Economic and mathematical modeling of demand subsidies for photovoltaic technologies

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Abstract. Determining the need for resources of development institutions is formalized in the form of a multi-criteria decision-making problem, for the solutions of which the principle of sequential maximin is used. Development institutions are extremely important for the formation of supply and demand for scientific knowledge of photovoltaic systems to achieve global sustainable development goals, they are necessary for sustainable economic growth and diversification of the national innovation system. The main characteristics of the national innovation system that can affect subsidizing the demand for scientific knowledge are identified, changes in these characteristics are analyzed and a number of economic and mathematical models are constructed to predict the effectiveness of development institutions in the field of photovoltaic technologies. The definition of the resource needs of development institutions is formalized in the form of a multi-criteria decision-making task, for which the principle of sequential maximum is used.

1 Introduction

Currently, socio-economic factors determine the urgent need to reform all areas of scientific and technical regulation to increase their efficiency and support the stability of the national innovation system. Development institutions are no exception, which are characterized by an increase in the level of risks, as well as significant fluctuations in performance.

Development institutions are extremely important for the formation of a knowledge economy. They are necessary for sustainable development and optimization of mechanisms

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for supporting research and development. They make it possible to overcome failures in the supply and demand market for scientific knowledge, i.e., to solve problems that cannot be optimally implemented by market mechanisms [1-6].

Accordingly, decision-makers were faced with issues of both improving development institutions and stabilizing the national innovation system. The solution to the last problem at the present stage of development is seen in the transition to subsidizing the demand for scientific knowledge. However, it is obvious that such transformations cannot be carried out simultaneously; therefore, the prerequisites for effective subsidization of the demand for scientific knowledge is increased control of development institutions over activity in the market for the influx of private capital, including through the active use of channels to support fundamental and applied scientific research and development.

2 Materials and methods

Science and technology policy is inherently concerned with regulating the research and development sector and managing the direction and speed of scientific research. At the same time, the goal of its implementation remains to maintain stability at the level of the innovation environment as a whole. In particular, for decision makers, the main goal is to support the stability of the development of the scientific and technical system, which is impossible without an effective transfer of impulses from regulatory measures from the financial to the research sector of the economy in achieving the goals. Accordingly, subsidizing the demand for scientific knowledge of development institutions, the principles and features of its operation, the opportunities and threats of using various tools are important for the national innovation system.

Works [3, 7-10] examined the impact of deviations of national innovation systems from the equilibrium level, and concluded that stimulating demand for scientific knowledge is highly important for the economy. The econometric apparatus of forecasting models is widely used in the preparation of comprehensive studies of mechanisms for stimulating the economy of developing countries [5, 11]. The interest and credit channels, as well as the channel of actors' expectations in the national innovation system, and the degree of response of the market environment to regulatory measures deserve special attention [12-18].

Econometric modeling allows us to draw conclusions about the most effective mechanisms of influence of development institutions on the real sector. In fact, the use of the corresponding class of models makes it possible to present subsidizing the demand for scientific knowledge as a set of impulses coming from regulatory instruments, first to development institutions and through them to the real sector. Accordingly, since this mechanism manifests itself through signal transmission, the decisive role is played by the strength and speed of their transmission, which depends not only on the characteristics of the impulses, but also quite significantly on the environment in which they are transmitted.

The mechanism for subsidizing the demand for scientific knowledge of development institutions in countries with transition economy differs from the mechanism in developed countries [9]. All channels of support for scientific research differ in that their action is directly related to the conditions of the environment through which the impulses pass. Thus, the interest and credit channels realize their direct effect through the financial system. They provide for the use of financial instruments to influence the policies of innovative enterprises. This is carried out in accordance with the establishment of interest rates and the lending volume for research and development. At the same time, the channel of the value of intangible assets is manifested in its impact on the financial system, including through measures to regulate the level of accounting for costs of development research for tax purposes. The channel of expectations of economic entities is the most complex from the point of view of the implementation environment, since the method of its action is directly

determined by the national innovation system as a whole. Taking this into account, the mechanism for transmitting impulses from the activities of development institutions through all these channels may change depending on the state of the economic system. That is, the characteristics of the R&D sector, the financial system, and the economy as a whole can significantly influence the strength of individual channels and the properties of the instruments implemented through that channel.

