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## Market Structure and Sustainable Use of Natural Resources

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# Market Structure and Sustainable Use of Natural Resources

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## Abstract

Sustainable use of natural resources becomes an important issue today not only due to global warming and pollution issues but also because of critical pressure on the Earth's regeneration possibility. We cannot use classical microeconomic approach here for two reasons: a) impossibility to create natural resources, both exhaustible and renewable, by simple use of labour and capital (like it is done on most of macroeconomic growth models); b) important role of spatial distribution and transport cost than leads to both overharvesting and under-harvesting in some regions. Due to these externalities market organization is extremely important for sustainability, and this question will be studied here in theoretical framework. The goal of this paper is to study the role of market structure for the sustainable harvesting of natural resources. This work is theoretical and uses explicit spatial structure as a component of production function. It continues other works of Yegorov (2005, 2007, 2009) where economic production function accounted explicitly for topological properties of geographical space. Contrary to the previous works, this uses also reproduction equation for renewable resources. The intensity of harvesting follows from market structure and is driven not only by population density but also by land ownership, land rent, transport cost and discount for future. The results show that overharvesting can originate in purely

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market laws because it does not account for an interaction between economy and nature.

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## 1 Introduction

Scholars from various fields of science have an interest in building models that have a validity in different disciplines. Models of interactions in space are at the edge of economics and geography. Regional science has a long tradition of dealing with such models.

This article models the influence of market structure on harvesting natural resources and studies its influence on their sustainable use. Methodologically, it follows the traditions of classical regional science that is surveyed in below.

Von Thunen (1826) was the first scholar to attract attention to asymmetric continuous structures in space. He focused on the model of isolated city surrounded by unbounded plain and the interaction between distributed peasants and market concentrated in a city. Weber (1909) has focused on a model of optimal plant location in continuous space with Euclidean metric, taking into account transport costs, linear in distance. In 1920ies-1930ies the interest to this area has been revived by the works of Hotelling, Chamberlain, Lösch, Christaller and other scientists. Later many other regional scientists have contributed to our understanding of spatial economic interactions, emergence of patterns, equilibrium and dynamics. Later development included the works of Samuelson, who focused on the impact of transport costs on equilibrium structure, Isard, who had a partly successful attempt to build a general theory involving space, Beckmann and Puu (1985), who has developed the theory of flows in continuous economic space.

Beckmann and Thisse (1986) give a good survey of what has been done in location theory before mid-eighties. An important branch is related to spatial competition across firms, a subsection of industrial organization theory. Hotelling (1929) started from spatial competition between two firms on an interval. Then Chamberlin (1933) generalized interval to a line, putting

infinite number of firms there, while allowing each of them to have local monopoly in its neighbourhood. Later Salop (1979) transformed interval into a circle. Despite the difference among these topologies, they have a common feature in the structure of neighbourhoods, which arises from the assumption about transport cost being linear in distance. All of them do require an assumption of continuous space. Two-dimensional generalizations already need an assumption about metrics. While Euclidean metrics is considered to be the most natural, particular topology of streets in some cities have led to an emergence of “city-block” distance, which is also often used in two-dimensional models of Hotelling type, due to easier separation of variables than Euclidean metric. From topological properties of the limit these metrics are equivalent. However, the discussion about proper assumptions related to metric nowadays become more philosophical, and different scientific schools choose different assumptions here. More is discussed in the Section 2.

Nijkamp and Reggiani (1992) review the models in regional science that address the problems on the border of economics and geography, using paradigms of social physics. They focus on gravity and entropy models when consider static interaction between spatially separated economic objects.

Ottaviano and Thisse (2004) give a survey of the recent results related to explanation of spatial distribution of economic activity. There exist two ways to explain it: a) with exogeneous, geographically determined differences, b) with endogeneous decomposition of initially homogeneous space into asymmetric structures. They focus more on the second approach, which is the core of the so called new economic geography, that was developed by Fujita, Krugman and Venables (1999).

