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Rationale of the Optimal Location of Production: a System Approach

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Abstract
The optimal decision regarding the place of production is an essential, sometimes determining factor of its effectiveness. The main drawback in substantiating the optimal location of production is the lack of a system approach to accounting in the analysis of potential sales markets. Orientation, when justifying the optimal location of production, only to some particular sales market (and orientation to specific sales markets is necessary both in terms of taking into account the costs of moving the benefit from the place of production to the places of consumption, and in terms of production capacity, since it depends unit cost of production) is erroneous because it does not take into account many other competitive options. The article develops a system approach to rationale optimal locations and production capacity, based on a comparison of combinations of locally optimal places, the total production capacity of which is equal to the total (system) demand. The variant of combinations of locally optimal places with minimal total costs is systemically optimal. The result of solving the problem will be information about 4 parameters of the production of benefit: "where?" (in what places), "how much?" (in each of these places), "how?" (with what technology in each of these places), "for whom?" (sales markets for each of these places). The system approach proposed in the article to rationale the optimal location of the production of a single benefit can be adapted to a more complex situation, when the optimal location of the production of several benefits is justified at the same time. Further research is promising in the direction of a clearer determination of the boundaries of the space of possible location of production, as well as in the direction of studying the possibility of aggregating potential sales markets.

Keywords
Location of production, System approach, Locally optimal place, Systemically optimal place, Space of possible location.

Introduction

The optimal decision regarding the place of production is an essential, sometimes determining factor of its effectiveness. Such situation is a consequence of spatial differences in the costs of producing a benefit in a certain volume and in the costs associated with moving the benefit (transportation costs, and, if necessary, storage costs, customs payments, etc.) from the place of production to the sales markets in the required volume (in case of mobile benefits) or in the costs associated with the movement of consumers to the place of production of the benefit (in case of non-mobile benefits). Therefore, the main purpose of the article is to develop scientific foundations for the correct justification of the location of production.

Literature review

There are a lot of scientific works where, to one degree or another, the issues of location of production are studied, starting from Adam Smith's "The Wealth of Nations" and ending with the latest research on the spatial organization of the economy in the conditions of pandemic threats (see References), but a universal methodology of substantiating the optimal location of production , which would be based on the correct methodological approach, was never created. We emphasized this in our previous publications (Stadnicki, 2018; Stadnicki & Terebukh, 2020;

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Stadnicki & Terebukh, 2022), and the world-famous researcher of the history of economic thought, Mark Blaug, explained this situation by the continued disregard by scientists of the spatial factor in economics, as well as the dominance of description in studies on the spatial organization of the economy [3, 4] (Blaug, 1979; 2006). Descriptiveness was characteristic of scientists who preferred qualitative rather than quantitative analysis, because they believed that the lack of relevant information would always be a problem for reliable calculations (Beckmann, 1968; Hoover, 1948; Losch, 1954; Marshall, 1890). The main drawback of theoretical approaches to the problem of optimal location of production is the lack of a systematic approach to take into account the analysis of potential sales markets (PSM). For example, in many scientific works on the optimal location of production, complex mathematical models were proposed, which, however, did not take into account the competition of various options for production capacity (Allen & Arkolakis, 2014; Brown, 1979; Fujita & Krugman, 1999; 2004; Hirsch, 1967; Isard, 1956; Krugman, 1995; 2010; Perroux, 1950; Weber, 1929). In a number of other works, attention is focused on individual factors of production location for a given production capacity, which greatly limits the possibility of universalizing the results obtained (Lejpras, 2015; Lloyd & Dicken, 1977; Sheppard & Barnes, 2017; Torre & Rallet, 2005; Torre & Gilly, 2000; Venables, 1996; Moses, 1958).

