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THE EMERGENCE OF POLYCENTRIC STRUCTURES AND THEIR PRACTICAL APPLICATION IN THE MODERN ECONOMY[1]

O.V. Nikulina, Doctor of Economic Sciences, Professor, Kuban State University,
E-mail: olgafinans@mail.ru
350040, Russia, Krasnodar, Stavropolskaya st., 149.
Y.A. Yegorov, Ph.D. Economics, Researcher, University of Vienna, Austria,
E-mail: yury.egorov@univie.ac.at
1090 Vienna, Oskar-Morgenstern-square, 1.

The purpose of the paper is to develop a model revealing consumer preferences towards cities of different sizes, which can explain the emergence and optimality of polycentric urban structures in the modern economy. The paper provides microeconomic foundations for the existence of polycentric urban structures on the basis of consumer preferences. It is shown that clusters of smaller urban centers can sometimes give higher utility than a large urban center. The model is based on generalization of a central business district model and takes into account not only the distance of commuting, but also its convenience. Some examples of polycentric urban structures of different topology are provided. It is proposed to apply the model of polycentric structure to form innovative clusters in the regions. Innovation clusters are formed on the basis of the existing specialization as a result of integration interaction of the innovative process participants. A polycentric structures model allows for formation of innovative clusters in regions when integration of the cluster members around the scientific core allows them to use the innovative potential more effectively and provides an opportunity to save on transaction costs.

Key words: polycentric structures, economic utility, optimization, innovative cluster.

1. Introduction

The spatial pattern of development of urban structures is quite complex. Percik (1999) [2] in chapter 1 presents a variety of agglomeration patterns. Typically, a territorial structure of large urban agglomeration includes central city (the core of agglomeration) and satellite cities.

The temporal development changes agglomeration patterns. Some cities of the same order being originally isolated become a cluster. There are many examples of these types in industrial areas (Ruhr in Germany, Southern Poland, Ural agglomeration in Russia).

Now we observe more polycentric urban structures that have replaced monocentric. There are several types of those structures. Even the structures can be classified along different dimensions. The first classification is linked to the relative role of different elements in urban cluster: a) symmetric with two or more cities of about the same population, b) asymmetric with one leading city and several satellites.

The second classification is related to spatial topology of urban structure. Hexagon structure of cities (of the same importance) on flat, homogeneous and limitless surface was first suggested by Christaller (1933) [5]. In his theoretical predictions he relied on traffic, market and administrative principles.

Later the principles of urban settlement became a part of microeconomic theory. Alonso (1964) [3] and Fujita (1989) [6] present the theory of central business district (CBD), where land rent is derived under the assumption of commuting of all citizens to the city center where all jobs are assumed to be located.

Fujita, Krugman and Venables (1999) [7] suggest the principles of new economic geography based on the interest of consumers towards variety of goods that can be produced in several locations. This gives rise to theoretical concepts of polycentric models. However, by going to a continuum of varieties, in most of their models they have forgotten the original continuity of geographical space.

The current literature on urban studies recognizes the importance of polycentricurban systems; a good survey of recent literature is provided in Kloosterman & Mustard (2001) [8]. The importance of commuting for the analysis of these structures is obvious.

The goal of this paper is to develop a model revealing te preferences of consumers towards different sizes of cities that can explain the emergence and optimality of polycentric urban structuresin the modern economy.

The paper consists of 7 points. Section 2 describes the interaction between spatial structures and market forces. Section 3 presents a model for consumer location when the preferences for both goods and services are taken into account. Section 4 compares utilities for polycentric and monocentric cities. Section

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5 presents some applications. In section 6 proved the possibility of using the model of polycentric structures to the formation of innovative clusters in the regions. Section 7 concludes.

2. Spatial Structures and Market Forces

Spatial structures are similar to links between atoms that make them molecules. Each structure can exist under certain conditions for its optimality and evolves over time. The difference between spatial economic structures and non-spatial equilibrium in economics is in the presence of frictions. Structures may not be able to adjust to any small changes in market forces, but they may stagnate under long push of market forces. Some principles of economic approach towards structures have been developed by Yegorov (2011) [12].

Empirically, we observe quite complex spatial structures of cities. It is interesting to find in what sense they are optimal and whether market forces can bring some equilibrium and optimality. One important difference between spatial structures and normal goods is that spatial structures involve fixed cost of building houses and plants in particular locations.