Ottaviano and Thisse (2004) summarize the legacy of location theory in five points: a) economic space is the outcome of a trade-off between increasing returns and mobility costs, b) production is dispersed due to price competition, high transport costs and land use, c) firms cluster in metropolitan areas when they sell differentiated products and when transport costs are low, d) cities are attractive to consumers and workers as they contain both labor and final good markets, e) agglomeration is the outcome of cumulative process involving both supply and demand. The space-economy is an interplay between agglomeration and dispersion forces. The creators of new economic geography have combined these insights into general equi-

librium framework. However, some of their assumptions are not very good from geographic perspective: in most of the models space is just the set of two points, so that its continuous properties are not taken into account. They also mention the importance of trade-off between increasing returns to scale and transport costs. So far, the main references can be found among anthropologists. The mathematical models of an interplay between these two factors have been suggested by Kuehn and Hamburger (1963), later by Yegorov (1997), while some ideas will be used in models of the present paper.

The problem of general theory depends on what results are considered to be of scientific importance. The theorem of Starrett (1978) about impossibility of competitive equilibrium in discrete economy with transportation has reduced the interest of general equilibrium school in economics to spatial issues, while another work of d'Aspremont, Gabzgewich and Thisse (1979) about impossibility of Nash equilibrium in original Hotelling model with linear transport costs has moved the interest of major group in industrial organization away from linear transport cost to quadratic, and thus from real geographical space to abstract product space.

These two papers could have lead to separation of interests of economic theorists and regional economists for some period, until Krugman has attracted attention to the problems of new economic geography. Based on general equilibrium principles, these models went deeply into variety of products (going even to a continuum), but at the same time reduced the spatial structure just to two points. Such a perspective is of less interest for regional economists, who wanted to have a theory maybe less rigorous but helping to answer the questions emerging from real or stylised geographical maps.

Czech (2013) surveys the history of economic thought related to land. He mentions the book of Henry George *Progress and Poverty* (1879) that presents the special role of land. However, later land has been mixed with capital in macroeconomic models. This might be misleading because land is in fixed supply contrary to financial capital.

Yegorov (1997) studies a monopoly in continuous space with low population density. In this case the trade off between scale effects and transport costs leads to its optimal spatial area to be covered. However, shock in transport costs might lead to its bankruptcy. Yegorov (2005a) studies an in-

terplay between costs and benefits for a stylized country arising from spatial scale and then derives its optimal size. Yegorov (2005b) elaborates along the concept of field in economics. The field depends on the distance between producer and consumer. The population density also plays an important role in field formation. Further, population density can influence economic growth. The role of population density in economics is further elaborated in Yegorov (2009). The influence of density on profitability and growth is addressed first. Then it is linked to the emergence of cooperative and non-cooperative games. It is shown that low population density (normally taking place in the areas with severe climate) encourages cooperation while the incidence of non-cooperative games is higher in overpopulated areas.

**Paper structure.** The Section 2 deals with assumptions about metric and topology in model choice. Section 3 presents a model about land use by farmers with the special cases about land rent and land ownership. Section 4 is about sustainability in resource use. Section 5 presents various extensions. Section 6 concludes.

## 2 Assumptions about Space and Emerging Topologies

The issue about the topology of space is typically out of discussion among neoclassical economists. In most cases real geographical space is simply neglected, while in new economic geography it degenerates to a discrete set of points, where discussion about metric becomes irrelevant.

Scientists from geography and city planning are on another extreme: they may calculate distances along the roads and even take into account different modes of transportation and how congestion can influence it. Such a detailed description may be relevant for consulting, but leaves little hope for a theoretical science.

Clearly, there exists a gap between these two extreme approaches, and the present study intends to contribute exactly in the intermediate field. The focus will be on continuous models in space, since we cannot define interesting topologies in discrete space.

The space works as self-organizing factor in economic life due to its two following properties: a) spatial distance between different agents and economic units can be overcome with transport cost, b) land is a component of production, especially in agriculture and mining, where production is necessarily spread over space.

