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The Impact of Supply Bottlenecks on Investment Efficiency[1]

Introduction

There are thousands of production processes in the economy, and in many of these we can probably identify as supply bottlenecks. It can be assumed that most of them are caused by changing demand structure or increased demand, neither of which can always be adjusted by substitution, export, or import. When such adjustments prove to be insufficient, investments in fixed assets are necessary. In this article, we will examine the impact of physical capital investments on economic growth. Investments are designed to mitigate or eliminate imbalances. An economic imbalance consists of many bottlenecks, which is why this article could very well be titled "The impact of supply imbalance on investment efficiency."

We will examine the impact of investments in physical capital on production growth and will try to describe to what extent this growth depends on the bottleneck (imbalance) that preceded the investment. The investment has overcome this production bottleneck. The investment decision to deal with economic disequilibria is enhanced by education (Schultz 1975, p. 843). Therefore, we will treat our model as an endogenous growth model.

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[1] The theoretical part of this article is the improved and condensed version of the theoretical section of our article in Polish (Sztaudynger and Sztaudynger 2019). A new concept of the supply gap was added. In the empirical part of the article we use a different growth model. We eliminated the quasi-identity relationship between the increase of the investment/output ratio and GDP growth and replaced it with the level of the investment/output ratio.

We would like to thank Paweł Baranowski, Michał Majsterek and Wojciech Zatoń, University of Lodz for productive discussions.

We theorize that the more a bottleneck slows down production, the more production will increase as a result of the investment[2]. Taking the construction of a road as an example, the larger the traffic jams there were before its construction, the greater the effect will be of putting it into service. Such regularity occurs on a single investment scale, but will it be observed on a macro-scale by examining the growth of gross domestic product (GDP)?

The concept of the study was developed while analyzing the effects of infrastructure projects. In this article, we try to relate the problems that are typical of infrastructure investments to the total investment in fixed assets in Poland (using annual data from the 1990s to 2019).

The discussion about the factors of economic growth has a long tradition, and it will most certainly continue. Despite the ambiguity of the concept, economic growth is widely regarded as an important criterion for a good, effective, and efficient economy and its institutions, which is why economists pay so much attention to it (see also Acemoglu 2012, p. 545[3], and Akcigit 2017, pp.1736–1737).

Because the only creator of new value in the economy – man – is evolving, the economy and the factors determining its growth are also changing. Moreover, due to the infinite complexity of man and the motives behind his behavior, including behaviors at work, creating a simplified model that reflects his role in the economy is an enormously difficult task. This is why it is important to consider the relationships between individuals and the social skills necessary for interaction and cooperation in groups.

Why is the economy growing? Why do employees increase their productivity? Our answer is that it is because they increase their knowledge and skills. In recent decades, greater importance has been attached to the ability to cooperate and improve social relations, and human capital and social capital appear with greater regularity in research on growth factors.

The increase in working efficiency occurs not only through education, patents, *learning by doing*, and the spread of knowledge but also through employees adapting to harmonized economic structures and thus turning investments into fixed capital. The increase in work efficiency also occurs as a result of technical progress, which is supported by the new, increasingly more modern, and efficient generation of fixed assets created through investments. Man's role is also to allocate investments as accurately as possible and then to use them creatively – creative in the sense that investments most often change, improving both the production process and the working environment of employees. We bring

[2] This approach is slightly similar to the 'plucking model', which was proposed by Friedman in 1964. M. Friedman (1993, p. 171) wrote that the magnitude of an expansion is "…related systematically to the magnitude of the succeeding contraction". He "…suggested a model of business fluctuations that stresses occasional events producing contractions and subsequent revivals rather than a self-generating cyclical process".

[3] "Economic growth continues to be one of the most relevant and exciting sub-areas of economics. (…) The problem of economic development remains a major one for humanity at large and for economics as a science" (Acemoglu 2012, p. 545).

up these rather obvious matters because investments are often thought of as an independent growth factor, and it tends to be forgotten that without man there would be no influence at all.[4]

In this article, we will focus on investments in fixed capital – on improving the skills and efficiency of employees thanks to modernized machines and devices and on extensive economic infrastructure. We will analyze the effects of the unbalanced structure of fixed assets resulting in the so-called bottlenecks.

In growth models, the effects of investments in fixed capital depend on their value. These effects occur in the current year or with an annual delay, and they usually do not depend on what was happening in the economy prior to the investment.[5] In particular, the effects of investments in these models do not depend on whether the purpose of the investment was to eliminate the bottleneck in the production process or how much the bottleneck slowed down production.

If we look at it from this point of view, it appears that an increase in employee performance depends not only on employees being equipped with machines and devices but also on the accuracy of locating investments to eliminate bottlenecks. These decisions are not related to a single employee and his workplace being provided with machinery and equipment. They are not related to factors affecting the performance of a single employee. Decisions regarding the elimination of bottlenecks are made from the level of the enterprise to the level of the entire national economy. We can state that the work efficiency of each employee depends on how the head of the company uses his potential in the company and how accurately his superiors allocate investments intended to eliminate bottlenecks. We hypothesize that the effects of investments depend not only on their size but also on the extent to which the investments eliminate the bottleneck.

