crises of the 1970s, the ups and downs of industrial investment, as well as active processes of globalization and technological change. All these factors contributed to the high volatility of capital elasticity. In later periods, after the stabilization of global markets and the transition to a post-industrial economy, the rate of fluctuation of capital elasticity decreased due to the growing stability in capital investment and technological development.

The elasticity of capital is higher for underdeveloped countries in the medium and long run (see Fig. 2), as these economies have a large potential for productivity gains through capital investment. In these countries, even relatively small capital investments can lead to substantial productivity gains, as the baseline level of capital and technology is often low. Thus, the effect of new investments in production capacity, infrastructure, or technology is more pronounced than in developed economies, where the market is already saturated with capital. In the long run, growing economies may continue to exhibit higher capital elasticities due to rapid capital accumulation and the transition to more efficient technologies and practices.

The elasticity of public capital increased for middle-income countries in the 1980s and 1990s due to the large investments in infrastructure, energy, and education that underpinned their economic development during this period (see Fig. 3). These countries actively used public investment to modernize their economies and increase productivity, which led to an increase in the elasticity of public capital. For underdeveloped countries, a similar increase in elasticity occurred only in the 2000s and 2010s (see Fig. 2), when global initiatives such as international aid and investment programs aimed at improving infrastructure, health care, and education began to be actively implemented.

The higher the growth rate of human capital, the higher its elasticity, as the rapid accumulation of knowledge, skills, and qualifications increases the economy's ability to adapt to new challenges and opportunities. When human capital grows rapidly, each additional investment in education, training, or innovation brings greater economic benefits by increasing labor productivity and facilitating the adoption of new technologies. In this case, the economy gains more from human capital, as highly educated and skilled workers are able to use resources more efficiently, create innovations and ensure sustainable growth.

The elasticity of human capital is higher for highly developed countries regardless of the length of the period (see Fig. 2), as these countries have well-developed education, health care, and training systems that allow for efficient use of human resources. In such economies, investments in human capital, such as education, training, and innovation projects, are quickly translated into productivity growth and the adoption of new technologies. This impact is stable and long-lasting, as the high level of knowledge and skills of the workforce constantly supports the economy's competitiveness in the global market, regardless of the short or long term.

The decline in the elasticity of human capital in the 1980s and 1990s (see Fig. 3) was driven by several factors, including economic crises and structural changes in the global economy. During this period, significant economic restructuring took place, including the transition to a post-industrial economy and the automation of production, which reduced the demand for traditional jobs, particularly in the industrial sector. In addition, financial instability and budget cuts in many countries have led to limited investment in education and training systems. This reduced the rate of accumulation of new knowledge and skills, which directly affected the elasticity of human capital, as economies did not reap as many benefits from investments in human resources.

The elasticity of the land or natural resource factor is much higher for underdeveloped countries in the long run (see Fig. 2), as these economies have large untapped resources that can generate significant economic growth if they are used efficiently. However, this elasticity has declined in recent decades as many underdeveloped countries have reached a certain level of resource exploitation and are also facing constraints from environmental problems and natural resource depletion. At the same time, highly developed countries that use innovative technologies and efficient resource management methods have achieved a more stable and less volatile use of natural resources, which reduces their elasticity. As a result, the elasticity of the land or natural resource factor in underdeveloped countries is currently lower than in highly developed countries (see Fig. 3).