## 2.1 The Role of Transport Cost

We start from the implications of strict positivity of transport cost. If we assume transport cost to be linear in distance and distances between all geographical points to be Euclidean, we seem to be moving in correct direction. First of all, this is a relevant assumption at least for helicopters, caravans in deserts and often for sea transport. Second, we capture the neighbourhood effects. In this sense, a difference between Euclidean or city-block distance is much less relevant than the difference between a model with discrete or continuous space. While the linearity of transport cost in distance might not be confirmed empirically in the case of fixed cost of uploading, it is much more relevant for geographical space than quadratic costs, which also create empirically strange consequence of zero marginal cost per unit of distance when this distance vanishes to zero. In other words, the world with quadratic costs is similar to an “eternal engine”: it sits on an assumption of having integration across all neighbourhoods at zero cost.

Which model of space is relevant for economic modelling, will be demonstrated on several examples in next sections. But here it makes sense to reply to potential critics of this approach.

The first criticism is related to the declining role of space in economic interactions. Indeed, the relative transport costs are declining with the development of transportation technologies. And one of the consequences is an increasing radius of integration for labour markets, for example. Without explicit consideration of space we cannot capture this result. And even if transport cost would be so small that consumers spent just 1 % of their budget on it, we still will not get such global integration of all markets, that the majority of people will make transcontinental flights for daily commuting with their job. In other words, the radius of integration of local markets is still small in comparison with the radius of the Earth.

The second criticism is related to the fact that, from an empirical perspective, the spatial pricing of physically identical goods (commodities that differ only in location) does not form a continuous pattern in space. Here we deal with a complex interaction between transport costs, information flows and trade chains. It is likely that hundred years ago both competition and information in agricultural production were relatively perfect. This has allowed for an emergence of spatial patterns of prices like isolines for potato prices in the USA reproduced in the book of Beckmann and Thisse (1985). At the present time, the agricultural market no longer consists of many farmers selling their output directly to consumers. Instead, we have intermediaries, who often monopolize the link and retailers who set their pricing based on imperfect information of consumers and their laziness. Besides that, the number of commodities has increased dramatically and bundling phenomena leads to a choice of one supermarket to visit rather than the optimal location of a place to buy each particular good.

It might be true that information rent is becoming more important now than transport cost. This, a decline in competition among retailers of agricultural goods, leads to more complex patterns in spatial pricing. Nevertheless, there information rent is likely just to add some noise, while average prices in small districts are still likely to change continuously with spatial location. In any case, the growing complexity of the real world should not discourage researchers from an attempt to understand its structure even in a simplified form.

## **2.2 Land as a Factor of Production**

The second property of space is that some technologies are land consuming, especially those related to harvesting of natural resources (mining and agriculture). While more developed economies typically have a small share of these activities in GDP, harvesting still plays an important role for the world economy. Moreover, the importance of its strategic role for the world well-being may become more apparent in the future, when the natural limits for both exhaustible and renewable resources will set more binding constraints for the world economy by becoming more scarce resources. This may push prices for real resources up in comparison to virtual resources.



The self-organizing role of land as production factor comes from the fact that distances and areas on any surface are interrelated. The local map around any point differs from the manifold of real Earth's surface only marginally, if the area is small. Euclidean distance gives the simplest mathematical link between areas and distances, and thus will be used in further models. In fact, similar considerations are often used by physicists to derive the formulae for physical properties of spatial objects.

Suppose that  $a$  is the typical scale of distance, then the typical scale of area will be  $a^2$ . If some production requires particular land  $L$ , then assuming that this land is square area, we get a typical spatial distance between productions of  $\sqrt{S}$ . If each production is owned by 1 person, then we can get corresponding spatial density of owners, and population density, if all agents are owners and this production is the only form of economic activity. Agriculture is the most relevant application, since historically individual ownership of a small farm was the dominant structure in many countries. This concept of spatially distributed production will be employed in the models of this paper.