In the article "Economic growth and investments: The role of bottlenecks" (2019), we verified another hypothesis – that the effects occur gradually in the first few years after the investment (e.g., structure matching, learning by doing). However, the verification was poor and was confirmed only for the period of the 1980s, with dummy variables describing the transformation from central planning to a market economy.[6]

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[4] P.M. Romer emphasizes that the source of technological progress is people's actions (Romer 1994, p. 12): "Technological advance comes from things that people do." A. Lincoln (1861) spoke in a similar way: "Labor is prior to, and independent of, capital. Capital is only the fruit of labor, and could never have existed if labor had not first existed."

[5] In GDP statistics, investments are defined as investment outlays and not as completed investments. Supply-side investments are more closely related to the increase in GDP from the supply side. Many investments are spread over several years. This makes economic growth dependent on investment outlays from previous years.

[6] In many previous estimates dating back to the 1980s, the results largely depended on the path through the transformation hole. The estimates can be made in several ways, but as a consequence, the results are ambiguous. To avoid this, we decided to skip the transformation period of the early 1990s and start estimating the model in the mid-1990s.

1. Bottlenecks in the economy

"Bottlenecks are generally recognized as some resources or utilities, which heavily limit the performances of a production system" (Wang, Zhao, Zheng 2005, p. 349). A bottleneck is a point of congestion in a production system.

There are two ways to identify bottlenecks: direct identification (Jershov, Sadykov, Sztaudynger 1987; Sztaudynger 1990) and indirect identification. Direct identification is finding the one factor that is the bottleneck. From the point of view of managing a company and eliminating a bottleneck, such precise identification is crucial. Indirect identification is when we are not trying to indicate the factor that limits the optimal production but simply observe the dynamics of lag production as a proxy for supply disequilibrium.

1.1. A fixed assets bottleneck at the company level

We shall try to define a bottleneck in the production process at the enterprise level. A bottleneck is one of the production factors that limits the volume of production. This definition is not completely accurate, however, because it does not specify that it refers to optimal production based on the criterion of the company's activity (e.g., gross value added). Therefore, it is necessary to specify what the optimal production depends on. Optimal production is dictated by the cost structure, the price structure, and the demand structure.

If the production structure (a derivative of the structure of fixed assets and employment) is adjusted to the structure of demand in such a way that the factors of production are highly utilized, then the production is optimal[7]. If one or more factors of production are not fully used, then the production is not optimal. It is not optimal because this factor of production is not highly used and because of the costs associated with it. The existence of a bottleneck always slows down the growth of the enterprise's gross value added.

We described the supply bottleneck above as determined by the least common production factor. This bottleneck is usually eliminated by investing in fixed assets.

Demand reductions occur most often when the structure of demand changes. For example, the demand for internal combustion engines is decreasing, while the demand for electric motors is increasing. It is then necessary to invest in fixed assets to increase the production capacity of electric motors. Thanks to investments in fixed assets, the production structure may adapt to the exogenous structure of demand, increasing the production of electric motors. The effectiveness

[7] The definition given by Lawrence and Buss is similar: "A shortage of one factor, which limits the possibility of achieving optimal production, is called the bottleneck of the production process. (…) Bottlenecks naturally arise when firms organize capacity design and demand volumes to (…) maximize profits." An economic bottleneck is "that workstation which most severely (…) limits profits" (Lawrence and Buss 1995, p. 355).

of investments depends on how big the economic slowdowns (bottlenecks) were before making these investments and how accurate the structure of investment allocation was.

1.2. Bottlenecks at the macroeconomic level

We will consider the supply, physical capital bottlenecks at the macroeconomic level. For our purposes, we understand supply bottleneck as one physical capital element which heavily limits the performances of GDP (see also *Macro structural bottlenecks*…. 2010).

We will only deal with the indirect identification of bottlenecks. We claim that when added production is characterized by low dynamics, it is because somewhere there is a bottleneck. When this dynamics is high, bottlenecks do not occur. High dynamics can also be caused by the elimination or widening of the bottleneck.

A bottleneck in the production process is always structural in nature; its occurrence is the result of a mismatch between the demand structure and the structure of the company's production capacity (and the factors of production that determine it). We assume that the demand structure is exogenous. Therefore, we have to ask the question: "How can supply and its structure be adapted to exogenous demand and its structure?"

Zatoń asks (e-mail, 3.08.2019): "What will happen if the demand decreases in the next period"? Employment will adapt, but fixed assets will remain unused, and after this period, the next increase in demand should not encounter bottlenecks (eventually, bottlenecks will not be so narrow). So, from the point of view of bottlenecks, not every GDP growth will have the same meaning. In this case, the accelerating growth would not be the result of investment.[8] This model does not take this into account.

We are trying to add something more. Without questioning the human and social capital sources of economic fluctuations, we state:

1. The important causes of economic fluctuations are the emerging bottlenecks.
2. Bottlenecks slow down economic growth; a slow economic growth is an indicator of the severity of the bottlenecks. We propose estimating the macroeconomic bottleneck by the average, lagged GDP growth (or its deviation from the trend).
3. The narrower the bottleneck, the greater the GDP growth effect achieved thanks to the investments intended to eliminate it.