Locally optimal place

Orientation, when justifying the optimal location of production, only to some separate variant of the sales market (and orientation to some variant of the sales market is necessary both in terms of taking into account the costs of moving the benefit from the place of production to the places of consumption, and in terms of production capacity, since unit costs of production depend on it) is erroneous because it does not take into account many other competitive options. For example, if there are three sales markets M1, M2 and M3 in the region with demand, respectively, D1, D2 and D3, then orientation when placing on the market M1 allows you to find among the attractive places of production (APP) the locally optimal place (LOP) P1 according to the criterion the minimum of the total costs of producing benefit in the amount of demand for the sales market M1 (D1) and the costs associated with the movement of benefits from each corresponding APP to the sales market M1. But if, when justifying the location, orientation occurs, for example, to all three sales markets together (M1, M2 and M3), then another place P7 from the list of APP, which will be the best according to the criterion of the minimum total cost of producing benefit in the volume the total demand of these three sales markets and the costs associated with the movement of benefits from each APP to these sales markets in the amount of the demand of the corresponding market.

Under these conditions, a conflict arises between the locally optimal places (LOP) P1 and P7 in the sales market M1, in which the producer with a larger production capacity, that is, P7, can become the winner. Under such conditions, the manufacturer P1 will not have a market. This example clearly shows that an isolated, non-systematic approach to the analysis of potential sales markets when justifying the location of production may not give the right result, since the P7 location will not be guaranteed to be the best location, because even in such a simple situation there are many other options of targeting sales markets when justifying the location of production (Table 1).

Table 1
Options of sales markets (OSM) and locally optimal places (LOP)

OSM	PSM			LOP
	1	2	3	
1	+	–	–	P1
2	–	+	–	P2
3	–	–	+	P3
4	+	+	–	P4
5	+	–	+	P5
6	–	+	+	P6
7	+	+	+	P7

Among the options of sales markets (OSM):

- three, where orientation takes place on one PSM (1, 2, 3);
- three, where orientation occurs simultaneously on two PSM (4, 5, 6);
- one, where orientation occurs on all three PSM together (7).

In general, the number of OSM depends on the number of PSM and LOP may be different for each OSM.

System-optimal places

LOP cannot be directly compared with each other, since their choice is due to the orientation towards different PSM. With a systematic approach, which is

methodologically correct, LOP combinations will be compared, the total production capacity of which is equal to the total (system) demand. With three PSM, there will be 5 options of combinations of LOP (1 option, providing for the location of production in three places, 1 option, providing for the location of production in one place, 3 options, providing for the location of production in two places), forming competing options of system-optimal places (SOP) of location of production (Table 2).

Table 2
Characteristics of competing SOP options

Options SOP	LOP of option SOP	Demand of option SOP
SOP1	P1 + P2 + P3	D1 + D2 + D3
SOP2	P4 + P3	(D1 + D2) + D3
SOP3	P5 + P2	(D1 + D3) + D2
SOP4	P6 + P1	D1 + (D2 + D3)
SOP5	P7	(D1 + D2 + D3)

Briefly characterize the competing options of SOP:

SOP1: location of production in three places, one with orientation on sales market M1 with production capacity D1 – in LOP P1, the second – with orientation on sales market M2 with production capacity D2 – in LOP P2 and the third – with orientation on sales market M3 with production capacity D3 – in LOP P3;

SOP2: location of production in two places, one with orientation on sales markets M1 and M2 with production capacity (D1+D2) – in LOP P4, and the second with orientation on sales market M3 with production capacity D3 – in LOP P3;

SOP3: location of production in two places, one with orientation on sales markets M1 and M3 with production capacity (D1+D3) – in LOP P5, and the second with orientation on sales market M2 with production capacity D2 – in LOP P2;

SOP4: location of production in two places, one with orientation on sales markets M2 and M3 with production capacity (D2+D3) – in LOP P6, and the second with orientation on sales market M1 with production capacity D1 – in LOP P1;

SOP5: location of production in one place with orientation on all sales markets M1, M2 and M3 with production capacity (D1+D2+D3) – in LOP P7.

