Modeling regional economic growth with the formation of innovative ecosystems of technological entrepreneurship as a factor of sustainable development

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Abstract. The article analyzes the potential of growth theories in the context of determining sources for further development of the Russian regions, taking into account the “new normality” in the economy. As a result of a comparative analysis of endogenous and exogenous theories, their similarity has been proven. Modification of the Aguion-Howitt model for a region subjected to the development of an innovative technological entrepreneurship ecosystem has been developed. This model will allow to evaluate the impact of the innovation ecosystem as a factor of endogenous growth of the region.

1. Introduction
Sustainable development of any type of region, including cross-border ones, is based on economic growth of the productive use of labor and capital. In context of the “new normality” in modern economy, the purposeful formation of variables that increase the returns on labor and capital (human capital and the technological level of the economy) are of particular importance.

Currently, the lack of research that links innovation policies at the meso-level with the territory’s economic dynamics is observed in regional science. Thus, the formation of innovative ecosystems for the development of technological entrepreneurship in theory and in practice is poorly evaluable from the standpoint of influence on regional growth. The purpose of this article is to develop a model of endogenous growth of the region using a technology entrepreneurship factor.

2. Materials and Methods
Recognized theories and models of endogenous and exogenous growth are widely presented and discussed in foreign scientific literature (Solow, Ramsey, Mankew - Romer - Weil, Acrrow - Romer, Uzava - Lucas, Aghion - Howitt, etc.). They serve as the material for research.

We used the following research methods: comparative analysis, logical-structural analysis, mathematical modeling, differential calculus to identify differences between models, as well as model allocation with the highest heuristic potential.

3. Results
The Solow model is a classic exogenous model. This model explores the stationary solution of a differential equation, showing that if the actual investment coincides with the necessary one, economic growth depends on the rate of technical progress and population growth. In the absence of a rapid growth in the number of able-bodied citizens, usually uncharacteristic for developed economies, it is
scientific and technical progress that would determine the dynamics of macroeconomic indicators (according to R. Solow, technological shifts explained 87.2% growth in the United States) [1], which, however, must be given exogenously. The Ramsey (Ramsey-Kass-Kupmans) and Mankew-Romer-Weil models became the development or modification of the Solow model.

However, exogenous models do not provide convincing explanations regarding differences in the influence of classical growth factors in countries and regions, and also they do not allow to quantify the impact of innovative technological effects. In fact, the introduction of new explanatory parameters changes their axiomatics and brings them closer to endogenous approaches. Another problem of exogenous models is the inability to constructively substantiate any pronounced economic policy [2]. Therefore, a greater heuristic potential of endogenous growth theories can be assumed.

P. Romer proposed one of the first modern models of endogenous growth (Arrow-Romer model). According to the model, the self-developing process of accumulation and use of knowledge occurs within the economy and individual firms [3]. The level of knowledge (technology development) is an independent argument of the function of output; therefore the growth of this value causes increasing returns on capital. This can explain the steady self-sustaining growth of countries with mature market economies. The spread of technology among firms and countries is also of independent importance [4].

Endogenous scientific and technological progress explains economic growth in the model of the creative destruction of P. Aghion and P. Howitt. It put economic growth in dependence on three parameters: (1) the flow of innovation (generation of innovations in the research and development sector, subject to the theory of probability), (2) the share of skilled labor (the model separates the number of skilled and unskilled workers), (3) the impact of innovation on the economy [5]. Thus, the growth in the model was explained only by the technical progress arising during the interfirm competition.

In 1998, P. Aghion and P. Howitt added to the number of growth factors also the accumulation of capital, not in its classical interpretation (as an autonomous source of growth), but as a driving force of technological changes. Now, the rate of flow of innovation has become dependent on the capital stock per employee in the field of research and development, and the innovation process has begun to be seen as capital-intensive [6]. As a result, the model began to largely overlap with the construction of Ramsey, but with an endogenous task of speed of technological development. In the 2000s, analyzing modern applications of the Schumpeterian growth paradigm, some new important effects were highlighted.

1. The growth rate depends positively on the rate of creation and liquidation of firms and jobs. This thesis points out contradictions between economic growth and living standards, which would not necessarily correlate in the medium term.
2. In many developing countries and countries with economies in transition, there is significant growth potential while reducing the boundaries and barriers of creative destruction, as well as institutional or educational reforms. The recommendation to many states to develop at an accelerated pace either higher or secondary education follows from here.
3. The market structure and size of firms are subject to deep institutional features of different countries. For example, the slow growth of India is largely due to the deliberate preservation of the small size of firms within the range of control of one family. With a weak social capital, low trust, poorly working laws, it is very risky to entrust managerial powers and assets to people outside their family. This constant circle of small firms uses unproductive capital and, moreover, has no incentive to innovate [7, 8].

We believe that it is the Aghion-Howitt model that can most adequately characterize the current problems of economic growth, both at the national and subnational levels.
4. Discussion

A comparative analysis of endogenous and exogenous growth models suggests their convergence. Theories of endogenous and exogenous growth do not differ according to the fact that production factors belong to residents or non-residents. Differentiation of growth patterns occurs on the basis of explaining a different range of factors from the model itself. Exogenous models consider only labor and capital, suggesting a certain unexplained remainder (“Solow’s remainder”), which is caused by factors not included in the model, i.e. external to it. Scientific and technical progress in a broad sense is most often such a factor.