The optimality of spatial patterns is a function of transport costs. If transport costs change, the old locations and plant size can be no longer optimal. Russian transition with its move to world price for oil has made the location and sizes of dachas no longer optimal; the corresponding model was described by Yegorov (1999) [11].

Mascarilla-i-Miro&Yegorov (2005) [9] have developed a relatively simple model of an optimal city size. They assume scale economies in industry that allow for paying higher wage in a larger city. On the other hand, larger city requires higher commuting costs to CBD and thus higher land rent in its center. The optimal city size is a city with such population that the difference between wage and price index is maximized. It was shown that this optimal population depends positively on scale effects in industry and negatively on unit distance transport costs. When two cities coexist and migration is allowed, tow cases are possible: equilibrium split of population among two cities and disequilibrium, when one city "sucks" all the population [13].

In modern Russia we observe different tendencies. On one hand, Moscow has too high scale economies and "sucks" a lot of population from smaller cities and rural areas. But this paper will be more about equilibria in polycentric urban areas.

2.1. The Role of Scale Economies

Arthur (1994) [4] investigates the role of scale economies for the processes of economic equilibrium and disequilibrium. He also analyses the role of historical events on the process of emergence of spatial patterns that can "lock-in" suboptimal structures and make them persistent.

Yegorov (1997) [10] shows that even a monopolistic firm might not survive if there are too few consumers; they simply cannot cover the fixed cost. This explains why there are no theaters or stadiums in very small cities or rural areas.

If we consider an array of services, we can derive the smallest city size that can provide it. For example, in a city with population N we can have a cinema and small shop. If its size grows to *2N*, hospital is added. A city of size *3N* might have dramatic theater, while only a city of size *4N* can afford to have an opera, and so on. Thus, a larger city can provide a larger set of services.

3. Individual Location Decisions

The derivation of the optimal monocentric city is based on Mascarilla-i-Miro&Yegorov (2005) [9]. Consider a radial city with uniform population density and identical type of housing. Urban economics endogeneously defines the outer edge of a city, r^*, as a point, where residential land rent, R(r), equals to agricultural rent, R_a. Consider a CBD in the city center, with agents commuting to it every day. Let t denotes transport cost per unit of distance. To make agents indifferent across locations, one needs to give them the same utility, and this happens if additional transport costs tr are exactly offset by land rent $R(r)$, which enters housing price:

$$R(r) + tr = R_a + tr^*. \qquad (1)$$

Hence, for constant R_a and t, total expenditure on housing and internal transportation depends linearlyon city spatial size, r^*. If population density $_{\rightarrow}$ is constant in a city, then its population is $N = \prec_{\rightarrow}(r^*)^2$.

Assume that agents spend a fixed fraction of their income on tradable goods, and other fixed fraction – on housing rent and internal transportation. Assume that tradable goods have identical price across different cities. Then, by arguments from the previous paragraph, the price index will depend linearly on city spatial radius, $P=1 + c\ r^*$, where c – is the rate of change of prices for housing and public transport in different cities.Expressing everything through population N, and denoting new coefficient by $\odot$ (it depends positively on internal transport cost, t), we get:

$$P(N) = 1 + \odot\sqrt{N}. \qquad (2)$$

3.1. Assumptions

1. All agents are identical with respect to preferences and income.

2. There is one generalized good in the economy (denoted by G) that includes all consumption ítems (food, clothing, housing, etc) except for services. The price index of this good depends positively on the city size (see the arguments above):

$$P(N) = 1 + \odot\sqrt{N}. \qquad (3)$$

3. There are n services, $S_i, i = 1,2,\dots n$, available in the economy, and each has unit price.

4. Cities can be only of discrete set of sizes, with population $N=jM$, where j denotes city type and $j = 1, 2, \dots$. Any city of type j offers $j=N/M$ types of different services.

5. There exists a discrete set of potential locations for a city at equal distances d from each other (hexagon structure). Each city can be of size $jM$and offer j services, where $j=1,2,3, \dots$. (This is quantization of space).