### 3 Farmers Optimize Harvesting Technology

There exist many economic activities that deal with interaction between worker and nature in continuous space. It includes all harvesting of both renewable (fishing, logging, etc) and non-renewable resources (mining), and it also includes agricultural activity. Only industry and services can be modelled in a different way; here explicit role of space is not very important (apart from international trade that includes transportation). Although the higher fraction of GDP worldwide is produced now in service and industry section, the neglect of the sector dealing with natural resources would be a mistake. Czech (2013) compares the hierarchical structure of economic activity with trophic levels in nature where vegetation serves as food for vegetarian animals, who serve as food for predators. Due to physical and biological laws, the biomass at the next level of food chain should be about 10% of the previous. If the bottom level cannot reproduce itself, then the whole food chain can become extinct. In a similar manner, healthy agriculture and resource harvesting is important for the health of the whole economy. At the

same time, financial indicators (valuation, capital) are subject to volatility<sup>1</sup>

Typical macroeconomic model of growth uses labour and capital as the only factors of production. Historically, land was also used as such factor, but later it has been merged with capital.<sup>2</sup> Here it is important to distinguish between land and capital for two reasons: a) land has limited supply, which the growth of capital can be unbounded; b) land is a frontier where economic activity interacts with nature.

How the harvesting can be modelled? Natural resources can be spread in space with different density, but to harvest them it is important to cover the space. A harvester can be a sole human or a team, with or without machine. But in all cases this harvesting unit has to move in space. Harvester has some territory where this activity is allowed for him. It can choose different intensity of harvesting. For example, a fishing boat might have a right to fish on the territory of 1 square km. It may choose to cover it in one or several tracks, and to do it with different speed. Let us fix the unit of supplied labour (and capital) associated with harvest in one unit of time. It is clear that the catch (return to harvesting activity) is an increasing function of covered territory, but the catch per unit of territory declines with its size. That is why it is natural to assume Cobb-Douglas production function of the type  $Y = HS^bL^{1-b}$ , where  $S$  is the land used and  $L$  is the labour. The coefficient  $H$  depends on location through the spatial distribution of resource stock.

Note that agricultural activity is quite similar. A farmer with a small land slot (let say, a square of size  $a$ ) with apply more labor (and capital) for the unit of slot, and can get higher value of crop per unit of land. It is also important that he will use energy proportional to the linear scale of his slot.<sup>3</sup>

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<sup>1</sup>Including speculative; we know this fact from the crisis of 2008, which was hit by housing price bubble, but was also accompanied by a bubble in prices for commodities.

<sup>2</sup>Czech (2013) argues about the reasons for such change.

<sup>3</sup>There might be also a component proportional to area, but it is less important in our analysis, because land rent is also proportional to it.

### 3.1 Assumptions

1. Elementary land slot is a square with size  $a$  and the territory  $S = a^2$ , where  $a$  is a scale parameter and can vary. Total land (of the same productivity factor  $H$  per unit of area) is divided into  $N$  elementary slots, where  $N$  is the population of farmers (or harvesters in this region).

2. Capital is not considered formally; one can think that it is joined with labour in an optimal proportion. Labour is supplied inelastically at the level 1. The output has price  $p$ , which can be viewed as equilibrium world price for this good. The production function of a land slot of size  $S$  (linear size  $a$ ) is then  $Y = pHS^b$ , where  $0 < b < 1$  is a parameter in Cobb-Douglas function.<sup>4</sup>

3. There are two major cost components in this model. The first is land rent,  $rS$ , and it is proportional to the land slot territory  $S$ . The second is transport (or energy) cost,  $\tau a$ , proportional to  $a = \sqrt{S}$ , the linear scale.<sup>5</sup>

### 3.2 The Case of Farmer-Land Owner

Consider first the case of farmer who is land owner. In this case he does not pay land rent and can exploit it in a sustainable manner, facing very long time horizon and low discount of future. Let us start from static optimization. The profit of a farmer is

$$\pi = pHa^{2b} - \tau a.$$

Suppose initially that we have an empty world (in the sense of Czech (2013)), where territory is not scarce and farmer can choose an optimal land slot that he can develop. The optimization problem with respect to parameter  $a$  gives the following first order condition:

$$2pHa^{2b-1} - \tau = 0. \quad \Rightarrow \quad a^* = (\tau/2bpH)^{1/(2b-1)}.$$

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<sup>4</sup>Since 1 in any power is 1, this production function does not depend on labour (and capital) explicitly. However, technology of harvesting depends on it, because higher land slot per worker (or farmer) will imply lower interaction intensity with land.