At some point, since the share of “Solow’s remainder” turns out to be too large, the inclusion of human capital and technological development in the models as new internal variables becomes logical. This underlines the continuity of exogenous and endogenous growth patterns. They have no conceptual differences. It is not by chance that the Aghion-Howitt model with adding the “capital” parameter makes it possible to obtain the Ramsey model as a trivial special case. Thus, the axiomatic of different growth models differs only in a different explanation of the variables associated with scientific and technological progress (from the external environment or the internal logic of the model itself).

In context of implementing the model of endogenous growth, the formation of innovative ecosystems of technological entrepreneurship can take a significant place. As was shown above, since productive technological entrepreneurship can be carried out only in the presence of an innovation ecosystem, the creation of the latter is a significant factor of endogenous growth. Based on the structural and logical analysis, identifying the following areas of the relationship between innovation ecosystems and the endogenous model of territory’s economic growth seems possible (see Table 1).

Thus, under the constraints of labor and capital, which are characteristic of Russia and its regions, the potential for economic growth is mainly associated with an increase in technological level, as well as human capital. The increase is also due to internal sources of self-development generated by the innovative ecosystem of technological entrepreneurship. In this case, a significantly higher return will be achieved from investments, if one manages to attract them in a significant amount. Consequently, the development and testing of models reflecting the influence of individual components of scientific and technological progress, including technological entrepreneurship, on economic growth and development of territories is necessary.

To simulate the contribution of technology entrepreneurship to regional growth, it seems most appropriate to modify the Aghion-Howitt model with differentiation of various components of the territory’s technological development. In general, this model looks like this (1) [8]:

\[ Y(t) = \left[ \int_0^1 A(v,t)x^\alpha(v,t)dv \right]^{1-\alpha}, \tag{1} \]

where \( x \) – capital stocks in the industry \( v \), used at time \( t \),
\( A \) – a technological level in the industry \( v \), existing at time \( t \),
\( L \) – labor amount,
\( \alpha \) – a capital elasticity ratio,
\( 1 - \alpha \) – an elasticity coefficient (according to labor).

| Specification of endogenous growth type | Potential of the innovation ecosystem of technology entrepreneurship |
|----------------------------------------|---------------------------------------------------------------|
| Use of already existing (endogenously) specified classical factors of production (labor and capital) | Increasing the effect of using existing growth factors |
|                                        | Increasing the territorial attractiveness with a developed innovation ecosystem both for investments and carriers of valuable human capital |
|                                        | Retention of own factors of production (human) |
The internal (endogenous) origin of new growth factors – human capital (skill level, competence), technology

- Increasing the multiplier effect of technological level due to own research and development
- Human capital development in the innovation ecosystem

“Stream of innovations” (according to Aghion-Howitt), particularly its speed and power

- Increasing the likelihood of innovation. Increasing the number of developments

Mediating a technological level of the economy by improving the institutional environment, including the speed at which firms are created and liquidated

- A developed innovation ecosystem creates favorable conditions for creating technological and other new firms

Given the regional level of analysis, the exogenous variable \( T \), which takes into account the effect of interregional technology transfer, should be included in the model (2):

\[
Y(t) = \left[ \int_{v_1}^{v} A(v,t) x^n(v,t) dv \right]^{Lv_{-n}} + T
\] (2)

The growth rate \( g \) due to the increasing technological level of equipment due to innovations:

\[
g(t) = \frac{\dot{A}(t)}{A(t)} = (\gamma - 1) \lambda n(t),
\] (3)

where \( \dot{A} \) is the technological level after introducing innovation, 
(\( \gamma - 1 \)) is the rate of increasing technological level, where \( \gamma > 1 \),
\( \lambda n \) – the probability of inventing (implementing) innovation due to one element of the whole innovation system \( n \).

As can be seen from the above data, increasing a technological level depends on the probability of inventing \( \lambda \) for one element \( n \) (for example, making a discovery by one researcher), as well as due to the number of elements \( n \). In other words, the probability of invention (innovation) in the industry \( v \) in the period of time \( t \) is \( \lambda n(v, t) \). At the same time, the parameters \( n \) and \( \lambda \) are characteristics of the innovation ecosystem of technological entrepreneurship.

The value of \( n \) will be associated with the state of “hard” innovation infrastructure, i.e. the presence of researchers, innovation support institutions, and technological entrepreneurship, the release of funding. The value of \( \lambda \) depends on the “soft” infrastructure, which most determines the productivity of the regional innovation ecosystem.

Then the parameter \( \lambda n \) of the Aghion-Howitt model is proposed to be written as follows (4):

\[
\dot{\lambda n}(v, t) = \frac{\dot{s}(t)}{s(t)} = (\gamma - 1) E \sum_{n=1}^{\lambda} n \sum_{j=1}^{\lambda} \lambda_j
\] (4)

where \( \dot{s} \) – a number of startups implemented after time point \( t \),
\( s \) – a number of implemented startups up to the moment of time \( t \) (before exiting the equilibrium state),
\( E \) – a coefficient reflecting the degree of interaction in the innovation ecosystem by the triple helix model,
\( n_i \) – a normalized (correlated with the maximum or minimum) value of the severity of the \( i \)-th element of the “hard” innovation infrastructure,
\( \lambda_j \) – a normalized value of the \( j \)-th element of the “soft” innovation ecosystem.

As a result, this model reflects the influence of the innovation ecosystem and its qualitative characteristics on the values of the coefficients of the Aghion-Howitt model, details, and clarifies the latter.
5. Conclusion
The proposed model allows a differentiated assessment of the impact of different elements of the innovation ecosystem on regional economic growth and start-up generation. In turn, this provides an opportunity to more reasonably develop and stimulate regional innovation ecosystems.

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