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ДВА РЕЖИМА ВОЗМОЖНОЙ ПОДДЕРЖКИ ФУНКЦИОНИРОВАНИЯ ЭКОЛОГО-ЭКОНОМИЧЕСКОЙ СИСТЕМЫ

Предложена простейшая модель эколого-экономической системы, с помощью которой можно изучать некоторые возможные аспекты састейнабельности. Переменные в модели описывают динамику численности населения и обобщенных характеристик экономического развития, инвестиций и качества окружающей среды.

Инвестиционный капитал образуется за счет налогов, собираемых с населения и как доля от экономического развития. Этот капитал используется в определенных пропорциях либо для дальнейшего экономического развития, либо для улучшения социальной инфраструктуры, либо для улучшения среды обитания. При ухудшении состояния окружающей среды замедляется или останавливается рост населения. В этой простой системе обнаруживаются два возможных режима функционирования, которые можно назвать састейнабельными. Когда высоки экологические приоритеты и велика доля затрат на восстановление экологических ресурсов, система приходит к равновесию, характеризуемому низкой численностью населения и низким уровнем экономического развития. При высоком допустимом уровне загрязнений система выходит на траекторию неограниченного роста населения и экономики, когда произведенного экономического капитала оказывается достаточно и для поддержания экономического роста, и для восстановления определенного минимального, необходимого уровня экологических ресурсов. Однако в этом случае экспоненциальный рост в системе приводит в конечном счете к неконтролируемым и резким скачкам в инвестиционных стратегиях, делая всю динамику системы неустойчивой и весьма рискованной.

Эти два режима можно связать с двумя возможными путями састейнабельного развития. С одной стороны, мы имеем небольшие изолированные сообщества, использующие природные ресурсы самовосстановления и функционирующие в рамках естественных природных процессов. С другой стороны, мы имеем интенсивный рост экономически развитых сообществ, которые поддерживают приемлемое состояние окружающей среды за счет значительных инвестиций в искусственные, антропогенные механизмы восстановления природных ресурсов, и по сути дела существуют в некоторой искусственно созданной и контролируемой среде обитания.

Ключевые слова: минимальные модели, сценарии састейнабельности, сильная и слабая састейнабельность, природные ресурсы, эколого-экономические модели.

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Two avenues of sustainability

A simple model of an ecological economic system is suggested to investigate some of the properties of system sustainability. The variables are population, economic development, investment capital and environment protection. The investment capital is generated by taxes collected from the population and from the economic development. It may be then

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spent to further development, to improve the social infrastructure and thus increase the population growth, and to clean up the environment. Decaying environment slows down or reverses population growth. The system displays two distinct modes of development. Under high environmental priorities of the population the system equilibrates at a trajectory with low population numbers and low economic development. With higher environmental tolerance of population the system follows a trajectory of economic and population growth, when the capital produced is sufficient both for economic development and environmental clean up. However in this case the ever-growing rates within the system eventually bring it to chaotic behavior with sharp fluctuations of investment strategies. The two modes of system development are associated with the two possible avenues of sustainability, one of which presents the sustainable development of small isolated communities in remote locations, based on native natural economics. The other avenue stands for the intensive growth in economically developed nations, that manage to keep the environmental conditions at reasonably high though artificially maintained standards, due to intensive investments in clean up practices.

Keywords: minimal models, sustainability scenarios, weak and strong sustainability, natural resources, ecological economic modeling.

The Model

Sustainability should be treated within the framework of generalized ecological economic models in order to take into account both the needs and priorities of the human component and the capacities and resources of the environment. However the existing attempts to couple ecological and economic models for quantitative analysis usually result in fairly cumbersome structures, which may be difficult both to assemble and to analyze. They need huge amounts of information and may operate within quite narrow domains of external and internal conditions.

As an alternative for qualitative analysis of features of sustainable systems we may look at simple generalized models, which though lacking the detail and potential adequacy of real-scale simulations, can nevertheless produce some curious theoretical results, leading to some new approaches and understanding of the sustainability concept.

There has been a considerable amount of critique for this kind of theoretical models (cf. Hall (1988), Hall (1991)), most of which however should be relayed to the improper use of such models and their results, rather than the models themselves and their potential for qualitative analysis of the possible. It is not the exact predictions and detailed recipes for decision makers, that theoretical models are supposed to generate, but the overall understanding of system dynamics, the possible behavior of systems in various domains of parameters and forcing functions, and hence the possible precaution that has to be made to avoid the unacceptable regimes.

This function of theoretical modeling was demonstrated by the well known studies of world dynamics by Jay W. Forrester (1973) and by further analysis undertaken by the team of Donella Meadows (Meadows et al., 1972). The theoretical analysis performed within the framework of a considerably aggregated and generalized model, though quite divorced from the exact patterns observed in reality, set up very important conceptual problems about the *possible* scenarios of development and displayed the *possible* dynamic behavior that may occur in the world system. In what follows we attempt to develop a similar approach.

Consider a hypothetical medium-scale region, like say a major watershed, or a small country, that is quite self-sufficient from the economic viewpoint, so that it may be viewed relatively independent from the rest of the World.