The option of combinations of LOP with the minimum total cost will be optimal and the LOP of this option will be system-optimal places (SOP) in which production facilities with the appropriate capacity should be located.

The sequence of actions in substantiating the optimal location of production

In general, our approach to justifying the optimal location of production and its optimal capacity involves the sequence of actions shown in Table 3.

Briefly characterize components of the sequence of actions from Table 3.

1. Decide on the benefit, the location of production of which will be justified. Benefit is something that has the property of utility, that is, it is capable of directly or indirectly satisfying certain human needs. Obviously, many benefits are obtained by man from nature, but most are created in the production process, which occurs according to a certain procedure ("recipe"), which is called "technology". Any technology is characterized by the resources necessary for its functioning, as well as the anti-benefits that are formed during its functioning (mainly pollutants).

Table 3
The sequence of actions in substantiating the optimal location of production

No.	Action content
1	Decide on the benefit, the location of production of which will be justified
2	Identify the type of space of possible location (SPL) of the production of benefit
3	Create a list of potential sales markets (PSM) of the benefit and evaluate the demand of each of them
4	Create, taking into account the PSM, a list of options of sales markets (OSM) and evaluate the demand of each of them
5	Create a list of potential options of production (POP) taking into account the OSM and set the production capacity of each of them
6	Create a list of possible technologies of the production of benefits
7	Reveal the factors of location of production of the side "production of the benefit"
8	Create a list of attractive places of production (APP) of the benefit
9	Determine for each POP a locally optimal place (LOP) of production from the list of APP
10	Based on the LOP, create a list of competing options of system-optimal places (SOP) of the location of production
11	Determine for each competing option of SOP the total costs
12	By the criterion of minimum total costs, identify the optimal option of SOP

2. Identify the type of space of possible location (SPL) of the production of benefit. It is advisable to distinguish the following types of SPL:

- universal – the whole planet Earth and near Space;
- nationally safe – according to the decision of the state;
- economically safe – according to the decision of the company;
- limited by the characteristics of the side "production of the benefit";
- limited by the characteristics of the "place" side.

In modern conditions, a universal approach to SPL for finding optimal locations of production is the whole planet Earth and near Space (more and more benefits are produced in Space, using its unique properties, in particular, weightlessness and vacuum). In cases where the requirements of the state in the field of national security or the company's policy in the field of economic security should be taken into account, the SPL, in order to find optimal locations of production, may be limited to the borders of the state or the boundaries of some common economic space (the coronovirus pandemic is precisely the factor that will limit SPL of the production of strategic benefits by the requirements of the state regarding national security or policy in the field of economic security). In cases where the "production of the benefit" side or the "place" side have specific characteristics (for example, a rapid loss of the quality of the benefit, if we characterize the "production of the benefit" side, or mountainous territories, if we characterize the "place" side), SPL is limited due to those specific features . It should be emphasized that the establishment of SPL may take into account the location of potential consumers, but the consumers (individual or even all) may be located outside SPL. Theoretically, if SPL is not established according to the decision of the state or firm due to national or economic security, in all other situations the correct approach is the universal approach, when the whole planet Earth and near Space are considered as the SPL.

However, adherence to a universal approach will be accompanied by the need to collect and process an extremely large amount of information, which will require a significant investment of time and money. Therefore, in the event of the possibility of reducing the SPL, this opportunity should be used, but, obviously, on the basis of a thorough analysis of the specific situation, taking into account the characteristics of the production of benefit and the characteristics of the corresponding space. An illustrative example in this respect can be a district heating system in a settlement, in which the boiler house cannot be more than 10 km away from heat consumers.