<sup>5</sup>There are several justifications for that. Suppose the fishing area of 1 by 1 km is covered by 10 moves of 1 km each and distance of 100 m between the previous and the next track. In a similar manner, a farmer with lower land endowment can decrease the distance between the rows of agricultural products, or to grow commodities that require more intense application of labour per unit of land.

It is important to consider two cases: a)  $b > 1/2$ , b)  $b < 1/2$ . In the case a) the critical point  $a^*$  is a minimum, and farmers will try to have unlimited size of their land. Of course, in reality this does not happen because there might be some costs proportional to land size (like use of fertilizers). But this result has theoretical importance.

In the case b) the output is concave in  $a$  and thus we get maximum. The power in formula is less than -1. Note the comparative statics:

$$\partial a^*/\partial \tau < 0, \quad \partial a^*/\partial H > 0, \quad \partial a^*/\partial p > 0.$$

It means that growing transport (energy) cost will induce farmer to reduce the size of his farm, while growing price of output will induce him to have a larger farm.

Note that those optimal land slots are realized only in non-competitive environment. If this optimal slot multiplied by the number of farmers exceeds total available land (of certain quality in a certain region), land slots will be smaller than optimal. Further, if this small size will make such economic activity not profitable (for example, due to negative shock in world prices for output or because of positive shock in energy prices), some farmers can shift to other activity. So far we did not touch sustainability of harvesting; this will be done later.

### 3.3 The Case of Farmer Who Rents Land

Here the cost of land rent should be added. We have the following problem:

$$\max_a \pi, \quad \pi \equiv pHa^{2b} - \tau a - ra^2. \quad (1)$$

In a general case of  $b$ , the first order condition will lead to transcendental equation, which can be solved only numerically. In order to keep working analytically, it is important to make an assumption  $b = 1/2$ , which will be used throughout the rest of the paper.

The f.o.c. now lead to the optimal size  $a^* = (pH - \tau)/2r$ . The comparative statics now is:

$$\partial a^*/\partial \tau < 0, \quad \partial a^*/\partial r < 0, \quad \partial a^*/\partial H > 0, \quad \partial a^*/\partial p > 0.$$

Similarly to the previous case (land ownership), the increase in land productivity and output price leads to selection of larger land slot, while an increase in costs (here energy and rent) lead to shrink of chosen land slot in favour of more intensive use of labour per unit of land.

### 3.4 The Case of Land Owner and Workers

Let us replace farmer by agricultural worker with fixed wage  $w$  (at competitive level). It is also possible to consider the case when land slot is fixed (this is typical in full world) while the number of worker can be variable. If wage rate is constant and capital investment is proportional to land size, the owner of large land slot can create more small land parcels, employ more workers with more intensive harvesting, saving on transport costs inside elementary land slot (developed by one worker) and capital per worker.

Let total large land slot is  $S$  and is divided into  $N = S/a^2$  elementary slots of size  $a^2$  and capital that is proportional to land size but may depend on slot as well,  $K(a)$ . We get the following expression for profit in a farm with  $N$  workers:

$$\Pi(a, N) \equiv (pHa^{2b} - \tau a - ra^2)S/a^2 - SK(a) - wS/a^2.$$

It is assumed that we do not have scale economies with respect to capital and each worker is endowed with one unit of capital,  $K$ . Since profit is linear in  $N$  and since wage does not interact with spatial scale, result will be the same. Difference in optimal land exploitation by big owner may arise at different stage, like export activity, where scale economies might work.