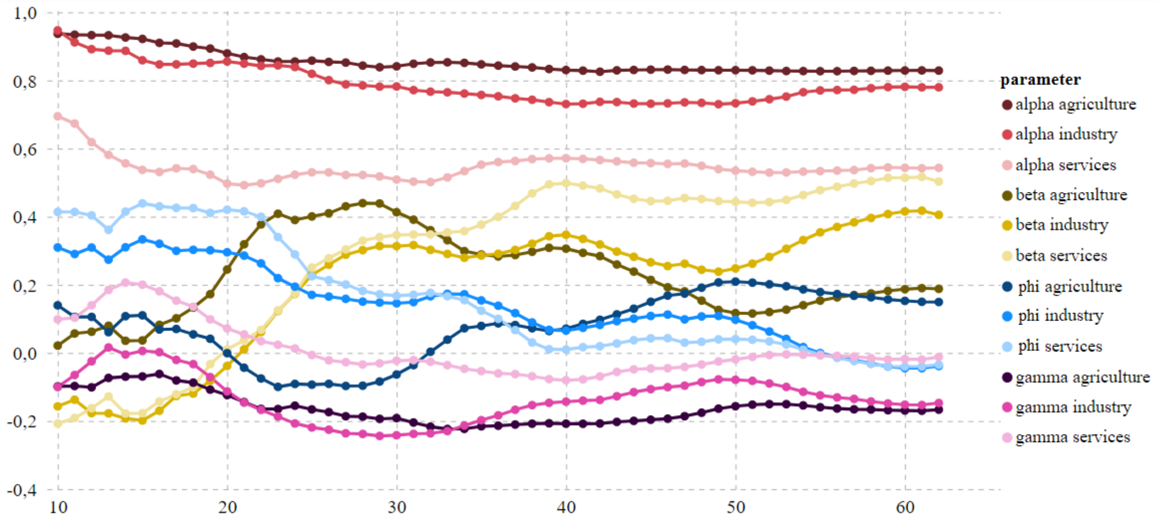

Figure 2 – Average factor elasticity parameters by economic sector by period length

The elasticity of private capital is much higher for agriculture and industry than for services (Fig. 2), as these sectors are often characterized by a high need for capital investment to modernize equipment, infrastructure, and processes. In agriculture and industry, significant investments can significantly increase productivity through the introduction of new technologies and modernization of production facilities. In contrast, the service sector, where capital investment has a smaller direct impact on productivity due to the lower need for physical inputs and equipment, shows a lower elasticity of private capital.

As for public capital, its elasticity is higher for services in the long run (Fig. 2), as investments in infrastructure, education, and health care can generate significant benefits and efficiency gains in services over time. In the short run, however, the elasticity of public capital in this sector may be lower, as rapid changes in public spending may have less of an impact on short-term outcomes.

The elasticity of human capital is highest in the services sector (Fig. 3), as high levels of education and training in this sector significantly increase labor productivity and innovation potential, making human capital particularly important for the development of services.

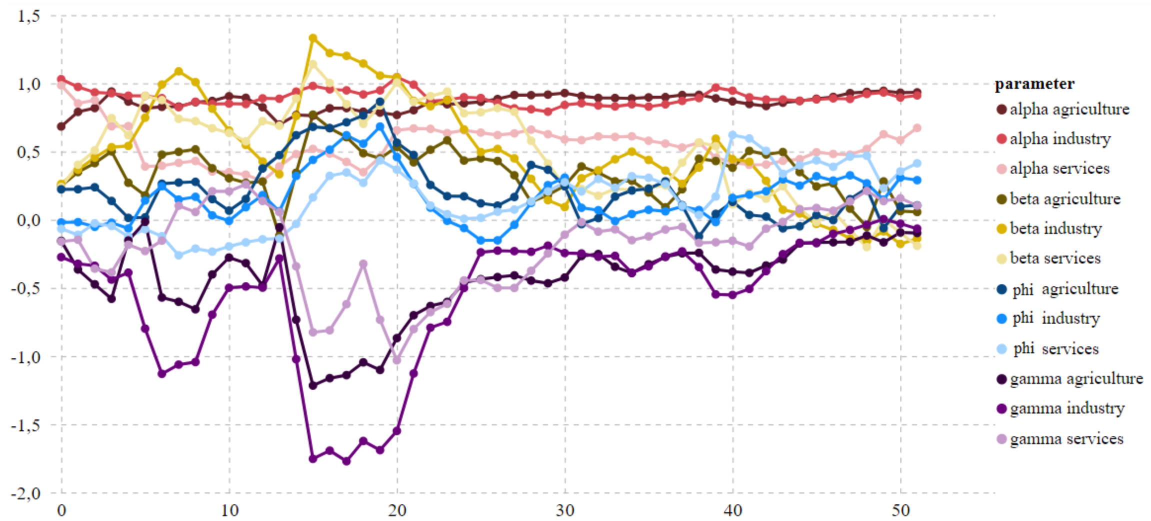

Figure 3 – Average parameters of elasticity of production factors by economic sector over time

