Chapter

Meso Trajectories in the National Innovation System and Their Regulation

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Abstract

The mesotrajectory is presented as a three-phase process of the development of mesopopulations: emergence (origination), diffusion (acceptance, assimilation and adaptation) and retention of a new rule (innovation). The central category of the NIS, i.e. knowledge, is considered from two positions: as a set of specific rules and as the most critical innovation resource. The proposed methodology also describes the three phases of mesostructure dividing each of them into two series–parallel sub-phases and incorporating them in the design of niches, technological and market ones. The methodology allows specifying the effect of the evolutionary selection and intermittent development of meso-units in the first two phases, as well as the mechanisms of changing the socio-technological regime in the third phase. The study set and analyse policy for creating motivation for innovative behaviour at different phases of the mesotrajectory. The actors' mesopopulation are represented as carriers of the properties of knowledge-rules-resources. The knowledge of the actor is taking into account not only as a rule but a factor breaking the mesotrajectory. Among other characteristics of mesotrajectory discontinuity, intermittent equilibrium is taken into consideration in the study. The problem of regulating trajectory continuity is analysed in the framework of public policy.

Keywords: knowledge-rules, trajectory, mesopopulation, factoring populations, incentives and disincentives, technological niche, selection (market) niche, public policy

1. Introduction

The possibilities for applying traditional approaches (including neoclassical theory and theory of growth) and their tools to the analysis of innovation systems are mostly limited [1, 2]. Frequently, the main conceptual statements of these approaches contradict the fundamental properties of the National innovation system (NIS) and its actors' characteristics. For example, it is not always possible to attribute NIS actors to the economic agents, especially in cases when gaining economic benefits is not their objective. Actors are not often represented as agents in the economic mainstream and not always benefit-oriented in short-term and sometimes medium-term perspectives. The actor of the NIS is often considered as decision-making under bounded rationality.

At present, the concept of a national innovation system covers all the major components of the innovation process, including organisational, social, political, and economic factors. Researchers and decision-makers widely use this concept at the regional, national and international levels [3]. At the same time, many authors indicated as one of the main disadvantages of the NIS approach that it lacks bridges between the macro and micro that are inherent in mainstream economic research. According to Edquist [3], when moving to a macro level, the innovation system is regarded as a single entity without breaking out into subprocesses and their actors [3, p. 186]. Here it may just be noted that in the current practice of NIS research, this approach often looks relatively static. Miettinen says that the NIS approach is poorly connected to … a dynamic way of thinking [4], p. 35.

The neo-evolutionary theory (NET), which has arisen relatively recently [5], is free from these shortcomings). Therefore, to eliminate the shortages and achieve a new quality analysis of innovation development, it seems reasonable to integrate the achievements of this theory and the NIS approach. The following facts indicate that these approaches are compatible.

Like the NIS approach [6–9], knowledge is the central category of the NET. According to [10], the bit of knowledge serves as the nuclear element of evolutionary economics. This bit is considered as a particular rule in the NET [11, 12]. In neo-evolutionary economics as well as in the national innovation system, the emphasis is on the consideration of new knowledge (rules). The NET and NIS actors are knowledge holders; their activity is associated with the generation and use of creative knowledge.

In the NET, the carriers of the same (rather complex) knowledge-rule are combined into a population. It is called a mesopopulation. Therefore, the couple of rule and mesopopulation is taken as a single object called the meso-unit in the NET. The dynamic process of the development of meso-units determines a mesotrajectory [11] or market trajectory [13]. As a result of passing through the trajectory, mesopopulation grows from one holder (entrepreneur or technology supplier) of a new technological knowledge/rule to a population. The mesotrajectory consists of the subsequent phases of the development of a complex rule. They are emergence (origination), diffusion (adaptation and assimilation) and retention of the rule.

It is worth noting that the introduction of the concept of mesotrajectory was an essential step in the development of evolutionary theory. However, neo-evolutionists consider the technological changes that have relatively smooth dynamics. According to the authors, the technological shifts are the result of gradual changes in technologies and socio-technological regimes. Therefore, leap jumping changes in technologies (their mutation) are left out of the consideration of mesotrajectories. At the same time, there are some authors of the so-called quasi-evolutionary point of view [14–17], who insist that radical technological changes are often the result of drastic technological changes that break the previous trajectory of technological development.

These trajectory gaps often result in the discovery of new markets and new industries. The authors mentioned above are also convinced that the emerging technological and market niches, either inside or outside socio-technological regimes, are the drivers of technological changes. The processes of origin and selection of variations in technological changes that can meet the requirements of a changing selection environment take place just there. In the NET, the concept of niches is not actively used and therefore, it is not related to the implementation of mesotrajectories. However, it would be logical to do so. Below we will try to present the process of functioning of niches as a necessary part of the phases of trajectories. To this purpose, we will expand the typology and definition of niches below.

Furthermore, it makes sense to combine the NET and NIS approaches into one concept. The use of mesotrajectory notion in the NIS would make it possible to introduce the dynamics into the analysis of the system and determine the transitions from micro to macro through meso-level. At the same time. The application of the NIS toolkit in the field of public policy in the NET would allow linking the public actions with the need for rule carriers passing the mesophases of trajectories. The embedding NIS in NET allows speaking of knowledge not only as a rule but also as a specific innovative resource. And finally, as the rule-carries' motivation, the analysis of internal and external factors affecting leads to the consideration of new aspects of mesotrajectories usually not taken into account in the NET.

2. External and internal factors hindering the implementation of mesotrajectories and their regulation

Certain factors influence the development of the phases of the mesotrajectories. They can be combined into two groups. The first of them are the factors that are shaped outside of the mesopopulations at the corresponding trajectory phase. The second is formed inside of the mesopopulations of the evolutionary trajectory.

In the first, we include two following categories of risks and uncertainties: 1) inherent in innovation; 2) associated with threats of adverse externalities of technological spillover. They stem from an external environment and determine anti-stimuli for the actors' activities in mesopopulations.

The second group comprises the factors whose elements are formed by some actors of mesopopulations. The actors that fall into a factor forming population are holders of the attributes of a distinguishing factor. Actions of these populations may promote or inhibit the phases of mesotrajectories.