But already in the situation, for example, with the production of some confectionery products, which cannot be located at a distance of more than 30 km from the sales market, there will be complications with the formation of SPL, since production for more than one sales market may necessitate competition with manufacturers from outside the 30-kilometer SPL around one sales market (for example, a city) and taking this fact into account when forming the SPL. Obviously, this will complicate the situation, as it will be accompanied by a significant expansion of the SPL, which should be taken into account in production location models. Therefore, in such situations that are not 100% convincing, one should adhere to the universal SPL and, in general, work on developing a methodology that makes it possible to simplify (without compromising the quality of justifying the location of production) calculations under the conditions of compliance with the universal SPL.

3. Create a list of potential sales markets (PSM) of the benefit and evaluate the demand of each of them. The list of PSM depends on the SPL: if the SPL is limited, then the list of PSM will contain only sales markets that, according to the relevant restrictions, will be able to supply benefits from the places of the respective SPL. In other situations, the list of PSM may formally be global. It should be emphasized that, depending on the specifics of the benefit, PSM can be considered individual enterprises (households) and aggregate spatial units (eg cities, regions, countries, continents). The demand of each PSM is estimated using well-known methods, taking into account the needs of potential consumers for the assessed benefit, their solvency, and the variability of these indicators over time.

4. Create, taking into account the PSM, a list of options of sales markets (OSM) and evaluate the demand of each of them. OSM are separate markets and their various combinations. OSM are formed by PSM included in its composition. The parameters of OSM are described by the location of PSM and the demand, i.e. each OSM will be characterized by places of demand and the amount of demand in these places. Obviously, individual PSM can be part of several OSM. The demand of OSM is defined as the sum of the demand of PSM included in its composition. If, for example, the demand of PSM1 is 100 thou, PSM2 is 300 thou, and PSM3 is 200 thou (example No. 1), then the demand of OSM1 is 100 thou, OSM2 is 300 thou, OSM3 is 200 thou, OSM4 is 400 thou, OSM5 is 300 thou, OSM6 is 500 thou, OSM7 is 600 thou (Table 4).

It should be noted that the demand of different PSM may be the same. In our example, this situation arose for PSM2 and PSM5, where demand is 300 thou

units. For PSM2, the demand corresponds to the demand of OSM2 (300 thou units), and for OSM5, the total demand of PSM1 (100 thou units) and PSM3 (200 thou units).

Table 4
Demand PSM and OSM (start of example)

OSM	PSM and their demand, thou			Demand OSM, thou
	1/100	2/300	3/200	
1	+	–	–	100
2	–	+	–	300
3	–	–	+	200
4	+	+	–	400
5	+	–	+	300
6	–	+	+	500
7	+	+	+	600

5. Create a list of potential options of production (POP) taking into account the OSM and set the production capacity of each of them. Each OSM corresponds to the POP, for which the search of the optimal location will be made. We accept the production capacity of POP of the benefit as equal to the demand of the corresponding OSM. POP1 will have a potential capacity of 100 thou corresponding to OSM1, POP2 will have a potential capacity of 300 thou corresponding to OSM 2, and so on (Table 5). The potential capacity of different POP, as well as the demand of different OSM, can be the same. In our example, such a situation arose for POP2 and POP5, where the potential power was 300 thou units. For POP2, the potential capacity corresponds to the demand of PSM2 (300 thou units), and for POP5, the total demand of PSM1 (100 thou units) and PSM3 (200 thou units).

Table 5
Potential power of POP (continuation of example)

POP (OSM)	PSM and their demand, thou			Demand OSM, thou	Potential power of POP, thou
	1/100	2/300	3/200		
1	+	–	-	100	100
2	–	+	–	300	300
3	–	–	+	200	200
4	+	+	–	400	400
5	+	–	+	300	300
6	–	+	+	500	500
7	+	+	+	600	600

6. Create a list of possible technologies of the production of benefit. In the vast majority of situations, the same benefits can be generated using different technologies. Particularly convincing is the interchangeability of technologies in the production of electricity (wind, solar, nuclear, water, thermal energy, etc.), but in general, for the production of almost every benefit, various technologies can be applied. Obviously, the production of the same benefit using different technologies may have different allocation factors.