The results of existing studies [11, 19] allow us to draw conclusions about the generalized characteristics of individual channels over a long period of time. We propose to use a systems approach that allows us to determine how and to what extent environmental conditions changing over time can influence individual channels of support for scientific research and development.

For a long period, the main channel of the mechanism for stimulating scientific research and development was the cost accounting channel, which can be attributed to the channel of the value of intangible assets [20-27]. Establishing direct control over the level of spending on scientific research, in addition to using the channel of expectations of economic entities, provides for the restoration of the effectiveness of the main channels that the decision-maker can use to directly influence the national innovation system. The advantages of using these channels to regulate the scientific and technical sphere are a wide range of regulatory instruments and the possibility of direct interaction with innovative enterprises within the framework of scientific and technical policy, and, accordingly, the relative ease of implementation of regulation.

However, despite such advantages, changes in the environment can lead to a deterioration in the effectiveness of these channels and necessitate a transition between regulatory regimes and the use of more comprehensive approaches. That is, even relatively simple interest and credit channels to support scientific research and development, especially in an economy subject to significant and constant shock fluctuations, without stable characteristics. Accordingly, this should be taken into account both when carrying out scientific and technological policy and when modeling the innovative sector of scientific research and development.

3 Results

To study the processes of subsidizing the demand for scientific knowledge of development institutions, vector time series models were used. This type of model allows us to trace the dynamic interdependencies between indicators and identify the strength of their response to fluctuations in each other's values. For modeling, it is proposed to use monthly data to evaluate models of the impact of scientific and technological policy instruments on interest rates and lending activity, and quarterly data to model the impact of financial indicators on the real sector of scientific research and development.

The essence of the interest rate channel for subsidizing the demand for scientific knowledge of development institutions is manifested in the influence of changes in rates on market interest rates on loans and deposits [15, 28]. Accordingly, to assess such a channel, it is proposed to use the value of rates on deposits and loans on the market as objects of regulation through monetary policy measures. In addition, the main instruments chosen were the key rate, the interbank lending rate and the rate on loans provided to secure applications for participation in competitions to support scientific research and development. The main rate of support for small innovative enterprises is the key rate. This rate is a guideline for the cost of attracted and allocated funds, but it is virtually impossible for innovative enterprises to receive funds [29, 30]. Thus, in addition to it, the model should include rates on real lending operations, in particular the interbank lending rate. All variables used in the model were estimated by first differences and integrated to achieve stationarity. The test for the lag length

demonstrated that the estimated model should include two lags; accordingly, in general it is described by the equation:

$$X_p^k = \alpha_0^k + \alpha_1^k X_{p-1}^k + \alpha_2^k X_{p-2}^k + \varepsilon_p^k \quad (1)$$

whereX_p^k is the functional of the first differences in the indicators of support for small innovative enterprises in period p according to the percentage channel k, α_i^k is the model coefficient, ε_p^k is the model error. Functional $X_p^k = f(\Delta x_{1p}^k, \dots, \Delta x_{5p}^k)$ depends on the first differences: Δx_{1p}^k is the key rate, Δx_{2p}^k is the interbank lending rate, Δx_{3p}^k is the loan rate, provided to secure an application for participation in competitions to support scientific research and development, Δx_{4p}^k is the weighted rate on deposits, $\Delta x_{5p}^k$is the weighted rate on loans.