As state variables let us consider population (**P**), development (**D**), investment capital (**C**) and environmental degradation (**E**). Population will be the simplest to explain out of the four. It is the number of people living currently in the region, with no age distribution, social or economic differences. Development is a measure of economic development of the region. This will basically be presented by the produced man-made capital plus the natural capital embodied in it. On the contrary loss of natural capital will be accounted for by the environmental degradation variable, which will be the amount of investment needed to clean up the environment and compensate for the uptake of natural capital.

This implies hypothesizing that natural capital can be regenerated. It is not exactly the hypothesis of substitutability of natural and man-made capitals, criticized by Costanza and Daly (1992), since our assumption by itself delimits the extend of possible damage and uptake: the natural capital can not be used beyond the limits of regeneration, the uptake of natural capital should provide for its renewal in such a way that at least its utility to humans may be restored. We do not specify how this will be done, through innovative technologies of regeneration or by switching to renewable resources.

Investment capital is the wealth produced by the economy of the region and used in a centralized way to benefit the region as a whole. It will be reinvested either in the development sector to enhance production, or in the social infrastructure that will make the region more livable and enticing for population growth, or in environmental restoration. Therefore the latter three variables can have a common measure in some monetary unit, say dollars. The overall conceptual model is as shown in Fig.1. The system dynamics will be described by four ordinary differential equations.

For population we will have:

$$dP/dt = P_growth - P_decrease,$$

where population growth

$$P_growth = (1-P/Car_cap)*net_p_growth*(P+Immigration),$$

and population decrease

$$P_decrease = C_pop_dec*F_EP_factor*P.$$

Population growth is limited by the carrying capacity (**Car_cap**) of the region and it grows in proportion to the coefficient of net population growth (**net_p_growth**). Carrying capacity at this point is assumed as an external parameter, which may be interpreted as the landuse type assigned for the region (and hence the associated probable population size) or as socially set limits to population growth. It is an exogenous factor that controls population growth.

Immigration rate is to be controlled by the same growth coefficient as for the local population. We assume that if the living conditions are enticing for the local population to multiply, they will be equally enticing for people to immigrate into the region and vice versa, therefore Immigration is treated in the equation in a way similar to the local population.

The coefficient of population growth is the natural birth rate (**C_p_growth**), modified by the function of region development (**Dev_fun**) and the function of investments into the social infrastructure (**Inv_fun**):