Consider a simple case with  $b = 1/2$  and no scale in capital use,  $K'(a) = 0$ . This case can be compared with the previous case of farmer, where capital was not considered. Differentiation w.r.t.  $a$  gives the optimal slot size:

$$a^{**} = \frac{2Sw}{pH - \tau}.$$

Now

$$\partial a^{**}/\partial w < 0, \quad \partial a^{**}/\partial \tau > 0, \quad \partial a^{**}/\partial H < 0, \quad \partial a^{**}/\partial p < 0.$$

Now the signs of partial derivatives are opposite to the previous case. A farmer was reacting on an increase in land productivity by the extension of

developed land slot (less intensive farming), while the rise in transport cost gave him incentive to save on it by shrinking land slot. Big landowner that has a fixed territory in his property reacts on those shocks in an opposite way. Higher price of the final good and higher land productivity induces him to employ more workers, thus diminishing the parcel per worker,  $a$ . In addition, lower wages also make  $a$  smaller. All those factors make land exploitation more intense.

## 4 Sustainability in Resource Use

Consider now the dynamic extension of harvesting model. Land productivity is naturally linked to resource stock associated with it. Here, in theoretical model, an abstract resource is considered. In reality, different renewable resources can play this role. It can be stock of fish, or stock of useful chemical elements in soil, or water supply.

Typically, the evolution of resource stock,  $R(t)$  is driven by the equation of logistic growth<sup>6</sup>, perturbed by harvesting intensity<sup>7</sup>,  $h = vRa/S = vR/a$ :

$$\frac{dR}{dt} = cR\left(1 - \frac{R}{\bar{R}}\right) - h.$$

Here  $R(t)$  is resource stock per unit of land in time  $t$ . Harvesting intensity is an output from unit of land. In our case, the slot of linear size  $a$  gives the harvest  $Y = HS^b$ , or  $Y = H/a$  per unit of land. The coefficient  $H$  should be proportional to resource stock,  $R$ , and harvesting intensity,  $v$ . That is why  $h = vR/a$ .

$$\frac{dR}{dt} = cR\left(1 - \frac{R}{\bar{R}}\right) - \frac{vR}{a}.$$

It is easy to find steady state for this equation. Setting  $\dot{R} = 0$ , we get:

$$R^* = \frac{c - v/a}{c} \bar{R}.$$

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<sup>6</sup>See, for example, Logistic function in wikipedia

<sup>7</sup>There are several intensities considered here. They differ by unit of application. Harvest is proportional to resource stock, which is proportional to resource density and area. Here we assume that  $b = 1/2$  and thus output is proportional not to area  $S$ , but to linear scale  $a$ .

There are two important observations here. First, harvesting leads to decline of equilibrium resource stock from  $\bar{R}$  to  $R^* < \bar{R}$ . Second, this coefficient of decline is proportional to  $c - v/a$ . Note that

$$H = vR^* = v(c - v/a^*)\bar{R}/c$$

in a steady state, while  $v$  depends on harvesting technology. Thus, land productivity is not exogeneous, but depends on the long term intensity of harvesting. If we start from the stock level above steady state, it will eventually decline to this level, and land output will drop also.

Now let us look how the chosen land slot will influence this productivity. The smaller is land slot (due to economic parameters), the lower will be land productivity,  $H$ , in the long run. This long term productivity is not observable to even rational farmer, since natural and environmental parameters are usually not considered in economic optimization.

## 5 Extensions

### 5.1 Rationalizing Land Use

Finally we assume that a farmer who owns land knows environmental laws and thus is rational also in this sense. Ownership is important here, because then we can analyse the static problem with steady state harvesting instead of a dynamic optimization problem with discounting. If farmer knows that sustainable use of land would require lower harvesting intensity, he will use  $H = v(c - v/a^*)\bar{R}/c$  in optimization function. Then he uses this expression for  $H(a)$  in optimization problem (1) (for  $b = 1/2$ ):

$$\max_a \pi, \quad \pi \equiv pav(c - v/a^*)\bar{R}/c - \tau a - ra^2. \quad (2)$$

Now the optimal land slot would be:

$$a^{**} = \frac{pvc\bar{R} - \tau}{2r}.$$

Although the signs of comparative statics will not change, this formula uses  $vc\bar{R}$  instead of  $H = vR$  that is currently above this steady state level (as  $R(0) > R^*$ ). Hence, super-rational farmer would choose smaller land slot,

but will exploit it initially at less scale than his labour can do. Then this will be sustainable use of land in the long run.