7. Reveal the factors of location of production of the side "production of the benefit". Factors of the location of production of benefit are reasons that should be taken into account when justifying or predicting the future location of production (answering the question "where?") or explaining the former or existing location of production (answering the question "why here?") of the benefit. The location factors of the production of benefit are part of the properties of such components of the "production of the benefit" side:

technologies of the production of benefits;
esources needed to produce the benefit with the help of the appropriate technology;
anti-benefits (mainly pollution) arising in the process of production of the benefit with the help of appropriate technology;
benefit to be produced.

Factors of location of production can be specific for each technology of production of the benefit, which, obviously, can cause an increase in the number of attractive places of production of the benefit, since there will be a change in three out of four components of the "production of the benefit" side (technology, resources, anti-benefits) and a corresponding change in the factors of location of production, which can lead to a change in attractive places of production.

8. Create a list of attractive places of production (APP) of the benefit. APP are places within the SPL that are characterized by properties that are important for the efficient production of the valued benefit abroad. These properties of the APP form pairs with the corresponding factors of location of the production of benefit of the side "production of the benefit" and can be called factors of the location of production of the benefit of the side "place". A characteristic feature of APP will be lower unit costs for the production of benefit and / or its movement to markets (we take into account transport and storage costs, customs payments) compared to other places.

9. Determine for each POP a locally optimal place (LOP) of production from the list of APP. The criterion of choosing a LOP from the list of APP is the minimum total cost of producing benefit in the corresponding place in the volume of demand of the corresponding OSM (POP) and transporting the benefit

from this place to the places of PSM in the amount of demand abroad. LOP will be characterized by the optimal geographic coordinates, production capacity, and production technology of the corresponding POP.

Production costs are calculated as the product of unit cost of production (for the corresponding volume) and the volume of production (production capacity). Unit costs of production depend not only on the place (the spatial differentiation of the costs of production of the same benefits is a consequence of differences in the corresponding properties of places), but also on the volume of production in the same place, that is, on production capacity. For each location, as a rule, the tendency of decreasing unit costs of production with an increase in production volume is characteristic. For places characterized by limited capacity, unit costs should be calculated with this in mind: for POP, the demand of which exceeds the production capacity allowed for any place from the APP list, the volume of production in this place should be taken equal to the allowable, and not equal to the demand of the corresponding OSM, as it is in the situation for places without capacity limit.

The transportation costs are calculated as the product of the unit costs of transportation (for the corresponding volume and distance) and the volume of transportation work (production volume and transportation distance). Unit transportation costs depend not only on volume and distance (there is a tendency for unit transportation costs to decrease with increasing volume and distance), but also on the direction of transportation.

As a result, for each POP, we obtain the optimal (minimum) indicator of total costs: on the production in a given volume and transportation in accordance with the needs of the sales markets. If for some POP LOP there is a place where, for some reason, it is impossible to produce benefit in the volume of demand of the corresponding OSM, then the unsatisfied demand forms an additional OSM and, accordingly, an additional POP. That is, for the option where the LOP will become a place that, due to limited capacity, will not be able to satisfy the demand of the corresponding OSM, the following tours should be carried out – until the moment the demand is fully satisfied. This approach solves the problem of existing production, the capacity of which is limited by the actual value, and its increase requires investment and can be considered as a separate option for the location of production. Some places (including APP) to comply with technogenic and environmental safety (large-scale production poses great threats to people and the environment in the event of an accident) or to strengthen national security (implementation of a policy of dispersal of production, which can become a target for the enemy) may have production capacity limitation. We emphasize that in the first situation, the requirements of the restriction are tied to the place, and in the second – to the industry.

10. Based on the LOP, create a list of competing options of system-optimal places (SOP) of the location of production. Based on the conditions of our example, then the total capacity of each SOP option, which is equal to the demand of the corresponding OSM, will be the same (600 thou), but its structure will differ (three places of production in the corresponding volume for SOP1, two places for SOP2, SOP3 and SOP4, and one place for SOP5 (Table 6)).