6. Consumers have the following utility function (it is Cobb-Douglas in composite good and

services but is discounted by price index in this city, that depends on *N*):

$$U(N) = \ln[G^{1-a} \prod_{i=1}^{n} \frac{1}{1+ \odot\sqrt{N}} S_i^{\frac{a}{n}}]. \quad (4)$$

7. Agents spend their income w on goods, services and commuting to services. If they live in a city of size *jM* (of type *j*), they need to commute to other locationsfor services. Commuting cost does not depend on the quantity of consumedservice[2]. If the city is of the type j, j services can be provided locally (without transport cost, since we neglect transport cost inside the city) and for the rest *(n-j)* services it is necessary to commute to other cities. Hence, the budget constraint is:

$$w(j) = G + \sum_{i=1}^{n} S_i + t(n-j)d. \quad (5)$$

3.2. First-Order Conditions

For the consumers from each city of size *jN* we have the following Lagrangian:

$$L_j = (1-a)\ln G + \frac{a}{n}\sum_{i=1}^{n} \ln S_j - \ln\left(1 + \odot \sqrt{M_j}\right) + \ell_j[w - G - \sum_{i=1}^{n} S_i - (n-j)td]. \quad (6)$$

The first order conditions lead to the following equalities:

$$\ell_j = \frac{1-a}{G};\ \ell_j = \frac{a}{nS_i};\ w = G - \sum_{i=1}^{n} S_i - (n-j)td. \quad (7)$$

It is clear (from the property of Cobb-Douglas function) that first one need to subtract commuting cost for services from the income, and then to split it proportionally to services and goods, depending on utility coefficient a. The solution can be formally written as:

$$G(j) = (1-a)[w-(n-j)td;\ S(j) = [w - (n-j)td]. \quad (8)$$

4. Comparison of Monocentric and Polycentric Utilities

In a monocentric city of size *nN* there are no additional transport costs, because all the services are provided inside this city. Hence,

$$G(n) = (1-a)w; S_i(n) = \frac{aw}{n}. \quad (9)$$

Let us calculate utility for both cases and then divide by common factor. Finally, we need to compare utility index for polycentric city, f_j, with one for monocentric city, f_n :

$$f_j = \frac{w-(n-j)td}{1+ \odot\sqrt{M_j}},\ f_n = \frac{w}{1+ \odot\sqrt{M_n}}.$$

(10)

It makes sense to start from graphical analysis. Consider the dependence of functions on income w, keeping other parameters constant. For monocentric city, we have a straight line, starting from the origin, with a positive slope. The higher is n, the lower is this slope. The corresponding graph for f_j ; $j = n-1$, starts from $w = d$, but has a steeper positive slope. Thus, both graphs intersect at some income level; let us name it w_1. Thus, for $0 < w < w_1$, monocentric city gives a superior utility. Starting from $w = w_1$, a city of size n - 1 dominates, but not forever. If we draw a graph for the city of type n - 2, the curve starts at $w = 2d$, but has higher slope. It first intersects the curve f_n, and later the curve f_{n-1}. For $w_1 < w < w_2$, the city of type *n - 2* gives the highest utility. The process can be continued.

4.1. Comparative Statics

Consider the process of urban development under economic growth. Assume that all variables stay constant, but income is increasing. Then, a monocentric city becomes suboptimal at some stage, i.e. for $w > w_1$. Agents are better off to live in a smaller city. If we have initially $n = 2$, then this city can be split into two cities of the same size, but twice smaller. Usually cities do not grow on empty spaces. It means that we can observe migration from monocentric city to another city, which was initially smaller, until both cities will stay with similar population. Also, these cities may split its services. In other words, a new city will grow and take over one of important services previously supplied by monocentric city. Now assume that n is larger (let say, 4). Keeping population constant, this system simply cannot be transformed into two subunits of size 3. Then, as income passes the first threshold point, w_1, no structural change will occur. With further growth of income, at point w_2, agents are indifferent to live in a monocentric city or a city of size 2. We can observe split into two cities of size 2 here.

[2]One service can be a visit to doctor, other – going to the theater, third– visiting library. One needs to have a trip which costs independently on the money paid for daily consumption of service.