Over time, the elasticity of private capital and human capital increases (Fig. 3) due to the accumulation of experience, improved technology, and increased resource efficiency. Private capital becomes more adaptive as investments in new technologies and modernization of production facilities yield significant productivity gains. Similarly, human capital becomes more elastic over time due to advances in education and training, allowing workers to use new knowledge and skills more effectively. However, the elasticity of public capital decreases (Fig. 3) as initial investment in infrastructure and public services reaches saturation and its impact on economic growth diminishes. Once a baseline level of infrastructure and social services is reached, additional spending does not generate as much productivity gains or economic impact as in the first stages of investment.

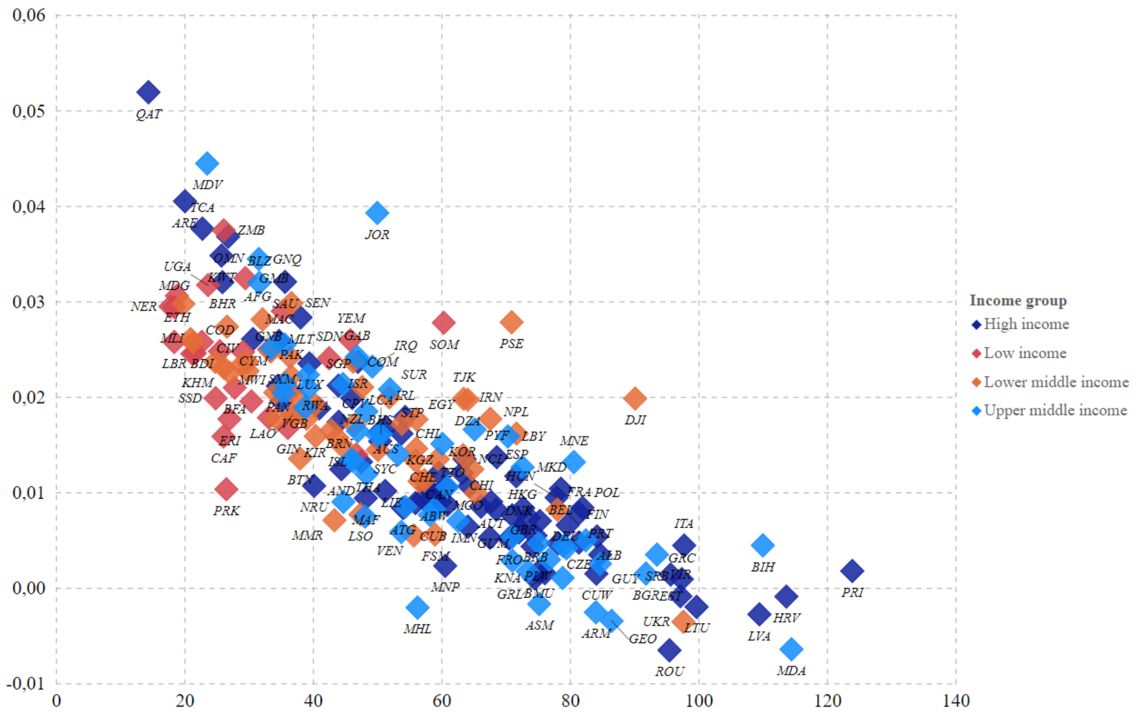

Figure 4 – Dependence of the parameter n on the growth rate of human capital per unit of labor

Population is growing faster in underdeveloped countries, reinforcing the negative correlation between population growth and human capital per capita (Fig. 4). In such countries, where education and training systems already face limited resources, rapid population growth overwhelms these systems, which negatively affects the quality of education and training. As a result, the growth rate of human capital per capita is slowing down as more people are spread over fewer resources that cannot keep up with the high level of learning and skill development. This creates a vicious circle where rapid population growth in underdeveloped countries hinders the effective development of human capital, which in turn can hinder economic development and reduce the potential for further improvements in quality of life.