[8] For example, Russia suspends the import of Polish apples. Apple sales fall. Apples are sent to Japan and Canada. Eliminating the bottleneck in this way is not associated with investments and is not associated with the increased efficiency of typical investments. At most, investments that adapt sales to long-distance transport can occur here. The greater the reduction in demand, the greater the effect of unblocking the bottleneck. This is the full analogy.

In other words, we will examine economic growth that results from a specific imbalance indicator, which is the average dynamics of the economy in the last few years[9].

Do these points give a new possible economic explanation for economic fluctuations?

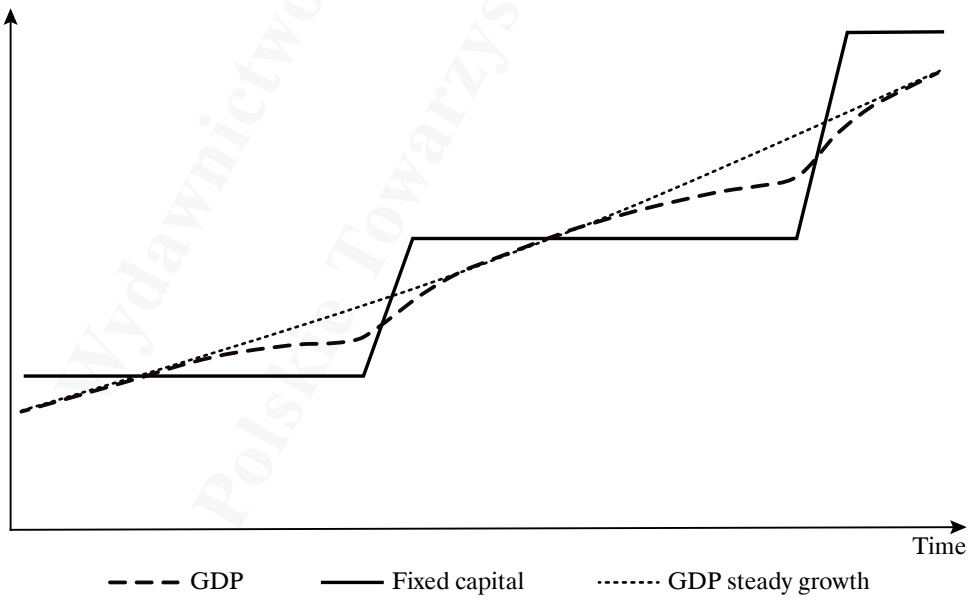
2. The problem of investment impact on growth and the role of bottlenecks

We will focus on the varying effect of investing in fixed capital during economic growth. We suppose that the production effects of investments depend not only on their size but also on the extent to which the investment eliminates the bottleneck in the process of GDP creation. We present our hypothesis in the two charts below. The first illustrates the level of GDP that is periodically slowed down by bottlenecks. The second depicts one bottleneck that slows down GDP growth before the investment and that accelerates as a result of the investment.

In Figure 1, we can see that when the level of fixed capital *K* is below the respective GDP level line, it is a bottleneck for the development of the economy.

Figure 1

GDP level and fixed capital

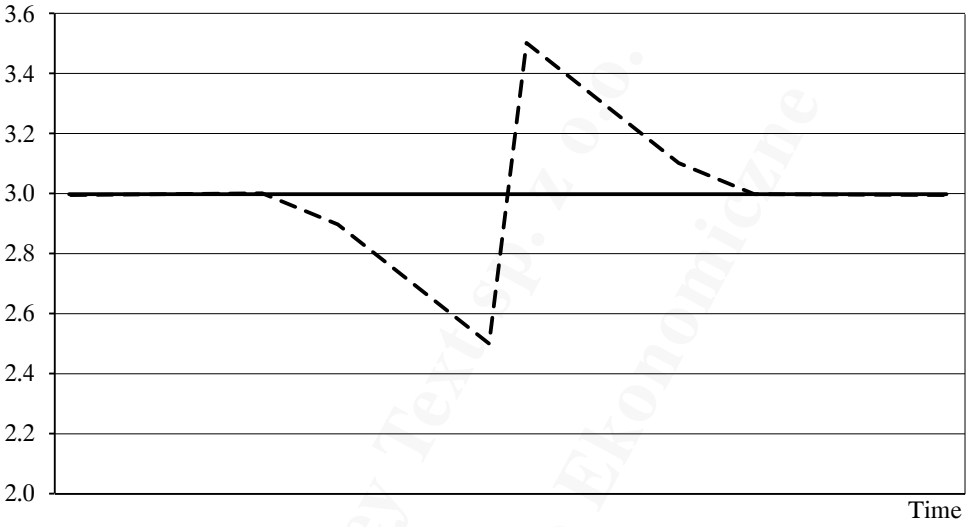


Source: own elaboration.

[9] Because the analysis is conducted at the macro level, we will only analyze the approximate identification of bottlenecks.

Figure 2

Steady GDP growth (straight line) and GDP growth changed by a bottleneck and a single investment (broken line) (%)



Source: own elaboration.

In Figure 2, the straight line shows the dynamics of a steady 3% GDP growth rate, while the broken line shows a decrease in the GDP growth rate as a result of a bottleneck and its acceleration at the end of the investment, which eliminates the bottleneck. The bottleneck build-up process and its elimination through investment can be divided into two phases (see Figure 2), as follows:

1. In the first phase, GDP growth occurs with initial fixed capital *K* and a gradually increasing shortage of this capital or increasing bottlenecks. When losses due to a deficiency of *K* grow to large proportions, under the pressure of diminishing efficiency (e.i., a bottleneck)[10], an investment is made.[11]
2. Depending on the limitations of the funds for investments, varying amounts of supply excess are generated by investments; they are in excess for shorter or longer periods.