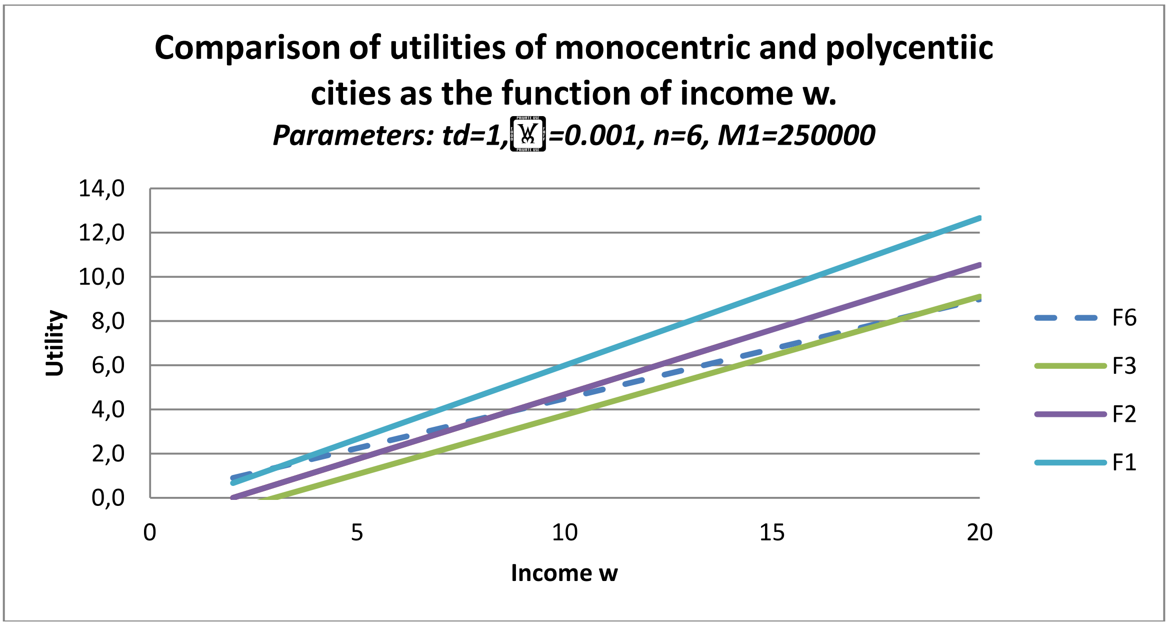

Fig.1. Comparison of consumer's utility in different cities as the function of income

Fig.1 shows the utilities in large city of the population 1.5 million (dashed line F6) versus utilities in smaller cities. We observe that smaller city with the population 250000 (line F1, *j=1*) becomes superior already at incomes *w>3*, while the line F2 gives higher utility for incomes *w>8*. This means that agents with higher income tend to migrate to suburban areas, because additional transport cost to access services in large city for them is lower than the benefits from overall lower price index in smaller city.

5. Applications for Russia

While there are many urban clusters in Russia, we will focus on few examples with different topology. The first example is the city of St. Petersburg, a huge agglomeration in North-West Russia. Historically the city was surrounded by summer residences to tsars in Peterhof, Pushkin and Pasvlovsk. Now there are more municipal towns around St.Peterdburg (see Fig.2). Those settlements grew in population. For example, the population of Peterhof grew from 11.3 thousand inhabitants in 1897 to 73.2 thousand in 2010. The relocation of some part of St. Petersburg State university to Peterhof in 1970s was driving population growth but also contributed to increasing commuting between St.Petersburg and Peterhof. In a similar manner, there is substantial commuting between other municipal towns and the core city (St.Petersburg), partly for job and partly for other services. In a natural manner, price index of housing in some municipal towns around St.Petersburg (Kolpino, KrasnoeSelo) is lower than in St.Petersburg.

Fig. 2. Polycentric structure, St.Petersburg [14]

Saint Petersburg consists of eighty-one municipal okrugs and nine municipal towns – Kolpino, Krasnoye Selo, Kronstadt, Lomonosov, Pavlovsk, Petergof, Pushkin, Sestroretsk, Zelenogorsk. These municipal towns can be viewed as small cities, while the whole system is polycentric urban structure.

Large Sochi is the major resort on Black sea. It has the population of 368 thousand people (2013) which is distributed along the coastline of 145 km long in 4 districts with centers in Sochi itself (145 th.), Adler (89 th.), Khosta (64 th.) and Lazarevskoe (68 th.) [15].

Winter Olympics 2014 has changed the local infrastructure. Recently the ski complex in Krasnaya Polyana has been added, so that Sochi became not only the place for summer, but also for winter tourism. Since not all tourist services can be located in one point, good and not expensive transportation between different districts of Sochi.

The model of this paper can also be applied for tourism. A tourist has an interest to visit many historical objects, and not all of them are located in one city. That is why he has to choose the hotel location to maximize utility taking into account the cost of trips to different places of interest. St.Petersburg and Sochi are both touristic centers, and the model can be applied for them as well.