Let us look now whether he will be competitive in economic sense. Clearly, he will get less output today than his rivals, who are rational only in economic and not ecological) sense. If his profit will stay positive, he can still survive. However, competition pressure and negative price shocks may drive him out of the market.

## 5.2 Dynamic Optimization Problem

Suppose further that a farmer has some time discount  $\rho$  and do not care about sustainability. To get maximal output he will use all his unit labour, but will take into account how productivity will decline with resource stock depletion. Then he solves the following dynamic optimization problem:

$$\begin{aligned} \max_a \int_0^\infty e^{-\rho t} (pvR(t) - ra^2 - \tau a) dt \\ \text{s.t.} \quad \dot{R} = cR(1 - R/\bar{R}) - vR/a. \end{aligned} \quad (3)$$

This is the simplest problem that includes only static parameter  $a$  and no rational choice of intertemporal harvest policy  $h(t)$ . But even here we can draw some conclusions. The presence of integrals and dynamic evolution of  $R(t)$  makes algebra more complicated but in principle allows to calculate optimal  $a$ . Some asymptotical results are visible even without calculations. If time discount is high, there is little care about future, and optimization will be not much different from one taken by farmer rational only in economic and not environmental sense. There will be optimal size only in the short run. Resource depletion from overharvesting will work similarly to price decline, and in future the size will be too large because land rent it too costly for declined productivity.

## 5.3 Applications

The model can have various applications. Some of important cases is described below.



The problem of fishing with overexploitation of the resource stock is often described by the tragedy of commons. It is typically recommended to introduce the property right that will bring the system to sustainability. The models of this paper can be applied directly to fishing. More water area per fisherman means less intensive catch that is more consistent with sustainability. But this work only in the case of many small fishermen that own or rent fishing area. However, large fishing companies can also overexploit the resource by employing more fishermen (for example, when their wage becomes lower).

A shift to market economy has demonstrated a lot of inefficiencies in sustainable harvesting. The first example comes from non-sustainable logging in Russia (Akishin, 2014). In Komi republic the logging in Soviet time was about 5 times higher than today. Due to subsidized transport cost, it was done in a planned way, so that both close and far regions have been exploited. Transition to market economy in Russia was also accompanied by sharp increase of transport costs relatively to prices of other commodities and by high increase in time discount. Under those conditions businessmen were engaging in cream skimming, logging the woods that had minimal transport cost for export, and this has lead too overexploitation of resource. At the same time, forest in far regions was not exploited when it has reached the optimal age for logging. Thus, not only closer regions were overexploited, but also the cumulative production has declined because of underexploitation of distant regions.

## 6 Policy and Conclusions

Space plays an important role in economic activity. Two-dimensional models in continuous space allow to track the role of scale on productivity and sustainability. The optimization of land slot where one worker is operating depends not only on external factors (like the price of final product, energy and transport cost, land rent) but also on the land ownership and market structure.

The models show that optimal harvesting of natural resources is highly sensitive to such economic parameters as the price of final good, energy price index, land rent and time discount.

Land ownership plays an important role. Small farmers and owners of large land slots react on price shocks in an opposite way. Land ownership by small farmers keeps the hope of more sustainable resource exploitation because they do not care about land rent and virtually have no time discount. However, they can also overexploit the resource if they have no idea about its dynamics under harvesting. Super-rational farmers who have such knowledge can choose lower land slots and exploit them moderately. However, they can lose competition to farmers who are rational only in economic sense and overexploit their land slots.

## 7 Literature

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