After the completion of a given investment, the phase of gradually decreasing the excess of *K* and the transition to the new phase 1 begins. The excess of *K* does not accelerate growth; there is no relationship between excess factor of *K* and production dynamics; excess of *K* means that there are other restrictions on production growth.

It should be added that because the bottlenecks are varied, the effects of the investments that level them are also varied. These differences occur at the micro

[10] The pressure is of a technical and economic nature, but it is also often social and political (e.g., by influencing election results).

[11] It seems that this problem occurs especially in infrastructure investments.

scale, that is, at the scale of a single investment. At the macro scale, that is, the aggregate of all investments, differences in time may not be visible if the "average bottleneck" of all investments does not change significantly over time.

3. The modification of the Solow model with bottleneck identification

We will look at the production process and economic growth in the context of a crucial analysis tool, the Cobb–Douglas (CD) production function (Cobb and Douglas 1928; Douglas 1976)[12]. This function forms the basis of the neoclassical, long-term Solow growth model. We will use the dynamic version of the CD production function[13]:

$$G\dot{D}P_t = \dot{B}_t + \beta_1 \dot{L}_t + \beta_2 \dot{K}_t, \tag{1}$$

where $G\dot{D}P_t$ is the GDP growth rate, $\dot{L}_t$ is the employment growth rate, $\dot{K}_t$ is the fixed capital growth rate, and $\dot{B}_t$ is the total factor productivity (TFP) growth rate,[14] expressing man's development and improvement when creating new value in the production process.

Due to the significant empirical difficulties in calculating the value of physical capital at constant prices, we will modify the production function (1) and replace the fixed capital growth with the investment to GDP ratio[15]:

$$G\dot{D}P_t = \dot{A}_t + \alpha_1 \dot{L}_t + \alpha_2 \left(\frac{Invest}{GDP} \right)_t, \tag{2}$$

where *Invest* is the investment in gross fixed capital, *Invest*/*GDP* is the investment/GDP ratio, and $\dot{A}_t$ is the modified total factor productivity (TFP) growth rate.

Let us repeat: we hypothesize that the effects of investments depend not only on their size but also on the extent to which the investments eliminate the bottleneck (disequilibrium). In order to model this, we relate the α_2 parameter with a measure of GDP disequilibrium – the supply gap – *sug*, defined as follows:

$$sug_t = GDPpo_t / GDP_t, \tag{3}$$

where $GDPpo_t$ supply is a potential GDP approximated by a simple deterministic, exponential function of time:

$$GDPpo_t = \rho e^{\delta t}. \tag{4}$$

[12] For simplicity of recording, the random term is omitted.

[13] Also called the Solow–Swan model.

[14] Because the only factor that creates new value is a person, instead of calling total factor productivity TFP, it would be better to rename it "total labor productivity" or "indirect labor productivity" as opposed to labor productivity. TFP measurement problems are described i.a. by T. Tokarski (2009, pp. 27–37) and J.J. Sztaudynger (2005, pp. 17–18).

[15] Replacing the rate of fixed capital growth with the rate of investment is a common practice.

The dynamic supply gap can be expressed in the following form:

$$\dot{sug}_t = G\dot{D}Ppo_t - G\dot{D}P_t = \delta - G\dot{D}P_t, \tag{5}$$

where δ represents the trend supply component of growth, while $\delta - G\dot{D}P_t$ is fluctuation, a supply gap component of growth.

Let us assume that in model (2) the effect of investment α_2 depends on the disequilibrium (bottleneck) and α_2 is a linear function of the supply gap:

$$\alpha_2 = \alpha_3 \dot{sug}_t. \tag{6}$$

It leads to model:

$$G\dot{D}P_t = \dot{A}_t + \alpha_1 \dot{L}_t + \alpha_3 \dot{sug}_t \left(\frac{Invest}{GDP}\right)_t. \tag{7}$$

Because the $\dot{sug}_t$ definition includes $G\dot{D}P_t$ and explains $G\dot{D}P_t$ we lag GDP growth in order to avoid the vicious circle (*idem per idem).* To properly describe the supply gap role, it is essential to consider the supply gap with a several-year lag. The bottleneck effect occurs gradually, the investment decision and the investment process takes time[16] and they have a long-term character.[17] So, we lag the supply gap $\dot{sug}_t$ two or more years:

$$\dot{sug}_{t-i} = \delta - G\dot{D}P_{t-i}, \quad \text{i} = 2, 3, \ldots \tag{8}$$

and use average lagged supply gap:

$$\text{av}\ \dot{sug}_{t-i} = \delta - \text{av}\ G\dot{D}P_{t-i} = \delta - \left[1/(k-2)\sum_{i=2}^{k} G\dot{D}P_{t-i}\right], \tag{9}$$

where $\text{av}\ G\dot{D}P_{t-i} = \delta - \left[1/(k-2)\sum_{i=2}^{k} G\dot{D}P_{t-i}\right]$.