In light of the previous, one of the tasks of public policy is to mitigate the risks and uncertainties. In this study, we do not take into account such external factors of innovation activities as components of framework conditions. The regulation of influence of the factor-forming populations on the trajectory is the second problem of the NIS. The present study attempts to crystallise the mentioned groups of factors and some measures of public policy to regulate their actions. It means that actors cluster the group (populations) of factor characteristic carriers according to the factors.

In this context, it is worthwhile to note that public policy on the evolutionary trajectory differs significantly from the traditional economic, particularly, industrial policy in its goals and role-playing behaviour of the government. Under the general economic (industrial) policy, government actions usually aim at a structural transformation of the economy as a whole [18], economic development and growth of manufacturing and other types of production. Below, the term public or government policy is referred to government regulatory action to facilitate the drivers of a country's development and eliminate barriers [19] or performing core functions of NIS. Moreover, in contrast to the traditional theory, the government has bounded rationality and is only one of the possible participants in the processes of destroying trends of the trajectory and searching and implementing new ones.

And finally, one must take into account that these government's efforts cannot be expected to succeed without solving the problem of encouraging actors to perform NIS functions as well as regulating the activities of factor-forming populations at different NIS levels. This section is devoted to the consideration of these problems.

2.1 External factors for mesotrajectories: risks and uncertainty emerging in the environment

For actors, the activity on the phases of the mesotrajectory has two sides. The first is positive, and it is related to the possible economic benefits of innovation. These benefits generate incentives for the activity of NIS actors. The second is negative, and it is determined by the presence of strong disincentives to perform core NIS function to get these benefits. The high risk and uncertainty of actors' activity lay the groundwork of the disincentives. Consequently, the stimulus must outweigh the anti-stimulus in order this activity takes place.

The disincentives are unevenly distributed along the mesotrajectory. If the proposed innovation is radically new, then the most significant uncertainty of positive results in the innovation activity occurs in the Meso 1 phase. However, if the successful development of the innovation processes provides the transition of the mesotrajectory to the Meso 2, then calibrated risks of getting innovative results will replace the uncertainty.

Risks and uncertainties in the NIS on the trajectory can be conditionally clustered into two groups [20]. The first group includes uncertainties and risks that are natural, i.e. intrinsic and inherent, in actors' activity. Their presence, especially on the early stages of technology creation, does not make firms eager to invest in innovation and support them.

Government, as a partner of an entrepreneur, tries to diminish the natural risks and uncertainties at initial phases of the trajectory. On the other hand, the government's steps may induce NIS actors to act as free riders and encourage them to receive rental income from the corresponding financial help of the government. The government to avoid this phenomenon should strive for such conditions that make actors accept a significant part of the innovative risks and uncertainties. In other words, dualism has to be inherent in government policy.

The dualism means that the domains of public policy will not only compensate for the system of anti-stimulus but also force the participants of the NIS to take on significant shares of uncertainties and risks. One of the methods of actors' compulsion to this sharing is an international competition [21].

The existence of the second group of risks and uncertainties can be associated with threats of adverse externalities or spillover [22] on the mesotrajectory. For example, if an actor was successful at Meso1, he succeeded in such a NIS function of an economic application of new knowledge. Nevertheless, the actor would not receive the full benefit from his innovations without sharing it with competitors, if the spread of innovations, i.e. fulfilment of such a core function as diffusion, took place due to the effect of technological spillover (the unauthorised use of these innovations).

This effect often does not arouse the actors' desire for creating innovations. An actor-innovator to avoid this effect could use substantial isolationist barriers protecting his new innovative knowledge [23, 24]. The durable protection of intellectual property supported by the government can act as such a barrier. However, it must be borne in mind that powerful isolationist barriers may hinder the diffusion of innovations (see Section 3 below). Then such an essential function of the NIS as the dissemination of new technological knowledge can be disrupted. The phenomenon may also sometimes impede the development of the new rules laid down in radical innovations as well as introducing innovative changes in related fields of activity.

In summary, the public policy, the purpose of which is to shape the actors' inducement, should include the following objectives:

1. holding dual policy measures of policy measures, on the one hand, to compensate uncertainties (on Meso 1) and risks (on Meso 2 and Meso 3) and, on the other hand, to force NIS actors to deal with these uncertainties and risks taking on with them through the trajectory;

2. maintaining a balance of performing various NIS functions at different phases of the mesotrajectory.

2.2 Internal factors for mesotrajectories: populations as holders of factor attributes

In addition to the mentioned above factors, uncertainties and risks, the factors formed among the mesopopulations play a significant role in the evolutionary trajectory. They are constructed by some members of the populations in the course of their activities along the mesotrajectory.

Such factors can include:

- Resource capability of NIS actors, i.e. their provision of primary resources (in particular, their shortage or redundancy).

- Firm forms of ownership.

- The technological complexity of innovative products.

- Spatial distribution of innovation processes and actors.

- Technological paradigms in the economy.

- Absorption capacity and its distribution among actors.

As an example, consider a factor such as resource availability or resource provision of enterprises. Let us assume that this level can be low, medium and high. According to these gradations, the set of industrial enterprises is broken down into factor-forming populations of small-, medium- and large-sized enterprises. For instance, these populations can include the following groups:

- Small enterprises up to 299 employees.

- Enterprises with the number of employees from 300 to 499.

- Large enterprises with employees between 500 and 9999, and above 10,000 personals.

The ranges of employees that are available for these enterprises are attributes of such the factor. It worth noting that enterprises within these specified factor-forming populations are not distinguishable; that is, at this level of consideration, the group of enterprises can be considered as homogeneous unless otherwise specified. In this context, for given attributes or gradations of the factor, the analysis deals with homogeneous populations (groups of enterprises).

Now, let us look at another example of factor-forming populations along the evolutionary trajectory. They are related to such a factor as forms of ownership of NIS actors. The sample of actors (e.g. innovative industrial enterprises) can be subdivided into factor-forming populations according to the gradations of ownership the actors are belonging. The structure of gradations can obey a hierarchy. In the case of Russia, it can be presented as follows. At the macro level of the hierarchy, ownership has two attributes, such as Russian and non-Russian property.