Table 6
Structure of options SOP

Options SOP	OSM as a component of SOP						
	1	2	3	4	5	6	7
SOP1	+	+	+	–	–	–	–
SOP2	–	–	+	+	–	–	–
SOP3	–	+	–	–	+	–	–
SOP4	+	–	–	–	–	+	–
SOP5	–	–	–	–	–	–	+

11. Determine for each competing option of SOP the total costs. The total cost for a potential SOP option is the sum of the LOP costs that form the SOM option. Based on the conditions of our example, the costs for:

SOP1 is the sum of costs for OSM1 (LOP1), OSM2 (LOP2) and OSM3 (LOP3).

SOP2 is the sum of costs OSM3 (LOP3) and OSM4 (LOP4).

SOP3 is the sum of costs for OSM2 (LOP2) and OSM5 (LOP5).

SOP4 is the sum of costs for OSM1 (LOP1) and OSM6 (LOP6).

SOP5 is the sum of costs for OSM7 (LOP7).

12. By the criterion of minimum total costs, identify the optimal option of SOP. The option of combinations of LOP with the minimum total cost is optimal and LOP of this option are systemically optimal places (SOP). The result of solving the problem will be information about the four parameters of the production of the valued benefit – "where?" (in what places) within PSM, "how much?" (in each of the justified places), "how?" (with the help of which technologies out of all technically possible), "for whom?" (sales markets). That is, the speech will justify the choice of optimal: places of production within the PSM, capacity and production technology in each of these places, markets for each place of production.

Here, attention should be paid to the fact that a systematic approach to substantiating the optimal location of production shows in a different perspective the problem of choosing the optimal technology for the production of benefit. In different places, different technologies for the production of the same benefit may be appropriate. At the same time, technology competition in APP (competition, which can be called "point" competition) will be quite rare, since each technology, as a rule, has its own APP. Although, of course, if the APP for different technologies of the production of benefit is the same, then "point" competition will automatically arise – but only when it comes to the same production capacity. In the "same place – different production capacity" situation, the competition of different technologies will not be direct, but will take place at the system level, that is, LOP combinations (potential SOP) will compete.

Technologies predominantly compete at a distance. First, competition of technologies at a distance (it can be called initial selection, because this is only the first stage of choosing optimal technologies and locating production) will occur when choosing LOP among APP for the corresponding OSM (for each APP, an optimal production technology is planned for a given capacity, which is equal to demand of the relevant OSM). At the second stage, options of LOP combinations (potential SOP) and their corresponding production technologies will compete. The option of LOP combinations with related technologies that wins this competition will be the SOP option, the technologies of which will automatically be recognized as the best. That is, the competition of individual technologies is direct, since LOP combinations (potential SOP) compete, the total production capacity of which is equal to the total (system) demand. Since each option of the LOP combination can have different technologies for the production of benefit, it is difficult to assess which of them ensured the victory in the competition of the LOP combinations and the transformation of one of them (which turns out to be optimal) into SOP. Therefore, the choice of optimal technologies should be justified on the basis of a systematic approach.

Conclusions

Thus, the rationale of the optimal location of production and its optimal capacity should be based on the following three main steps:

1) formation of a list of potential production options based on sales market options and establishing the production capacity of each of them;
2) determination of each potential production option of a locally optimal place of production;
3) formation on the basis of locally optimal locations of a list of competing options for systemically optimal production locations.

Directions for further studies. The systematic approach proposed in the article to substantiate the optimal location of production of a particular benefit can be adapted to a more complex situation, when the optimal location of production of several benefits is justified at the same time (including when one of these benefits is used to produce other of these benefits). Undoubtedly, in further studies, the issue is related to the space of possible location (in the direction of a clearer establishment of its boundaries), as well as with potential sales markets (in the direction of studying the possibility of their aggregation).

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