So, the lag av $\dot{sug}_{t-i}$ is the difference between the exponential trend supply growth and the average lagged GDP growth. It is a kind of rule about decreasing investments returns.

In models (1) and (7), employment dynamics describes the role of the employed person only in quantitative terms. The increase in the quality and complexity of work – the effectiveness of the employee – is expressed in models (1) and (7) by an exponential function of time and, indirectly, by investing in fixed capital. We will try to modify the production function by introducing the lagged GDP growth deviation from the trend that expresses a structural imbalance (bottleneck) in the economy. We will measure this imbalance globally and relate them to the bottleneck of the production process. As a result of these consider-

[16] At the beginning, disequilibrium occurs. Next, the investment decision is made, followed by the investment process. Finally, the fixed assets investment is introduced to production. This time is different for each investment. Thus, we must consider not a single lagged supply gap but the average, from years $t-2$ to $t-3$, and so on. The length of lag in the average av $\dot{sug}_{t-i}$ was empirically estimated.

[17] On the other hand, the one year lagged GDP growth is usually positively correlated with coincident GDP growth due to inertia.

ations, parameter α_2 is not a constant but a linear function of the lagged GDP deviation from the trend:

$$\alpha_2 = \alpha_3\left(\delta - \text{av } G\dot{D}P_{t-i}\right). \tag{10}$$

Substituting in the formula (9) as in (10), we obtain:

$$G\dot{D}P_t = \dot{A}_t + \alpha_1\dot{L}_t + \alpha_3\left(\delta - \text{av } G\dot{D}P_{t-i}\right)\left(\frac{Invest}{GDP}\right)_t. \tag{11}$$

This model shows the relationship between the investment/GDP ratio and the rate of economic growth. In the empirical part of the article, we will try to use the model (11).

We have made the following hypothesis: Investment efficiency depends on the scale of imbalances (bottlenecks) that are eliminated by this investment. The slower the economic growth preceding the investment, the greater its effect, i.e. the greater the acceleration of economic growth. At the macro scale, the range of imbalances can be measured by the lagged deviation of GDP growth from the trend.[18] If there has been an economic slowdown in previous years, we interpret this as being a result of increased imbalances (bottlenecks) in production, supply, and sales processes. If this is the case, the effectiveness of the investment that eliminates these bottlenecks will be substantial. We can also point out that the economic slowdown causes, among other things, a shortage of funds for investments, and this leads to only the most necessary and effective investments being made.

If there is a lack of fixed assets, they can be substituted in some situations, but this involves additional costs and reduces added production. Returning to the analogy of a road, if a road that is most convenient for us is heavily used (e.g., traffic jams after a slight increase in the number of users), we can take a different route. But other roads, the substitute ones, take longer to get there and are more time-consuming and less effective. In other words, there is an excess of fixed assets that creates a safety margin precisely because they are inferior, and their use is less efficient economically.

What is the essence of the investment process? Does it simply widen the bottleneck, or does it increase the margin of safety? If investments in fixed assets increased the safety margin, the relationship between investments and GDP could be observed only when the level of utilization of these investments is relatively constant. We hope that the estimation of the model parameters will help resolve this dispute. The phenomenon of a decrease in investment efficiency with decreasing imbalances (bottlenecks) can be described by a linear decreasing function (Figure 3).[19]

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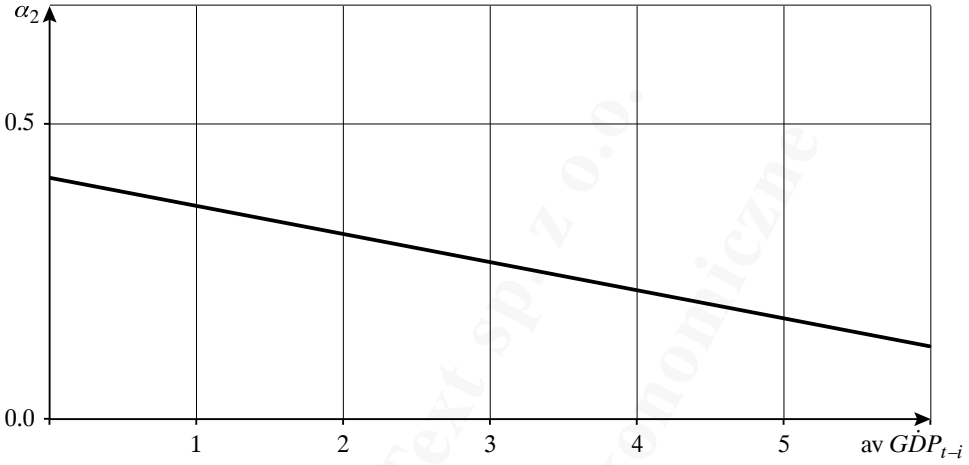
[18] The deviation of GDP growth from the trend in (11) is a bit like the concept of the error correction model (commentary from M. Majsterek).

[19] Thanks to M. Majsterek and P. Baranowski for comments on the role of investments.

Figure 3

Parameter α_2 in (10) depending on the average GDP growth in previous years



Source: own elaboration.

Therefore, we assume that high investment efficiency is preceded by growth slowdowns (bottlenecks) and, vice versa, relatively lower investment efficiency is preceded by dynamic GDP growth. Formally, our hypothesis involves treating the α_2 parameter in model (2) as a variable parameter presented in Figure 3.