6. Possibility of formation innovative clusters in the region based on a model of polycentric structures.

Polycentric model structures also clearly demonstrates the possibility of formation innovative clusters in the regions. In this case, participants clustered polycentric structure will serve government agencies, enterprises and entrepreneurs, research and educational institutions and organizations as well as consumers of goods and services, which include both legal and natural persons. It should be noted that innovative clusters are always formed around the nucleus, which is based on scientific and educational institutions and organizations with innovative potential [1].

The decision on the integration of economic agents in the cluster are influenced by two factors: the ability to share innovative potential and opportunity cost savings.

In this connection we can propose the following model of cluster associations of enterprises, based on the desire of economic agents to maximize their benefits at the expense of synergistic effect. We can assume that the cluster is formed and maintained, if the added value created by the participants, and the savings on transaction costs associated with the absence of the need to carry out transactions on the market will not be outweighed by the additional transaction costs of innovative products that arise when running a cluster.

Even with equality we now value added in terms of work both independently and as part of the cluster enterprise more profitable from an economic point of view to work in a cluster, as transaction costs in the cluster is less than the sum of all costs of the enterprise, to innovate on their own.

Innovative enterprises cluster is a strategic inter-organizational network of innovative character, combining resources and core competencies not only businessmen, but also research organizations, educational institutions, government agencies, consumer product innovation. During the formation of a cluster of several n-economic entities formed some economic effect of integration and interaction of economic agents, surpassing the effect of self-functioning individual on a certain value, defined as the synergetic effect. The effect of the joint interaction of economic agents cluster can't be determined as a simple sum of the results of innovation activities of individual participants as integration interaction generates a synergy of their activities, resulting in the possibility of sharing the resource base, innovative capacity and experience that each member brings to the development of their innovation. Synergies from the integration and interaction of economic agents in the cluster exceed the sum of the effects of their operations on their own outside the cluster.

Clustering processes in the Russian economy are rudimentary, despite the fact that this issue is being actively considered by many scholars and is widely represented in the economic literature. In practice, unfortunately, clustering processes are implemented very slowly, due to the problems of development of integration processes in the economy. Clusters are created based on stable relationships between economic actors in the process of innovation, and are usually formed on the basis of the existing backlog of industry specialization. Since innovation cluster has special properties that distinguish it from ordinary industrial clusters, in the author's interpretation of innovation cluster is considered as the super-system that integrates the efforts of individual participants in the innovation process and allows you to use the innovative potential of industrial enterprises and scientific organizations that form the core of the innovation cluster and ensure its development. The main stages in the formation of clusters based on existing integration processes in the national economy, which are not always clear.

On the example of the Krasnodar Territory consider the current stage of clustering. By historical rules of business turnover, linkages and relationships between economic entities, a favorable investment climate, favorable geographical position in the economy of Krasnodar Territory was formed industry specialization, which allows you to select three clusters: tourism cluster comprising a sanatorium sphere; agro-industrial cluster based on the development of agricultural sectors; transport cluster, allowing the system to actively develop the communication interactions between economic agents. Currently, the economy of Krasnodar Region formed a new type of clusters that are associated with the implementation of mega-projects in the region. For example, the project "The Olympics - 2014" contributed to the formation of mountain-skiing cluster, and clusters based on new and innovative for the region objects that will promote the development of recreational areas.

Industry clusters are formed on the basis of sectorial specialization and also include strong ties between enterprises, which in a single process create a product. However, innovation clusters require mandatory availability of scientific ideas, which is the basis of innovative development, which is generated by the scientific community and implemented by industry, turning into innovation as a result of practical implementation. In many developed countries, scientific ideas generated by the system of higher education that in the modern economy is being promoted in the Russian practice, when based on the optimization of integration processes scientists universities have the opportunity to put their ideas into practice scientific industrial companies. Just innovation clusters should facilitate the connection of scientific ideas with practical activities of industrial enterprises and to develop innovative processes that ensured by the attraction of the innovation process, their concentration around the cluster core.

7. Conclusions

The model of this paper explains an emergence of polycentric urban spatial structures. They take into account transport cost which is increasing function of distance. Spatial separation between cities is derived as optimization decision.

The model takes into account the demand of consumers for particular services. A resident of small city is paying less housing price due to lower location rent, but has to commute to other cities to fulfill her demand for services that are not locally available. The balance of these factors leads to emergence of different spatial patterns. The wage *w* plays the role of order parameter (in the sense of Haken's synergetic approach). With economic growth, wage increases, and spatial pattern changes, like in kaleidoscope.