The construction of a generalized autoregressive model over a period of ten years allows us to assess the degree of explanation for fluctuations in the level of interest rates on deposits and loans in response to scientific and technological policies using the interest rate channel. Estimates of the coefficients of model (1) can be represented as a matrix $A = \left(\hat{\alpha}_{ij}^k \middle| \hat{\varepsilon}_i^k\right)$, $i = 1 \dots 5$, $j = 1 \dots 10$.

$$\mathrm{A} = \begin{pmatrix} 0.53 & -0.97 & -0.14 & 0.13 & -0.65 & -0.75 & -0.91 & 0.37 & 0.56 & 0.23 & 0.68 \\ 0.23 & -0.02 & 0.13 & -0.33 & -0.83 & -0.71 & -0.32 & 0.87 & -0.19 & -0.93 & 0.86 \\ 0.25 & -0.34 & 0.72 & -0.56 & -0.39 & 0.15 & 0.57 & -0.07 & 0.55 & 0.92 & 0.53 \\ 0.62 & -0.13 & 0.14 & 0.03 & -0.58 & -0.62 & 0.29 & 0.63 & -0.33 & 0.87 & 0.95 \\ 0.19 & -0.74 & -0.67 & -0.62 & 0.48 & 0.72 & -0.52 & -0.27 & 0.23 & -0.55 & 0.22 \end{pmatrix}$$

The modeling results indicate that during the study period, rates on loans and deposits of development institutions responded most strongly to fluctuations in the level of the key rate. Fluctuations in the deposit rate are explained by changes in the key rate, and changes in the loan rate also significantly depend on changes in the key rate. At the same time, the remaining instruments included in the model have little effect on changes in interest rates in the supply and demand market for scientific knowledge. Such results may indicate that direct regulatory instruments do not have a significant impact on the setting of interest rates, while the benchmark for the value of intangible assets can play the role of a target indicator. At the same time, this gives grounds to assert that the credit channel of the transmission mechanism for supporting scientific research and development is weak. The modeling results are adequate, which is confirmed by the tests performed; in particular, there is no autocorrelation of the residuals, the model is stationary and has a sufficient degree of explanation of the dependent variables.

However, the relevant question is how realistically such a generalized result reflects the characteristics of the mechanism for supporting research and development. As already noted, the specifics of the channel's operation and the main guidelines for scientific and technological policy for the interest rate channel depend on the state of the environment in which it operates. At the same time, the main characteristics that determine the potential for transmitting impulses for regulating development institutions are three factors:

- the ability to pursue scientific and technological policy regardless of the needs of budget financing and in order to maintain the stability of the monetary unit determines the possibility of studying the effectiveness of direct regulation of development institutions;
- the level of filling the knowledge economy with monetary resources ensures the sensitivity of the system to changes in the conditions for the supply of financial resources from development institutions;

- the degree of liquidity and its fluctuations determine the use by the regulator of diverse measures that satisfy the current goals and needs of the market for supply and demand for new knowledge.

Changes are needed in the main instruments and guidelines for monetary regulation of development institutions. Subject to the need to support the planned level of government spending on research and development, which involves the use of a variety of monetary levers to provide development institutions with financial resources. The subordination of monetary policy to fiscal goals also affects the level of monetization. Depending on the supply of funds, development institutions can change their influence on the market for supply and demand for scientific knowledge. The level of monetization is important because it determines the degree of availability of financial resources for development institutions, which will determine further principles for the formation of interest rates.

To regulate rates under different conditions of access to resources, it is necessary to use different instruments to subsidize the demand for scientific knowledge of development institutions. Thanks to high monetization and the influx of foreign capital, development institutions have a sufficient level of financial resources. These resources, in order to quickly increase profitability, are actively placed in loans even with a high degree of risk, assigning the task of compensating them to the significant income of knowledge-intensive enterprises. At the same time, the activity of financial flows allows maintaining a balanced level of liquidity. In the event of a crisis, development institutions need refinancing to maintain liquidity. The excess funds released into the national innovation system through budget financing can be sterilized by mobilizing funds. In conditions of high levels of risk and low levels of lending, development institutions base their policies primarily on mobilizing excessive liquidity of the national innovation system [19].