Further, Russian property should be split into public and non-public ones. The former has two gradations: federal property and ownership of Russian Federation subjects. The following features can classify the latter as follows: municipal property, the private one, the property of consumer cooperatives, ownership of public and religious organisations, mixed (private and state-owned) property. Finally, last but not the least, the non-Russian property includes foreign and joint possession. The private (52–53% of enterprises) and mixed (14–16% of enterprises) ownership concentrate the main resources (human and material) of innovation. The federal and joint property (19–23% of enterprises and resources) are next in importance.

This just mentioned set of features can be regarded as finite; that is, it is not subject to further division. It means that organisations grouped by the listed attributes are taken as homogeneous regarding the corresponding form of ownership. In this context, it is worthwhile to point out that in other cases, for instance, considering the technological complexity of innovative products, the hierarchy of attributes of the factor must be deeper and homogeneous factor-forming populations of higher hierarchy level have to be split into subpopulations on the next lower level.

Now let us turn our attention to the analysis of dynamics of populations forming attributes such as the resource capacities and forms of ownership in Russia (see also [25]).

2.2.1 The resource capacity

The characteristics of evolutionary trajectory depend substantially on the level of common resources available for enterprises, i.e. sizes of enterprises.

In particular, for innovation-active enterprises of Russia, representatives of populations of small dimension, that is, small and medium-sized enterprises have a significant share of innovative products in their sales. It is worth pointing out that although in 2010–2012 some populations of large enterprises showed growth of this indicator at times, many of them were apparent outsiders (hereinafter, Rosstat data are used). They had had shares of innovative products in sales well below the those of three out of four populations of small and medium-sized businesses. Only the population of enterprises with employment between 1000 and 4999 people managed to exceed the level for small and medium-sized businesses populations.

In 2012–2015, the situation repeated: three out of four resource-rich populations had the lower meaning of the indicator compared to three resource-poor populations. (see **Figures 1** and **2**). However, the shares of innovative products in sales for the enterprises of 500–9999 and 50 to 99 employed became close (16.1% versus 16.2%). It turned out to be significantly below for the class of small businesses employed up to 50 people and the class of medium-sized enterprises with employment in the range of 100–199 people. The values of the indicator for the classes were 17.1% and 18.4%, respectively.

By contrast, it is worth noting that, despite the steady outsider's positions of the large enterprises' populations, they managed to reduce the gap with the leadership positions of small and medium-sized enterprises on Meso 2.

Here, not the last role could be played by the circumstance that the state-owned enterprises belonging to the populations of large enterprises were forced to accept the special innovation development programs (IDP) in which the government drafted the share of innovative products in sales. According to the plans, the enterprises must be answerable to the government for achieving the target value of

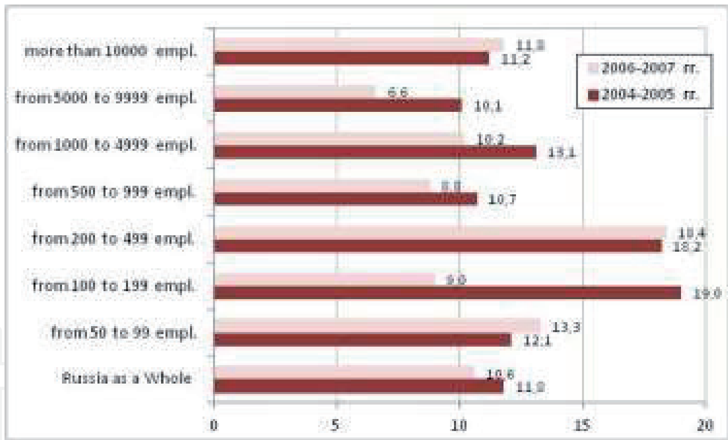

Figure 1.
Average share of innovation production in the sales of innovation-active enterprises by size classes in 2004–2007 (%).

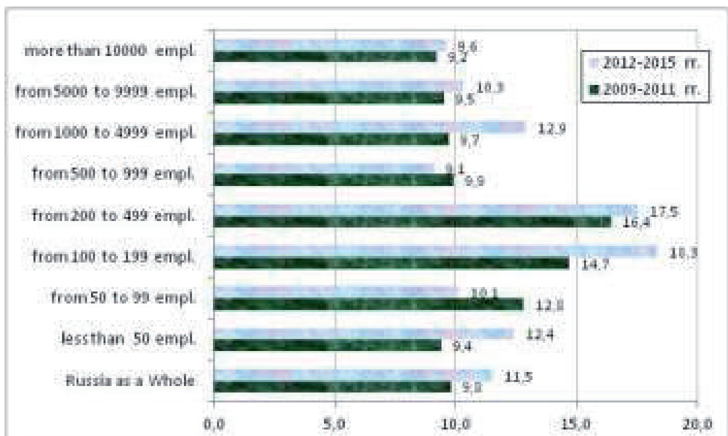

Figure 2.
Average share of innovation production in the sales of innovation-active enterprises by size classes in 2013–2015 (%).

this indicator. This responsibility, posing significant risks of over-statement and falsification of this indicator value for large state-owned enterprises, may trigger the sharp increase of its meaning in these years.

It is worthwhile to point out that in the country the level and dynamics of indicators of the innovation activity scale and economic efficiency along the meso-trajectories continue to be almost wholly established by the populations of large enterprises due to their dominance in the economy. However, as just mentioned, the indicators of large enterprises often point to a lack of their activity along evolution trajectories.

It is essential to overcome the innovative passivity of large enterprises and increase the groups of small and medium innovative business to find a way out of the situation. Furthermore, policy measures are needed to constitute a framework of conditions in the field of entrepreneurship. It concerns, in the first place, reducing regulatory and administrative barriers and developing and providing competitive environments in markets.

The populations of small and medium enterprises had primary positive, innovative attributes. The populations need increasing and supporting by the state. The critical task of public innovation policy is to establish conditions for the rapid growth and prosperity of new firms based on one technology on the mesotrajectories. The urgency of the issue is determined by the fast development of outsourcing processes on the final stages of R&D as well as the traditional disability of large firms to implement quickly new methods of doing business and introducing quite drastic changes in production and delivery methods.