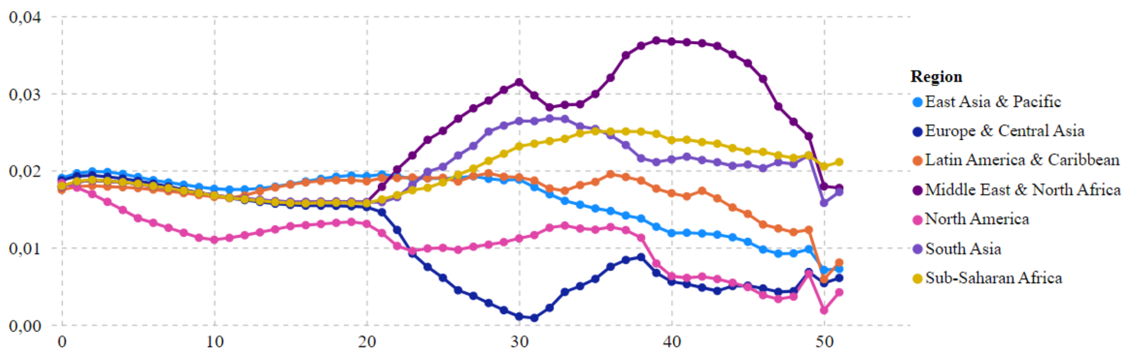

Figure 5 – Average parameter n by region by time

Demographics depend on a number of key factors, such as the level of urbanization and quality of life (driven by economic development), health care and access to it, education, social and pension provision, and cultural characteristics. For example, underdeveloped countries, mainly in

Africa and parts of Asia, are facing high population growth rates, often exceeding 2% per year, due to high birth rates and declining mortality. In comparison, developed countries in Europe and North America are experiencing much lower population growth rates or even population stagnation, due in part to low fertility and aging populations. Central and South America, as parts of Asia, are experiencing average growth, which is declining as living conditions improve and fertility rates decline (see Fig. 5).

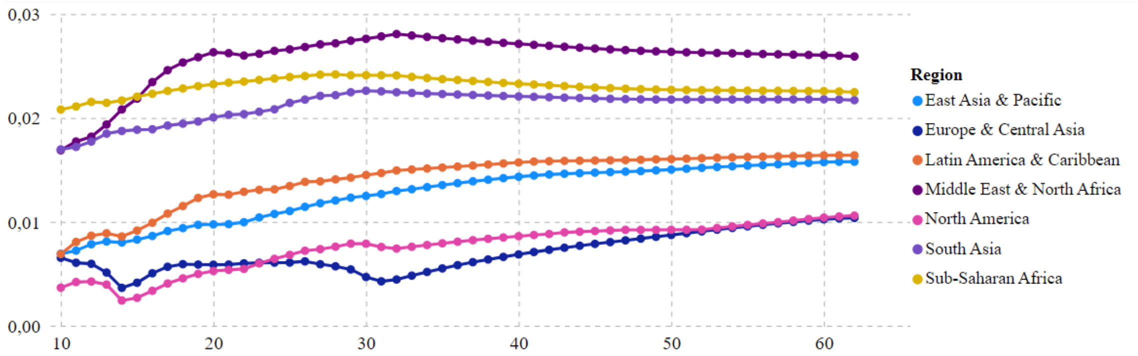

Figure 6 – The average parameter n by region by the duration of the period

Population growth rates tend to decline (decrease) in all regions of the world, due to global demographic changes. In developed countries, this process is already clearly visible, as low fertility and aging of the population lead to stabilization or even decline in population size. At the same time, in underdeveloped countries, population growth rates are also gradually declining, thanks to improved living standards, access to health care and education, which affects the decline in fertility (Fig. 6).