Polycentric model structures can reveal the possibility of formation of innovative clusters in regions where integration of cluster members around the scientific core allows them to more effectively using the innovative potential and provides an opportunity to save on transaction costs.

References

1. Nikulina O.V. Institutional approach to the formation of innovation capital of industrial enterprises in the economy clustering. *National interests: priorities and security*, 2012, no 46. pp. 19-26.

2. Pertsik E.N. *Cities. Geography of World Urbanization*. Moscow: International Relations, 1999, 382 p.

3. Alonso W. *Location and land use*. Cambridge. Harward University Press, 1964.

4. Arthur W.B. *Increasing returns and path dependency in the economy*. Michigan Press, 1994, 201 p.

5. Christaller W. Die zentralen Orte in Süddeutschland. Gustav Fischer, Jena, 1933.

6. Fujita M. *Urban Economic Theory: Land Use and City Size*. Cambridge University Press, 1989, 367 p.

7. Fujita M., Krugman P., Venables A. *The Spatial economy. Cities, Regions and international trade*. The MIT press, Cambridge, Massachusetts, 1999, 367 p.

8. Kloosterman R., Musterd S. The Polycentric Urban Region: Towards a Research

Agenda. *Urban Studies*, 2001, Vol. 38, no 4, pp.623-634.

9. Mascarilla-i-Miro O., Yegorov Y. Modelling Functional Area and Commuting Flows. *Cuadernos de Economia*, 2005, Vol. 28, pp. 39–56.

10. Yegorov Y. Self-Organization of Spatial Structures. *Santa Fe Institute WP*, 1997, no 55, 18 p.

11. Yegorov Y. Dacha Pricing in Russia: General Equilibrium Model of Location. *CASE-CEU Working Paper*, March 1999, no 18, Warsaw, 27 p.

12. Yegorov Y. Elements of structural economics. *Evolutionary and Institutional Economic Review*, 2011, Vol. 7, no 2, pp. 233-259.

13. Yegorov Y., Trullen J. Polycentric urban models. *Unpublished manuscript*, 2003, University of Barcelona.

14. *Saint Petersburg*. Wikipedia, the free encyclopedia. Available at: http://en.wikipedia.org/wiki/Saint_Petersburg (accessed 15.01.2015).

15. *Sochi*. Wikipedia, the free encyclopedia. Available at: http://en.wikipedia.org/wiki/Sochi (accessed 15.01.2015).

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ВОЗНИКНОВЕНИЕ ПОЛИЦЕНТРИЧЕСКИХ СТРУКТУР И ИХ ПРАКТИЧЕСКОЕ ПРИМЕНЕНИЕ В СОВРЕМЕННОЙ ЭКОНОМИКЕ

О. В. Никулина, докт. экон. наук, проф.,
Кубанский государственный университет, Россия, 350040, г. Краснодар, ул. Ставропольская, 149.
Ю.А. Егоров, докт. экон. наук, научный сотрудник,
Венский университет, Австрия, г. Вена, 1090 Вена, Оскар-Моргенштерн-площадь, 1.

Цель данной статьи заключается в разработке модели исследования потребительских предпочтений относительно отличных по размеру городов, что может объяснить возникновение и оптимальность полицентрических структур в современной экономике. В данной статье рассматриваются микроэкономические фундаменты существования полицентрических городских структур на основе потребительских предпочтений. Показано, что кластеры меньших по размеру городских центров зачастую обладают более высокой общественной полезностью, нежели крупные городские центры. Модель основана на генерализации образца центрального делового района, где учитывается не только расстояние, преодолеваемое во время ежедневных поездок из пригорода на работу в город, но и удобство самих поездок. Ниже приведены некоторые примеры полицентрических городских структур различной типологии. Предложено применить модель полицентрической структуры к формированию инновационных кластеров в регионах. Инновационные кластеры формируются на базе существующей специализации в результате интеграционного взаимодействия участников инновационного процесса. Модель полицентрических структур позволяет раскрыть возможность формирования инновационных кластеров в регионах, когда интеграция участников кластера вокруг научного ядра позволяет им более эффективно использовать накопленный инновационный потенциал и обеспечивает возможность экономии на трансакционных издержках. Статья выполнена в рамках работы над грантом РГНФ №14-12-23006а(р) «Методология формирования кластерной архитектуры инновационного развития экономики Краснодарского края».

Ключевые слова: полицентрические структуры, полезность, оптимизация, инновационный кластер.

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