2.2.2 Forms of ownership

The form of property has a substantial impact on the behaviour of the firm and its development and affect the choice of organisational model, management and innovation activity of the firm. The enterprises of private and mixed ownership demonstrate the most significant influence on the overall situation in innovation. In 2015, the number of privately-owned enterprises was 47% (versus 52% in 2006) among innovation active industrial enterprises on Meso 2, along with that the mixed-owned ones consisted 11% (versus 17% in 2006). Consequently, both populations concentrate about 65–70% of the general (human and material) resources of innovation. The next in importance to the influence were the populations of the federal property (15–17% in the number of enterprises and quantities of resources) and joint ownership (7–10%).

For many years, private ownership has not been a leader in entrepreneurial activity in innovation. In particular, the organisations of this form of property has been significantly behind those of federal property. It concerns a share of innovative products in sales (see **Figure 3**). Moreover, according to this indicator, the gap between these forms of ownership has increased dramatically in recent years (see **Figure 4**). Two circumstances can explain that increase. First, as mentioned above, federally owned enterprises had adopted innovative development plans with a commitment to enhancing innovative products in sales dramatically. Secondly, the government had undertaken intensive financial interventions to support state-owned enterprises.

According to the Center for Strategic Research, within the framework of the IDP, there was a significant increase in funding for the state-owned corporations and companies with state participation leading in high-tech industries in 2011–2016. In 2016, the gross expenditures of the state budget on R&D in these companies reached 1.7% of GDP [26]. As a result, the spending on technological innovations of these companies increased more than 20 times (from 2.15 billion rubles in 2010 to 56 billion rubles in 2015). It would seem that this surge in subsidies should drastically enlarge the scale of innovation activity and its effectiveness of these companies. However, that did not happen. The increasing share of innovative products compared with it in the mid-00s was not proportional to the subsidies surge.

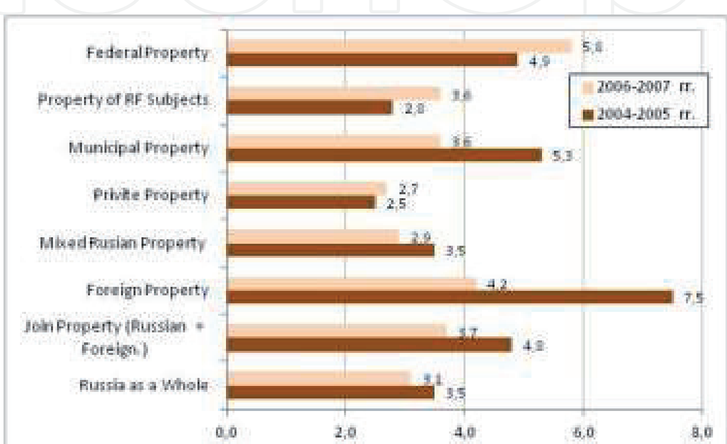

Figure 3.
Average share of costs for technological innovations in the sales of innovation-active enterprises by ownership classes in 2004–2007 (%).

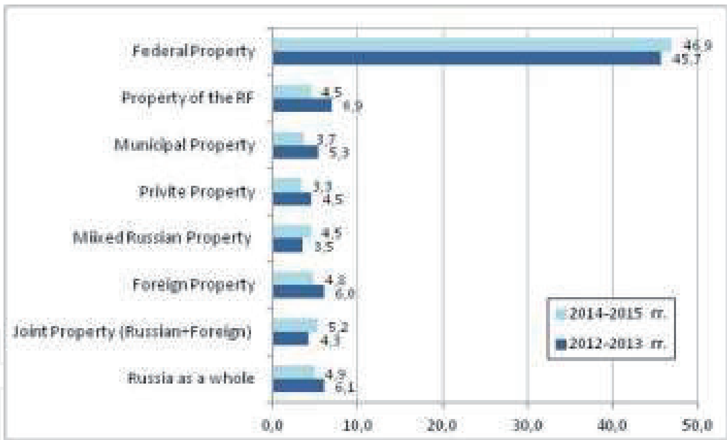

Figure 4.
Average share of costs for technological innovations in the sales of innovation-active enterprises by ownership classes in 2012–2015 (%).

What made the situation even more difficult was the level of innovation efficiency of these state-owned enterprises. It is worth noting that the supremacy of Federal ownership over private property had always been "broken" when one tried measuring the innovation efficiency on Meso 2 calculated as the value of the innovative product per employee. However, this "defect" turned out to be very significant in 2013–2014. If the meaning of this indicator for federal ownership enterprises had been 60–70% of the national average in 2004–2005, it dropped to 12–15% of the average in 2013–2014.

As it follows from the above, the policy measures should be aimed at the following components.

- Forcing the enterprises of private and mixed ownership to innovate, for example, by developing competitive processes in relevant markets.

- Reforming the management of state-owned enterprises.

- Increasing the share of enterprises of foreign and joint ownership in the manufacturing industry, for instance, by creating a favourable investment and business climate.

3. Knowledge as a rule or a resource generating gaps of mesotrajectories

The NIS is often presented as storage of innovative resources and processes that transform these resources [27]. At the same time, the major category of the resources is knowledge, more precisely, innovative rules in the terminology of NET. They play a leading role in providing the functioning of the system.

According to the economic tradition, primary resources or factors of the production process are understood as labour, business, capital, and natural resources. For creating long-term advantages, unique resources stand out among the firm's resources [28]. The resources have a value, and they are rare and poorly replaceable. They have limited mobility, and it is difficult to imitate them [28]. The property of uniqueness of the resources, as it is easy to see, is primarily associated with their scarcity in the economic system. Their supply shortage can be both external and internal. It can occur for ether some entrepreneur population as a whole or for internal subdivisions of a particular focal firm. In respect to a traditional (rivalrous) resource, the internal deficit does not allow the firm to expand outcome and turn into a marginal producer or monopolist displacing less efficient competitors from the market. If the internal deficiency is stable, it leaves no chance for the focal firm to get monopoly rent. Then, the only recourse it has is to receive Riccardo's rent (see also [23, 28]).

However, the situation looks somewhat different when it comes to such an unconventional (non-rival) production resource as the knowledge that provides the birth of a firm's innovation, in particular, a new technological rule. In conjunction with other resources, knowledge has a significant impact on reducing the cost of a product and increasing consumer benefits. The lack of such knowledge among competitors gives the focal firm a competitive advantage in generating and appropriating economic rent. The firm can lose the rent appropriated if particular barriers do not protect the resource from imitation by its rivals. In other words, the firm requires isolationist barriers [22, 29, 30].