We suppose that the fluctuation component – the supply gap – should be included in parameter α_2 in model (2); this parameter varies over time. We use the GDP dynamics in previous years[20] $G\dot{D}P_{t-i}$ to change that parameter. The lags were chosen by a trial and error method of empirical model estimation. "Economic theory rarely provides a basis for specifying the lag lengths in empirical macro-models" (Stigum 2003, p. 388; see also Holden 2005, p. 467, and Nerlove 1972). The delays were chosen, taking into account the *F*-statistic, *t*-statistic and adjusted R^2 values.

Model (8) can be treated as a modification of the endogenous growth model with a smoothing of economic fluctuations.[21] Economic fluctuations are the result of bottlenecks (imbalances) and are offset by effective investment allocations. This is achieved by the precise choice of technology and the innovation level as well as the territorial location.

[20] We omit $G\dot{D}P_{t-i}$ due to the inertia of economic growth and a positive correlation with current GDP growth. Moreover, between the occurrence of the bottleneck and the commissioning of the investment, which contributes to bottleneck being eliminated, there is time to make sure that the bottleneck is of a lasting nature, to gather funds to finance the investment, and in the case of construction and assembly works to carry out design works, taking into consideration the period from the start of the investment to its commissioning. This last argument does not apply to the investment in machinery and equipment.

[21] "…Education and experience influence the efficiency of human beings (…) to undertake action that appropriately reallocate their resources" (Schultz 1975, p. 827).

4. Results

The economic situation preceding the investment in year t is characterized by a moving average of GDP dynamics in the previous five years from $t-2$ to $t-6$. The investment efficiency parameter is a linear, decreasing function of such a defined economic situation (Table 1).

Table 1

GDP growth model with variable parameter α_2

Variables	Parameters	t-statistic absolute values	ADF
GDP growth	–	–	-4.2^{***}
Employment growth rate $_{t,\,t-1,\,t-2}{}^{a}$	–	–	-
Investment/GDP ratio	0.41	11.2	-3.5^{**}
$\frac{1}{5}\sum_{i=2}^{i=6} G\dot{D}P_{t-i}$ · Investment/GDP ratio	–0.046	5.6	-4.5^{***}
Dummy 2012–2016	–2.0	4.4	–

Adjusted $R^2 = 0.679$; $S_e = 0.9$; JB = 0.46; DW = 1.97; ADF (residuals) = –5.40; estimation period 1997–2019; equal lagged GDP weights.

[a]With this variable, no significant parameter estimations have been obtained so far.

Source: own calculations.

The $\hat{\alpha}_3$ parameter of the average GDP dynamics (from the previous five years) is significant at the level of 0.99. So, if in the previous five years the GDP growth was slow (2%), then the investment efficiency was more than twice as high than if the GDP growth had been rapid (6%) (α_2 being 0.32 and 0.13, respectively; see Figure 3).

The model presented in Table 1 can be considered a specific mapping of economic fluctuations. GDP lags by 2–6 years (on average, 4 years) are opposite to the stage of fluctuation to year t. Therefore, it can be interpreted as a specific 8-year "cyclical" regularity because $G\dot{D}P_t$ is negatively correlated with the "average" lagged – $G\dot{D}P_{t-4}$. This result confirms, to some extent, the presence of a fixed investment fluctuation similar to the Juglar cycle.[22] But the bottlenecks occur irregularly. The presented model shows a special kind of regularity in eliminating bottlenecks and reducing the disequilibrium.[23]

[22] This fixed investment cycle was identified in 1862 by C. Juglar (Morgan 1990, pp. 40–44). The length of the Juglar cycle is 7–11 years. In Juglar, by contrast, we only find the assumption that by simple elimination of the excesses the crisis will bring the system back to a state of stable (momentarily, at least) equilibrium (Besomi 2005, p. 32).

[23] This result seems to support the view that in the economy we do not observe regular cycle fluctuations: "Since no two cycles are alike in their details, some economists dispute the existence of cycles and use the word 'fluctuations'…" (Nagakawa 2008, p. 1). In reality, there is no regularity in the timing of cycles. "In many ways the term *business cycle* is misleading. (…) Most economists, however, believe (…) booms and recessions occur at irregular intervals and last for varying lengths of time" (Romer 2008).