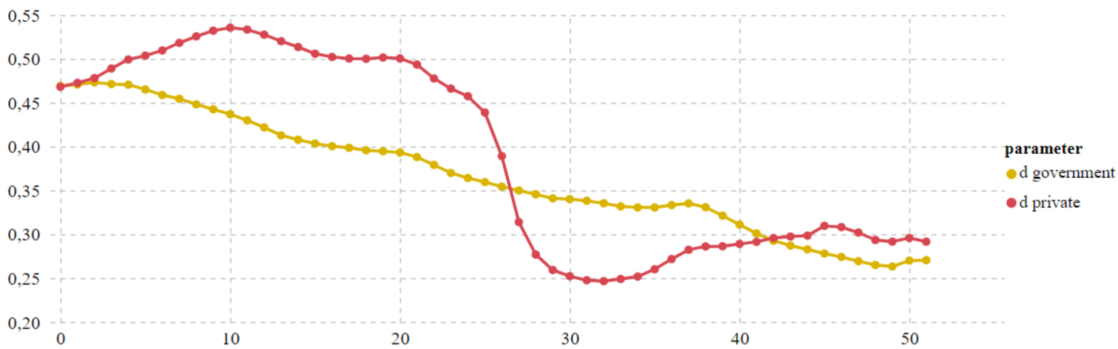

Figure 7 – Average parameter d by region by time

As for capital depreciation, this indicator is gradually decreasing (Fig. 7) due to several important factors related to technological progress and changes in the structure of the economy. Modern technologies make it possible to create more durable and efficient capital assets, which reduces their physical wear and tear and the need for replacement. In addition, the growing share of intangible assets, such as information technology, patents, and innovative solutions, which are subject to less physical depreciation than traditional production assets, contributes to the overall decline in depreciation. The reorientation of the economy to more technology-intensive sectors, where capital depreciates more slowly, also plays a significant role in this process.

There are cyclical fluctuations when the depreciation rate of the private sector exceeds that of the public sector and vice versa (Fig. 7). During periods of economic recovery and increased private investment, enterprises actively modernize and replace equipment, which leads to higher depreciation costs in the private sector. In contrast, during economic downturns, the private sector may reduce investment and delay asset renewal, which reduces its depreciation costs. To summarize, these fluctuations are related to different economic conditions, government policies, and cyclical changes in investment activity.

The savings rate for highly developed countries is significantly higher than that of underdeveloped countries due to higher income levels, more stable economic conditions, and a developed financial infrastructure. Highly developed countries have greater opportunities for capital accumulation due to high levels of economic stability, access to financial instruments and savings programs, and cultural and social norms that encourage savings. In contrast, in underdeveloped countries, limited incomes, economic instability, and insufficient access to financial services prevent significant savings from being generated. These resource constraints and high levels of consumer spending in such countries reduce their ability to accumulate capital, which affects their economic development and investment activities.

In order to improve the economic model based on the analysis, two key factors should be taken into account: cyclical parameters and parameters with constant dynamics. First, in order to more accurately reflect real economic conditions, it is necessary to take into account cyclical fluctuations of parameters such as the level of depreciation of private sector capital, which behaves according to the phase of the economic cycle. Secondly, for parameters with constant dynamics, such as decreasing depreciation of public capital or decreasing population growth, it is important to integrate long-term trends into the mathematical model, i.e., to dampen certain factors. This will allow the model to better predict the future behavior of the systems under study.

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ДОСЛІДЖЕННЯ СИСТЕМИ ЗАХИСТУ КОРПОРАТИВНИХ ДАНИХ ЗА ДОПОМОГОЮ ІМІТАЦІЙНОГО МОДЕЛЮВАННЯ

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Сучасні вимоги цифрової ери сприяють перебудові інформаційних систем і змушують компанії приймати нові стратегії для вирішення проблем інформаційної безпеки. Окрім переваг (наприклад, скорочення часу на підготовку та представлення корпоративної інформації, автоматизації виконання поточних операцій, підвищення точності для кращої зовнішньої звітності), використання IT несе нові виклики (наприклад, підвищені ризики витоку даних, порушення конфіденційності корпоративних даних, фішинг, електронне шахрайство, видавання себе за іншого та інші проблеми інформаційної безпеки) [1].

Інформаційні системи компаній і підтримуючі бізнес-процеси можуть бути інтегровані лише через набір основних характеристик інформаційної безпеки. Тобто, будь-яка система безпеки повинна забезпечувати конфіденційність, цілісність, доступність та зберігання оброблених даних. Це відповідає концепції CIA [2], яка була запропонована ще в 70-ті роки минулого сторіччя, але згідно з сучасними дослідженнями залишатиметься унікально актуальною для фахівців з безпеки і продовжуватиме служити точкою відліку в управлінні безпекою [3].