It brings up to the question of whether the firm protecting and apply its specific innovative knowledge is always limited to Ricardo's rent. More likely, no than yes. If a firm's specific knowledge is explicit and codified one, such as results of research and development, then there are hardly any natural barriers to its dissemination within the firm. The absence of barriers and internal scarcity suggests that Peteraf's assumption about the dominance of Riccardo's rent does not work in the case. At the same time, it is profitable for the firm to obtain monopoly rent in the market. It has the opportunity if there is an ability to create or use the existing isolationist barriers (in particular, the protection of intellectual property) to safeguard the innovation rule. The barriers make it difficult for competitors to imitating the innovation rule. Consequently, they support the external deficit of the specific knowledge in the external environment of the firm.

From what has just been said, it follows that the use of monopoly rents by NIS actors protected by isolationist barriers results in gaps in a mesotrajectory. The originators of neo-evolutionary theory usually do not focus on this aspect of innovation activity. However, these barriers can significantly limit the processes of diffusion of innovative rules among actors' populations in the second phase of mesotrajectory and even break them. The special public policy measures them reducing are needed to close the gaps and restore the growth of the rule carriers' population.

4. Phases of a mesotrajectory and core functions of the NIS

In the first phase (Meso 1) of the evolutionary trajectory, the emergence of ideas adopted by a mesopopulation and their first actualisation occur at the microlevel. Following Schumpeter's point of view on entrepreneurial activity [31], this phase is dealing with an active entrepreneur showing ingenuity under conditions of uncertainty and risks. Moreover, this entrepreneur is able not only to overcome scepticism proposing a new rule, but he also can take a fresh look at the well-known rule. Besides, he may even find sources of funding for his activities to build a mechanism for the implementation of the new or updated rule. If successful, the targeted actions of the economic agent may change the existing boundaries of entrepreneurial activity and perhaps alter the essence of this activity. At the same time, as current practice shows, a discoverer or carrier of a new rule can be not only the manufacturer of new goods and services but sometimes a consumer revealing demand for products and services not previously produced [32].

In the second phase (Meso 2) of the evolutionary trajectory, the adoption and adaptation of the novelty at the local level, i.e. diffusion of innovation and its support in the economic system, take place. The macro-effect of the phase is the beginning of the destruction of the prior coordination and re-coordination caused by reformatting the behaviour of actors. It is a result of the spread of the new rule. This process of the institutionalisation is an essence of the Schumpeterian approach to economic evolution.

Meso 3 is the boundary and final phase at which the retaining and replicating of the rule and at least the preservation of its carriers occur, and the establishment of a new macro-order takes place. The phase is a well-structured state in which innovation is already introduced into the system, and metastable structures provide the basis of the order. Profit is at a reasonable level; uncertainties have completely transformed into risks; actors' expectations are based on ongoing experiments and comparisons of their results. Technology is widely initialised and adopted by a significant number of users, and markets using the technology are transforming into large-scale ones.

As for the NIS approach, it is worthwhile to note that although here the emphasis is not explicitly made on dynamics, the main (core) functions of NIS processes take after the abovementioned characteristics of the mesotrajectory phases. These functions of NIS can be established from the existing definitions of the national innovation system (see, for example, [6–9]). One can easily see the following ones: creation (generation), storage, distribution (diffusion or transfer) and effective economic use of knowledge. The similarity of the content of NIS functions and phases of mesotrajectories is obvious. However, it is worth point out the task of knowledge retaining is absent among the NIS core functions. Maybe this task needs combining with such a score NIS function as storage. The newly expanded role, on the one hand, ensures the corresponding institutionalisation of the technological regime. Thanks to the task, technological innovation is accepted by a significant number of users and the markets where it is realised become mass. On the other hand, the excessive conservation of the technological regime can generate a track effect slowing down the technological development of the country. Consequently, the mesotrajectory can be presented as a sequential process of performing core functions on the different phases.

Let us also assume that there are two evolutionary mechanisms at work in mesotrajectories. The first of them is the mechanism of natural selection, and the second is the mechanism of spontaneous mutation, that is, the interruption of evolutionary equilibrium. The actions of these mechanisms rely heavily on existing tools for the selection and development of technological and market niches. The niches can both support the functioning of the dominant socio-technological regime and contribute to the formation of a new, more progressive one.

5. Meso-units passing through the phases of a mesotrajectory in the NIS

So, let us turn to the analysis of the mesophases of the innovative development trajectories and split every phase into two sub-phases. We represent Meso 1 as the sequential-parallel processes of creation and diffusion of open codified knowledge (subphase 1.1) and the methods of transforming open knowledge into pre-competitive one (subphase 1.2). Meso 2 contains the processes of shaping a new selecting (market) environment (subphase 2.1) and the development of the pull of this environment (subphase 2.2). Finally, Meso 3 combines two processes:

- formation of an exit from the previous development track (subphase 3.1);
- introduction of a new one, in particular, construction of new mass-consumption environment (for instance, the market for goods and services produced according to the new rule) and maintenance of its metastability (subphase 3.2).

It is worth to note that the first attempt introduces such phase portioning belongs to [11]. However, the proposed partition is somewhat different from that of the just mentioned work. We will not specifically analyse the difference between the formulations. Let us only note that the partitioning does not contradict the meaning Doppfer' one. The terms defining it are closer to specialists whose activities are directly related to the analysis of innovation processes. Besides, we included in the third mesophase the process of destruction of the previous development track, which Dopfer did not single out at the beginning of the phase.

5.1 Mesophase 1: origination of an idea/rule and meso-units shaping

The first phase starts a process of de-coordinating the selective environment (particularly, market) and creating new complex knowledge. In the first subphase, public policy has the objectives: 1) direct support of basic research; 2) creation and support of open information channels, that is, mechanisms for decoding and transfer available codified knowledge [20].