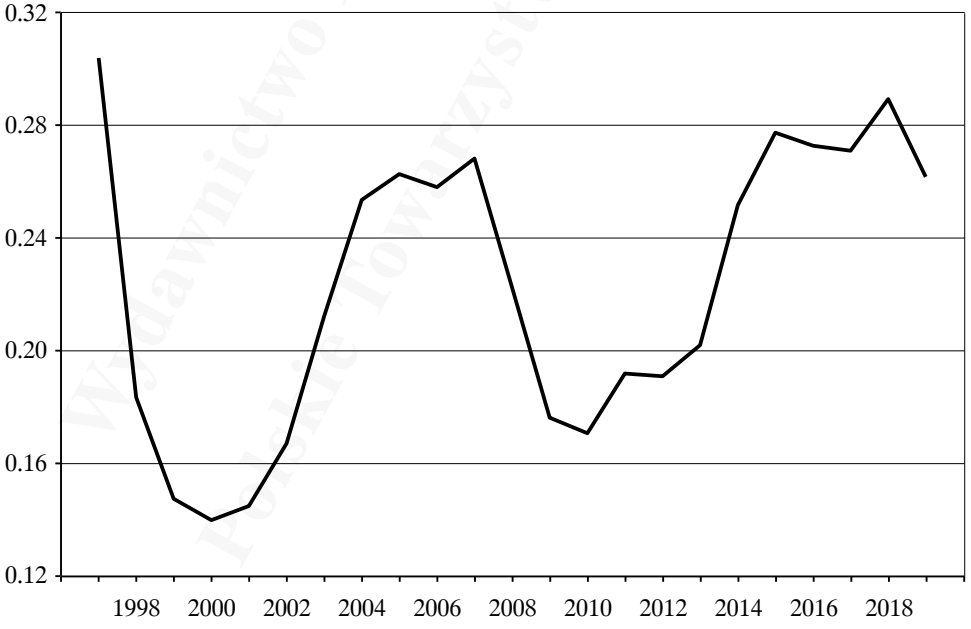
Fixed capital investments are unsystematic and irregular, happening every once in a while. They are far from having a regular character or cycle. However, according to the result of our estimation, as a reaction to investments, economic growth follows a specific pattern related to the preceding imbalance. For example, in the basic equation, as a result of the slowdown of GDP growth in year $t - 2$ by 1 pp, we get:

- an increase in the α_2 parameter in the years from t to $t + 4$ equal to 0.01 and
- an increase in the GDP growth in the years from t to $t + 4$ in the range 0.2 pp each, jointly by 1 pp.

In the article, we tried to confirm the validity of the hypothesis that the effects of investment depend not only on the investment/GDP ratio but also on the extent to which the investment was preceded by a bottleneck characterized by the average GDP dynamics of the previous five years (from $t - 6$ to $t - 2$). The result is described by the formula:

$$\hat{\alpha}_2 = \hat{\alpha}_3\hat{\delta} - \hat{\alpha}_3 \quad \text{av}\, G\dot{D}P_{t-i} = 0.41 - 0.046 \cdot \left(0.2\sum_{i=2}^{i=6} G\dot{D}P_{t-i}\right). \tag{12}$$

Figure 4
Investment effectiveness: $\hat{\alpha}_2$ parameter, 1997–2019



Source: own calculations, based on the equation presented in Table 1.

The α_2 parameter took values from the range of 0.15 in the years 1999–2001, when there was a relative lack of bottlenecks, to around 0.26–0.28 in the years 2004–2007 and 2015–2019, when bottlenecks appeared to a substantial degree.

Table 2

The average supply gap as percent of GDP

1997	6.6	2003	4.6	2009	3.8	2015	6.0
1998	4.0	2004	5.5	2010	3.7	2016	5.9
1999	3.2	2005	5.7	2011	4.2	2017	5.9
2000	3.0	2006	5.6	2012	4.1	2018	6.3
2001	3.1	2007	5.8	2013	4.4	2019	5.7
2002	3.6	2008	4.8	2014	5.5		

Source: own calculations, based on the equation presented in Table 1.

As a by-product of our analysis, we can pinpoint bottlenecks in the Polish economy. The bottlenecks took place in the periods 2004–2007 and 2015–2019. In these years, investment efficiency, as expressed by the α_2 parameter, was the highest as well as the supply gap.

We also estimated an alternative equation with polynomial distributed lag weights (Table 3) (R^2 is similar size).

Table 3

GDP weights – equal weights and polynomial (parabolic) distributed lag weights

$G\dot{D}P_{t-i}$	Equal – table 1 model		Polynomial distributed lag	
	weights	*t*-statistic	weights	*t*-statistic
$G\dot{D}P_{t-2}$	–0.20	5.6	–0.17	3.4
$G\dot{D}P_{t-3}$	–0.20	-"-	–0.27	3.7
$G\dot{D}P_{t-4}$	–0.20	-"-	–0.30	4.3
$G\dot{D}P_{t-5}$	–0.20	-"-	–0.25	5.5
$G\dot{D}P_{t-6}$	–0.20	-"-	–0.12	2.1

Source: own elaboration.

On the basis of the equation with polynomial weights, we got very similar curves to those presented in Figure 4.

The model (7) can be interpreted as a modification of the endogenous growth model with a smoothing of economic fluctuations.[24] Growth slowdowns are the result of bottlenecks and are offset by effective investment allocations.

We think that it has been initially confirmed for the Polish economy after 1997 that an economic slowdown reinforces the growth effects of an investment. The slower the growth is before the investment, the greater the effect of the investment. This is expressed by the decreasing linear function that describes the impact of the average GDP dynamics of the five preceding years on the α_2 parameter.

[24] "… the ability to deal successfully with economic disequilibria is enhanced by education and that this ability is one of the major benefits of education…" (Schultz 1975, p. 843).