Different science and technology policy mechanisms have different strengths depending on the characteristics of the supply and demand sector for scientific knowledge. The level of monetization and liquidity shifts the emphasis of the interest rate channel from lending instruments to instruments for mobilizing funds from development institutions. Rates are especially relevant for mobilizing funds during periods of increased pressure from the budget deficit, since they are used for sterilization operations. The presence of significant interdependencies between the monetary and fiscal sectors is also evidenced by the high level of influence of rates on repurchase operations on the market rate on loans to knowledge-intensive enterprises during the crisis period.

The credit channel is relevant at the stage of economic development, since it implies an increase in the level of access to financial resources for knowledge-intensive enterprises in the real sector of the economy. To evaluate and model this channel, indicators of the level of loans issued and deposits received are used as targets. The main instrument of this channel is the level of the monetary base. Accordingly, the generalized specification of this model is as follows:

$$X_p^l = \beta_0^l + \beta_1^l X_{p-1}^l + \beta_2^l X_{p-2}^l + \beta_3^l X_{p-3}^l + \beta_4^l X_{p-4}^l + \varepsilon_p^l \quad (2)$$

where $X_p^l = f(\Delta x_{1p}^l, \Delta x_{2p}^l, \Delta x_{3p}^l)$ functional of the first differences in indicators of support for small innovative enterprises in period p through the credit channel l, Δx_{1p}^l is the volume of loans issued to small innovative enterprises, Δx_{2p}^l is the volume of deposits issued to small innovative enterprises, Δx_{3p}^l is the volume of money supply, β_i^l is the model coefficient, ε_p^l is the model error. Estimates of the coefficients of model (2) can be presented in the form of a matrix $B = \left(\hat{\beta}_{ij}^l \middle| \hat{\varepsilon}_i^l\right)$, $i = 1 \ldots 3, j = 1 \ldots 13$.

$$B = \begin{pmatrix} 0.78 & -0.33 & 0.25 & 0.91 & 0.69 & 0.18 & 0.13 & 0.38 & 0.62 & 0.02 & 0.03 & 0.34 & 0.95 \\ 0.93 & 0.17 & 0.02 & 0.13 & -0.81 & 0.14 & 0.27 & 0.08 & 0.79 & 0.13 & 0.26 & 0.69 & 0.43 \\ 0.22 & -0.95 & 0.84 & 0.34 & 0.92 & 0.61 & 0.86 & 0.21 & 0.91 & 0.63 & 0.23 & 0.98 & 0.68 \end{pmatrix}$$

The proposed credit channel model is an error correction model. There is a long-term equilibrium relationship between the volume of money supply, the level of deposits and lending to small innovative enterprises. The model is adequate, taking into account the tests performed for the absence of autocorrelation of residuals and the absence of unit roots. The presence of such a connection determines the fact that, despite changes in the external environment, the overall configuration of the channel and the strength of the responses will be constant in the long term. That is, for the credit channel of development institutions, in contrast to the interest channel, changes in the environment are less important. Fluctuations in the level of lending to small innovative enterprises can be explained by changes in the level of the monetary base. The impulses transmitted through this channel subside on average over five periods. Accordingly, the strength of this channel is moderate.

After assessing the mechanism for transmitting signals from development institutions to small knowledge-intensive enterprises, it is necessary to model the final phase, that is, the reaction of the real sector. For this purpose, the principle of consistent maximin of the efficiency of knowledge-intensive enterprises y_p to the corresponding period of the previous year was used as an indicator of the state of the economy. The estimated model demonstrates the influence of the level of interest rates on deposits and loans in the supply and demand market for scientific knowledge, as well as the volume of attracting deposits and lending on the level of development of the national innovation system. To optimize the model, we used not absolute values, but indices of growth in the volume of deposits and loans compared to the corresponding period of the previous year for a set of small knowledge-intensive enterprises Ω. All variables included in the model are of first order of integration. The model specification is described by the equation:

$$\max_{y_p \in \Omega} F(y_p) = \max_{y_p \in \Omega} \min_{i \in I_{n-1}} (\dots \max_{y_p \in \Omega} \min_{i \in I_1} (\max_{y_p \in \Omega} \min_{i \in I} (\gamma_{ip} \Delta x_{ip})) \dots) \quad (3)$$

where I_1 is obtained by excluding from number I the factor with the worst efficiency value of a small science-intensive enterprise y_p, γ is the weighting coefficient of the joint influence of channels k and l.

The influence of financial market indicators on the real sector of the knowledge economy is significant. In general, the level of interest rates on loans and deposits and the volume of lending and depositing of development institutions largely determine changes in the gross domestic product in terms of revenue of innovative enterprises. The intensity of transmission of signals from regulatory measures to the national innovation system through the interest rate channel depends quite strongly on the state of the financial system and is often unsatisfactory. Regulatory measures to change the volume of money supply do not have a significant impact on the level of lending to small innovative enterprises. The conditional total strength of the influence of the interest rate channel on the real sector of the economy is weaker than the influence of the credit channel.

4 Discussion

A generalized assessment of the effectiveness of instruments for changing interest rates over long periods of time may not be informative enough to determine the most powerful levers of influence of development institutions on the knowledge economy. As the conditions of the national innovation environment change, the tools that are most effective for implementing

science and technology policy also change. This phenomenon must be taken into account both when regulating and when assessing the interest channel of the mechanism for subsidizing the demand for scientific knowledge of development institutions for the influx of private capital. In order for the modeling results to be as close to reality as possible, it is necessary to demonstrate changes in the price level benchmarks for credit resources in the supply and demand market for scientific knowledge. This can be done through the calculation of an integral instrument, the values of which will change not only depending on the level of rates on instruments of development institutions, but also due to changes in the characteristics of the national innovation system. In addition, for different types of models, switches between variables or complex mechanisms of multi-criteria decision-making can be used, which make it possible to change the guidelines for the level of rates depending on the need for resources of development institutions and other environmental conditions.

The credit channel for subsidizing the demand for scientific knowledge of development institutions for the influx of private capital at the first stage of its operation is not effective enough; the volume of subsidies issued largely depends on factors directly related to the level of risks, production activity, rates, but is little explained by changes in the level of money supply in circulation, especially due to changes in the level of the monetary base. The impulses transmitted by development institutions due to changes in the monetary base subside quite quickly in the credit market, without having a significant impact on the state of the innovative economy. However, this channel is quite stable in the long term, in particular due to its low level of impact. Changes in the national innovation environment do not make significant changes to the mechanism for its implementation.

5 Conclusion

The credit channel for subsidizing the demand for scientific knowledge of development institutions for the influx of private capital is stable and rather weak due to the insignificant influence of the volume of the monetary base on the lending and deposit activity of development institutions. But, despite the fact that the level of interest rates and the volume of deposits and loans have a significant impact on the level of efficiency, regulation through interest and credit channels is complicated by changes in the efficiency of signal transmission depending on the conditions of the national innovation environment and the weakness of the response of the research and development sector to regulatory measures. The identified influence of the environment on changes in the characteristics of development institutions determines the need to take this feature into account when modeling. It is also important in the future to study exchange rate channels and inflation expectations in the context of the characteristics of the national innovation system. In addition, it is advisable to analyze the impact of financial indicators on the price level for high-tech products. Environmental change plays an important role in the implementation of regulation through the interest channel of science and technology policy. Adapting regulations to such changes improves channel efficiency. Directing significant financial flows to the needs of development institutions, not justified by the needs of the real sector of the economy, weakens this channel. The credit channel is stable and weak due to the insignificant dependence of credit and deposit operations on the level of the monetary base.

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