The transmission or transfer of codified information through an open information channel is an essential element of knowledge diffusion. It allows ensuring the process of pre-competitive cognition and technology invention if the acquisition of knowledge that is not special but generic enables its application in a reasonably wide range of areas. It is all the more relevant as the actor is unable to realise an available technological stock without additional scientific knowledge of an academic nature. The absence or ineffective operation of the open information channel creates gaps between the first and second subphases and significantly reduce the efficacy of the latter.

In the second subphase, the government supports for the channel for converting and transforming open knowledge into pre-competitive one [20]. Its content is to keep:

1. the functioning of technological niches implemented, for example, in business incubators or initial stage venture business;

2. intra-company R&D incorporated in setting up technologically new processes and products;

3. NIS actors' cooperation in the generation of pre-competitive knowledge. At this phase, the activity of population actors occurs under conditions of significant uncertainty (see Section 2). The active innovators need information, organisational and financial assistance from the government.

It is worth noting that at this phase, the activity of population actors occurs under conditions of significant uncertainty of a result (see Section 2.1). The active innovators need information, organisational and financial assistance from the government.

Technological niches. Using a niche enables NIS actors to counter emerging threats in development trends (for example, environmental degradation and reducing market demand). In these cases, innovators work in niches in the hope that they will help smooth and diminish these threats, while also through a series of technical improvements will be able to take into account the nature and future dynamics of the pressure of the selection environment.

As mentioned earlier, forming technological niches, it is necessary to take into account that in the socio-economic environment, in contrast to the biological one, there should be a co-evolution of technology and the selective settings [33].

It means that the selective environment is not steady and not exogenous to the evolution of the group of carriers of the technological rules. Therefore, consumers cannot be considered in isolation from producers and investors.

Niches make a protected technological space in which inventions are tested and become a starting point for radically new technologies and products. The actors' population in the niche can include both actors of the previous technological regime and new players, carriers of new technologies. The process of growing technology and evolutionary learning help generate demand for technology and its products. They also include proto-markets, where the first interactions between producers and users of these technologies and products take place. If the proto-market is successful, the technological niche turns into a rather broad market.

The protection of technological niches and their entry into the selective (market) space are organised by NIS actors investing in promising fledgeling technologies. Financial resources for the development of technological niches are private investments in strategic R&D and public grants or subsidies from the target users, for example, defence agencies.

Business incubators, technology parks, advanced technology programs, and support for pre-competitive cooperation between business and public organisations in the development of radical technologies can serve as a form to arrange public support for technological niches. There is a need in policy aimed at actors seeking the status of innovators who are able to create specialised technological niches themselves, and thus resist the established rut of development.

The implementation of the concept of technological niches in many ways enables us to create prerequisites for solving the problem of advanced innovative development, in particular, by forming quasi-evolutionary mutations.

5.2 Mesophase 2: rule adoption and diffusion in the selection environment

At the beginning of the phase, the first adoption of the rule by the market (selection environment) occurs. The randomness of the environment and its bifurcations give rise to uncertainty of innovation rule perspectives. If it is possible to reduce this uncertainty, then the turnover of innovations becomes large-scale [12], the rule belongs to a group. At the end of the phase, the significant population of rule-carriers is emerging. Its shaping allows saying that a mesolevel bringing future innovative changes has appeared in the economy.

Selection (or market) niches created for the new technological rules are tools that give an opportunity reducing the chaos of the environment introduce order and, ultimately, achieving the spread of the new rules among consumers. If the market acts as a selective medium, then at this phase, there is a transformation of pre-competitive into competitive knowledge.

The phase can be represented as two subphases.

At the first of them (subphase 2.1), a new selection (market) environment is shaped. It has a perceptual ability to adopt the proposed new technological ideas. Public policy supports the formation and development of selection niches for them (for example, within the technology parks and advanced technology programs, late stages of venture capital business supported by specialised tax breaks). Besides, to protect emerging niches, isolationist barriers that partially and sometimes completely block the diffusion of the innovation rule to competitors are raised.

At the second subphase (subphase 2.2), a new selection environment develops. It means that there are growth and blurring of the most successful (selection) market niches, that is, a conquest for market space by niche actors. The government innovation policy in NIS is aimed at supporting and developing the demand for new products produced according to new technological rules, new technological knowledge diffusion among producers and consumers. The policy facilitates the reduction of isolationist barriers and provides the operating of channels of commercial knowledge transfer [20] from the niches.

The sub-phases can be linked in the mesotrajectory. As a result, the second one turns out to be a continuation of the first. At the same time, it is worth recalling that the requirements for public policy at different sub-phases may come into an inevitable conflict with each other (see also Section 3). At the first one, the public policy should support isolationist barriers protecting the innovative rule owners. At the second subphase, it may turn out that the introduced protective barriers, being demotivators for actors to enter the population of rule carriers, prevent the expansion of mature niches into the market or other selection space. Therefore, there appears a need for mechanisms reducing the barriers.

This phase has to make certain the progress of the rules at the level of micro and macro inventions that appears in the previous phase, i.e. particularly, implement them to produce products useful to the consumer. A safe space for the adaptation of the rules can be organised in isolated niches (a separate environment). At the start of the phase, a niche product is scarce. However, if it successfully diffuses among consumers outside the niche, it can ensure the steady growth of its market. Consequently, the successful niche might put the corresponding meso-unit on the trajectory of increasing economies of scale.

Types of selection (market) niches. Within the niche, the direction of the evolutionary technological process is mainly determined not by variations of existing generations of technologies, but by changes in the selective environment. However, the changes in the selection environment of a niche can force niche actors not only to reject unsuitable technologies but also create a preferred technology option by organising a step-by-step process of improving existing options. This process of changing technological rules takes place in the interaction of producers and users.

The types of emerging niches should be distinguished both by the method of formation and by their content. According to the first item, we should distinguish two types of niches. One of them includes the niches that are the result of the transformation of the technological niches that arose in the previous phase of a mesotrajectory. The second one singles out the niches that are purposefully created for the organization of local adaptation and evolution of mainstream technologies that maybe are not widely spread in the country. In terms of content, it is necessary to take into account that some niches implement natural selection; that is, they prolong a continuous evolutionary process. In contrast, other niches provide a change in the direction of evolution, that is, intermittent development.