Conclusions

The impact of physical capital investments on macroeconomic growth was examined. We tried to show to what extent it depends on the supply bottleneck (disequilibrium), which existed before the investment was made and which is eliminated by this investment. We confirmed the hypothesis that supply bottlenecks have impact on the investment efficiency. The narrower the bottleneck and the more it slows down macroeconomic growth, the more output growth will result from this investment in physical capital. In order to verify this hypothesis, the bottleneck variable was added to the growth model – the average lagged GDP growth (lags 2 to 6 years). The results of calculations for Poland's economy in the years 1997 –2019 confirm that economic slowdown preceding investments strengthens their growth effect.

Because bottlenecks occur irregularly, GDP fluctuations generated by the model are also irregular (not cyclical). So we agree with the view of Burns and Mitchell (1946, p. 466) "…that irregular changes in cyclical behavior are far larger in scope than secular or cyclical changes" and each economic episode depends on "… the peculiar combination of conditions prevailing at the time, and that these combinations differ endlessly from one another" as bottlenecks differ. The sequence of change is repeated but not periodic, recurrent but not periodic. According to our research regular is economic reaction on bottlenecks.

In the dispute about the essence of the investment process – whether it widens the bottlenecks or increases the safety margin – it seems that the result is in favor of the first view.

We consider the confirmation of our hypothesis important but also preliminary. It is important because it seems to show a possible new modification of the growth model. We use the simplest potential production – and a deviation from it – to determine the imbalance.[25] It is preliminary because the model should include variables that characterize human and social capital.

In future research, we intend to consider the endogenous nature of the investment-to-GDP ratio and use the instrumental variable method instead of the least squares' method. All considerations contained in the text can be related to infrastructural investments.

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[25] Potential production can be determined in many ways, which makes the analysis ambiguous.

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THE IMPACT OF SUPPLY BOTTLENECKS ON INVESTMENT EFFICIENCY

Summary

In the paper, the impact of physical capital investments on macroeconomic growth is examined. The authors try to show to what extent it depends on the supply bottleneck (disequilibrium), which existed before the investment and which is eliminated by this investment. The narrower the bottleneck and the more it slows down macroeconomic growth, the more output growth will result from this investment in physical capital. In order to verify this hypothesis, the growth model was modified. Because bottlenecks occur irregularly, GDP fluctuations generated by the model are also irregular (non-cyclical). The authors propose to estimate the macroeconomic bottleneck by the average lagged GDP growth (lags 2 to 6 years). The results of calculations made for Poland's economy in the years 1997–2019 confirm that economic slowdown preceding investments strengthens their growth effect.

Keywords: economic growth, physical capital investment, supply bottleneck, Solow model, endogenous growth model

JEL: O40, E13, E20, E22, C20, F43

WPŁYW WĄSKICH GARDEŁ PODAŻOWYCH NA EFEKTYWNOŚĆ INWESTYCJI

Streszczenie

W artykule badany jest wpływ inwestycji w kapitale fizycznym na wzrost gospodarczy. Autorzy próbują pokazać, w jakim stopniu zależy to od ograniczeń podażowych (braku równowagi) występujących przed podjęciem inwestycji i przez nią eliminowanych. Im ciaśniejsze jest wąskie gardło podażowe i im mocniej hamuje ono wzrost gospodarczy, tym większy będzie wzrost produkcji wynikający z danej inwestycji kapitałowej. Aby zweryfikować tę hipotezę, został zmodyfikowany model wzrostu. Ponieważ wąskie gardła występują nieregularnie, wahania PKB generowane przez model także są nieregularne (niecykliczne). Autorzy proponują szacować makroekonomiczne wąskie gardło za pomocą średniego tempa wzrostu PKB, rozpatrywanego z opóźnieniem 2–6 lat. Wyniki obliczeń wykonanych dla gospodarki polskiej w latach 1997–2019 potwierdzają, że osłabienie wzrostu w okresie poprzedzającym podjęcie inwestycji wzmacnia jej efekt w zakresie wzrostu produkcji.

Słowa kluczowe: wzrost gospodarczy, inwestycje w kapitale fizycznym, wąskie gardło podażowe, model Solowa, endogeniczny model wzrostu

JEL: O40, E13, E20, E22, C20, F43

ВЛИЯНИЕ УЗКИХ МЕСТ ПРЕДЛОЖЕНИЯ НА ЭФФЕКТИВНОСТЬ ИНВЕСТИЦИЙ

Резюме

В статье анализируется влияние инвестиций в физическом капитале на экономический рост. Авторы пытаются показать, в какой степени это влияние зависит от ограничений предложения (отсутствия равновесия), имеющих место до начала инвестиции и которые данная инвестиция устраняет. Чем теснее узкое место предложения и чем сильнее оно тормозит экономический рост, тем выше будет рост производства, вытекающий из данной фондовой инвестиции. Для того чтобы проверить эту гипотезу, была модифицирована модель роста. Узкие места возникают нерегулярно, поэтому колебания ВВП, генерируемые моделью, также нерегулярны (нецикличны). Авторы предлагают оценивать макроэкономические узкие места с помощью среднего темпа роста ВВП, рассматриваемого с опозданием в 2–6 лет. Результаты расчетов, произведенных для польской экономики в 1997–2019 годах, подтверждают, что ослабление роста в период, предшествующий началу инвестиций, усиливает ее эффект в области роста производства.

Ключевые слова: экономический рост, инвестиции в физическом капитале, узкое место предложения, модель Солоу, эндогенная модель роста

JEL: O40, E13, E20, E22, C20, F43