In other words, technological niches are often at the origin of selection (market) niches. As mentioned above, a successful technology niche generates some primary markets build by coalitions of actors-agents to test and develop new technologies. The proto-market can eventually transform into a niche market. The likelihood of such a transformation is high if the technologies presented on the proto-markets take into account a perspective for the co-evolution of producers and consumers in a certain market segment. These transformation mechanisms usually operate in developed countries at the stage of development based on innovations. In the initial stages of this transformation, small and medium-sized enterprises often act as original technology carriers [34].

Following the above, another option for the emergence of market niches is also available. In this variant, micro or macro inventions continuing the trends of the mainstream evolve in market niches. As a result of this isolation, the technology development can lead to the development of the technology for the local environment (including step-by-step improvement of known, in particular, imported technologies or the development and adaptation of inclusive options for advanced technologies). The emerging technology can also diffuse into other market niches contributing to the origination of new socio-technological regime in the economic system. If a certain degree of local maturity of the regime is reached, it penetrates the mainstream markets and begins to compete with the other regime modes that are widespread there. Niches of this development model can be shaped within special economic zones to create a pool of new technologies for the country. The implementation of the pool could be necessary to reduce the gap with the mainstream of technological development. The formation of market niches of this kind is typical for actors in developing countries undergoing the investment stage of development [34]. Moreover, large national companies act as actors of mainstream technology carriers if government organises their protection and support in the niches.

Transformation of technological niches into selection (market) ones. Considering the processes of formation of selection (market) niches for which technological ones serve as a prototype, it is worth to take into account the following circumstance. The radical technological changes are the result of a process of ether gradual changes, accumulated step-by-step cumulative innovation or rapid progressive changes accompanied by opening up new markets and creating new industries [33].

Following what has just been said, one can distinguish niches of natural selection and discontinuous equilibrium.

Niches of natural selection (quasi-classical evolution). In a selection (market) niche, the direction of the evolutionary process is determined not by the variations of emerging technology generations but by alterations in a selective environment. The alterations made actors not only reject unsuitable technologies but also forces them to organise a step-by-step process of improving the existing advantageous technologies. This process occurs in the interaction between a producer and user (see, for example, [32]) Besides, the carriers of the technology should take into consideration not only the market but also institutional factors of selection. As a result of the process, among the actors, the number of carriers of improved technology technologies increases. In contrast, the number of actors who have technologies with features unfavourable for the altered environment decreases.

Niches of intermittent equilibrium. However, periods of gradual accumulation of new technological features characterised by the absence of visible changes or minor shifts can be disrupted if technologies that have an intermittent nature arise. Then there are technological changes that are considered analogous to the so-called intermittent equilibrium, studied in biology [33].

Within the framework of this equilibrium, long periods of relatively steady dynamics of mesotrajectories, which are characterised by the accumulation of smooth evolutionary variations of technological species, suddenly end and there are leapfrogs to new types of technologies. The leaps originate at the Meso-1 phase in technological niches of interrupted (or punctuated) equilibrium. Mutations destroy the selection environment. Therefore, the task of the mesopopulation is to transform the technological niche of intermittent equilibrium into a selection (market) one to begin shaping a full-fledged environment. In other words, the goal is to turn the niche, eventually, into the widespread domain (mass market) that can provide the basis for changing the dominant socio-technological regime.

5.3 Mesophase 3: changing the old rule and retaining the new rule

At the Meso 3 phase, the main role is played by the dominant institutional or socio-technological regimes [35], which establish the prevailing system of meso-unit coordination. The socio-technological regime is characterised by the rules that define the technological (technical) structure and market development (user's preferences), as well as the processes of their regulation. In this sense, a regime is a set of sequential rules that are carried by a certain range of actors including firms, users and government. Changing the system of rules leads to a transition to a new type of mesotrajectory.

A particular socio-technological regime supports the dominant technology genes (see [33], pp. 607). A genotype of technology refers to the rules for how to produce, use and regulate specific products. The technology is considered as the constructions (analogous to the biological genotype) whose implementation in products and processes (technology phenotypes) is promoted by various firms. The functions of the regime also include such actions as transferring and storing the rules (see [33], p. 608–609). The technology genes determine the generality and differences between technological species.

Such components of the knowledge system stipulate the metastability of Meso 3 as routines, competencies, and the ability to use them. Conserving and preserving knowledge (rules) and reproducing them allows actors to create a space for step-by-step technological mutations. In this space, there is a dynamic balance of developing technological types supported by their incremental improvement and improvement.

In theory, a regime exists as long as its rules remain essential for the economic system. The fundamental nature of the rules is to maintain an optimal balance between increasing returns to scale (short-term effect) and the desired degree of diversity, i.e. the possibility of considerable recombination of innovations (long-term benefit) for the existing genotype of technologies. However, this balance cannot remain optimal for a long time due to the internal conflict between the achieved level of economies of scale and the demand for expanding the diversity of technological genotypes. The conflict causes a change in technological genotype after a while. Finding and implementing a new optimal balance may not be easy. Therefore, at this stage, there is a danger to fall into the trap of a well-worn track. In result, a systemic failure of the national innovation system takes place. This trap gives rise to the severe dysfunction of the NIS, that is, the failure to perform such its primary function as gaining and implementing innovative knowledge.

Resistance to changes in ideas, institutions, technologies, and the behaviour of actors can be an additional factor in maintaining the existing track. In addition, one can also attribute some historical restrictions to the resistance factor. In biology, such circumstances are referred to as a development constraint [36] or phylogenetic inertia [37]. In economics, this phenomenon is interpreted in terms such as dependence on the path of development, blocking the future path [38].

However, if a rule carriers' population passed Meso 2 manages to overcome this resistance and shape promising market niches external to the existing socio-economic regime, then the stability of the previous development track is violated. The search for a new technological balance starts, new technological genes that are not a continuation of the existing ones begin to dominate. New evolutionary shifts on meso-trajectories change the order at the macro level, and a new socio-technological regime appears. This mode initiates a new ordered (metastable) state with its structure and order.

Influence of niche development on the change of socio-technological regime. A significant factor in extending a life span or changing the dominant socio-economic regime is the process of spreading market niches. The set of market niches that coexist with the mode facilitates the stability of its functionality. Elements of such niches can be associated with global socio-technological regimes. The existence of the set of niches compatible with the socio-technological regime points out a mosaic of technological evolution. A similar idea of mosaic evolution of branching species is also present in biology [39].

If in the process of their development, all niches remain internal to the regime, then they support various elements of its functionality and realize its internal diversity. In the process of diffusion of innovative rules, thanks to the incremental changes in technologies and rivalry between them, the new socio-technological regime adjusting to the new requirements of the selective environment evolves. Its evolution gives rise to a new equilibrium of the system. In the process of diffusion of innovative rules, thanks to the incremental changes in technologies and rivalry between them, the new socio-technological regime adjusting to the new requirements of the selective environment evolves. Its evolution gives rise to a new equilibrium of the system.

The increased variability of the niches leads to their transition to the category of external ones if the changes introduced in niches are fundamental. The active progress of external niches can ultimately lead to the transformation of the socio-technological regime, that is, the formation of a new evolution direction. In this case, the situation changes radically. First of all, it may be associated with the emergence of market niches of punctuated equilibrium and powerful incentives for the actors of the innovation system to invest in these niches.

There may also be another case when the rules changing so after some correction allow actors of mesopopulation to keep previous dimensions of development. As a result, the dominating regime improves and adapts to the new requirements of the selection environment. For example, the pressure of growing demand for electric cars forces traditional car manufacturers to focus their efforts on meeting environmental needs of the social environment within the framework of the previous model of a vehicle with an internal combustion engine. Thus, the existing socio-technological regime is being adjusted.

As it follows from the above Meso 3 should be divided into two subphases:

1. Getting out of the rut of previous development.

2. Forming a new track of development.

To pass these subphases, it is necessary:

1. To initiate the narrowing of the differences between the country's technology pool and the existing variety of technological genotypes in the world.

2. To determine the dimensions of necessary technological shifts from the positions of existing technological genotypes in the world.

3. To facilitate the penetration of technology genotypes created at the Meso 2 phase to mass markets.

The solution of the first and second tasks determines the conditions for getting out of the previous development track isolated from the technology mainstream. The country must participate in international value chains and use international competition as a driver of the necessary shifts. The result might be the design of socio-technological regime that, on the one hand, has common technological genotypes with regimes of advanced countries, and, on the other hand, satisfy the particular needs of the country's technological development. Carefully thought-out government policy is needed to implement such a manoeuvre [21].

Public policy should encourage the diffusion and development of the wide range of technologies to expand the diversity of those that promote structural shifts towards more advanced technological genes. It can also foster the development of modular technologies facilitating innovative combinations and exchanging information, so that cross-fertilisation or pollination in modular innovations become possible. The use of recombination of technological innovations can be a key element to get out of the rut trap, for example, through switching to environmentally friendly technologies.

6. Conclusions

Thus, one can present a mesotrajectory as a sequential process of performing core NIS functions on the different its phases.

The study of the problems of regulating the mesotrajectory should take into account that the focus must be on the impact of policies on two groups of factors. The first is external factors whose action is manifested in the existence of high risks and uncertainties distributed over different stages of the mesotrajectory. The high risks and uncertainties generate strong disincentives to perform core NIS function. The second group occurs within the mesopopulations, some of whose actors shape the factors of the group and can be teemed into factor-forming populations.

Regarding the first group of factors, two conclusions can be drawn. First, government policy that aims to mitigate inherent risks and uncertainties must be dual. It means that, on the one hand, the innovation system should facilitate compensation for a part of uncertainties and risks inherent in innovation activity, and, on the other hand, make the actors carry a significant portion of risks themselves. Secondly, if the NIS is intended for regulating the effects of externalities (e.g. technological spillover) on different phases of the trajectory, then its task is to reduce risks of their adverse influences on the evolutionary trajectories. In this case, the policy should maintain some balance of these influences on different NIS core functions on mesotrajectories. Notably, it could provide a choice between a strong or weak public support of intellectual property rights.

The actions of factor-forming populations also contribute to realising the core NIS functions on the different phases of trajectory. It is worthwhile to organise support and expansion of those factoring-forming populations that have a positive effect on the phases of mesotrajectories. If the factor-forming population harms the trajectory phases, then the targeted policy should neutralise it, in particular, weakening this actors' population. In the case, when a factor-forming population demonstrates both positive and negative influences on the trajectory, the policy should facilitate a transformation of the actors' behavioural models dominated in the population. It means that it may assist in strengthening the useful parameters of the models and eliminating or smoothing their harmful ones.

A significant limitation of the neo-evolutionary approach is not taking into account the fact that in addition to changing the size of the mesopopulation and transforming the innovation rule, it is necessary to consider also other its characteristics. Among them, innovative resources of the population, elements of the production processes embodying the rule into products and technologies. One of the most critical innovative resources is the knowledge that underlies the technological rule.

Therefore, it is necessary to consider populations of system actors not so much as a set of carriers of the knowledge-rule pair, but as a set of carriers of the knowledge-rule-resource triple. At the same time, it should be taken into account that knowledge as a resource can be a source of innovative rent for actors. The contest for its possession can break the continuation of mesotrajectory. The isolationist barriers built by the firm and the state to preserve the innovative rent rights largely facilitate the emerging gap. This gap gives rise the problem of public regulation of innovation diffusion in mesotrajectories. The problem is not simple. On the one hand, monopoly isolationist barriers protecting market niches promote the development of radical technologies. However, on the other hand, they make a hindrance to diffuse innovations into the market space.

However, the reasons for the discontinuity of the trajectory may not only the factors mentioned above. They can include both the origin and spread of disruptive technologies. The emergence and development of these technologies can disrupt the relative stability and continuity of the former mesotrajectory due to the appearance of significant mutations of technological species. The appearance of such gaps poses difficult tasks of regulating the mesotrajectory and managing technological and market niches.

Also, embedding the design of niches into the three-phase model of mesotrajectories of the new evolution theory is, in our opinion, an essential theoretical and practical aspect of its development. The introduction of a system of niches gives an opportunity to tie together better all three mesophases. Moreover, it allows considering more adequately control loop of the trajectory. In particular, it concerns the incorporation of evolutionary and intermittent development into the dynamics of meso-units at the first two mesophases and the mechanisms for changing or prolonging the span of the socio-technological regime at the third phase.

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