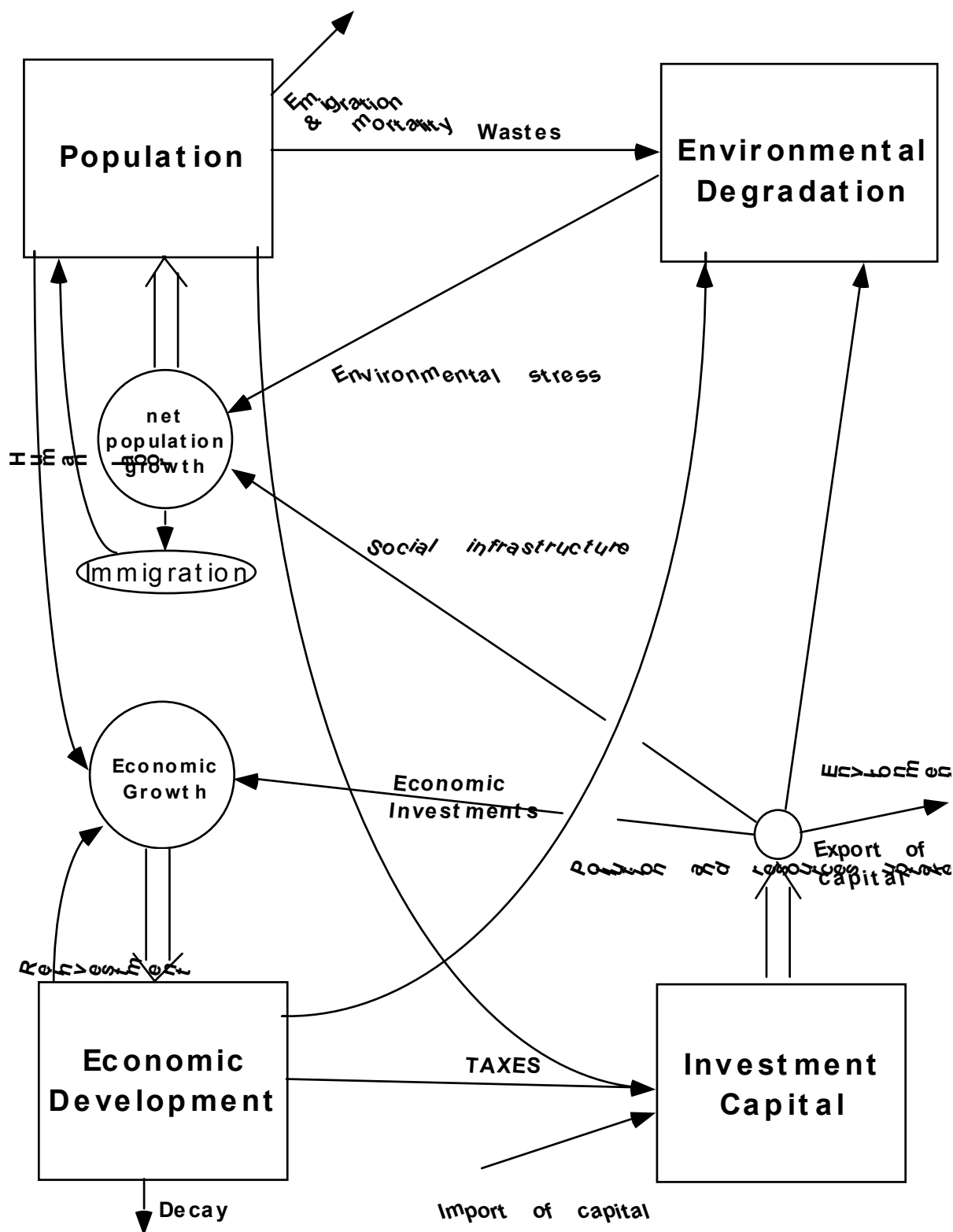


Fig. 1. Conceptual model

$$\text{net_p_growth} = C_p_growth + \text{Dev_fun} + \text{Inv_fun}.$$

Both are assumed in a form of functions with saturation:

$$\text{Dev_fun} = C_dev_ef * D / (C_dev_1:2 + D);$$

$$\text{Inv_fun} = C_soc_P * \text{Inv_soc} / (C_soc_1:2 + \text{Inv_soc}),$$

where C_dev_ef and C_soc_P are the appropriate maximal rate coefficients and $C_dev_1:2$ and $C_soc_1:2$ are the half-saturation constants.

Population decreases in proportion to the natural mortality coefficient (C_{pop_dec}) with account of the function of environmental degradation:

$$F_{EP_factor} = C_{ED_effect}^4 / (C_{pol_1:2}^4 + C_{ED_effect}^4),$$

which is also an s-shaped function with saturation at 1.

This decrease of population may be due to both increased mortality and increased emigration. Both processes seem to be driven by similar factors, very much related to the state of the environment.

Economic development can be described by the equation:

$$dD/dt = D_{growth} - D_{decay} - D_{to_C},$$

where growth is being stipulated by the work of population (P), the amount of capital invested into development (Inv_dev) and the efficiency of the existing economic development for creating additional capital ($C_{reinv} \cdot D$):

$$D_{growth} = C_{P_D} \cdot (Inv_dev + C_{reinv} \cdot D) \cdot P,$$

where C_{P_D} is the productivity.

The decrease of economic development is due to natural wear and decay

$$D_{decay} = C_{decay} \cdot D,$$

and taxes being paid to create the common pool of investment capital:

$$D_{to_C} = C_{bus_tax} \cdot D.$$

Capital for investments is created by taxes paid by the economy and by the population:

$$dC/dt = P_{to_C} + D_{to_C} - C.$$

It is assumed that all the population is taxed at the same rate:

$$P_{to_C} = C_{income_tax} \cdot P.$$

The generated capital is invested into the social infrastructure (education, medical care, etc.) at a rate C_{inv_soc} . The remaining capital will be either reinvested into the economy (C_{inv_dev}) or used to take care of the environment ($C_{inv_cleanup}$), decreasing its degradation. Therefore $C_{inv_dev} + C_{inv_cleanup} + C_{inv_soc} = 1$. We may also assume that a certain amount of capital is exported from the system and is not reinvested into the local economy. In this case another term C_{inv_ex} will be added to the expression above.

$$C_{inv_cleanup} = (1 - C_{inv_soc}) \cdot F_{EC_factor},$$

where the effect of the state of the environment is a function with a threshold at $C_{pol_1:2}$, when its value is triggered from 0 to 1:

$$F_{EC_factor} = Env_Degrad^4 / (C_{pol_1:2}^4 + Env_Degrad^4).$$

Therefore the three flows of investments will be:

$$Inv_cleanup = C_{inv_cleanup} \cdot C,$$

$$Inv_dev = C_{inv_dev} \cdot C,$$

$$Inv_soc = C_{inv_soc} \cdot C.$$

For environmental degradation we will have:

$$dE/dt = Env_Degrad_growth - Env_Cleanup.$$

E is enhanced by two factors. On the one hand it is the growth of economy (**D**), on the other hand it is the population growth (**P**). The relative contribution of these two factors is controlled by the coefficients **C_dev_pol** and **C_pop_pol**:

$$\text{Env_Degrad_growth} = \text{C_dev_pol} * \text{D} + \text{C_pop_pol} * \text{P}.$$

Cleanup is due to self-purification and the restorative capacity of the environment that occurs at a rate of **C_self_cl**, and due to the human activities that are stimulated by the investments into this field:

$$\text{Env_Cleanup} = \text{C_clean_ef} * \text{Inv_cleanup} + \text{C_self_cl} * \text{E}.$$

Results and Discussion

It is most convenient to run such simple models using a modeling software such as STELLA™. This saves considerable amount of time avoiding the stage of model coding and provides a handy interface for calibration and scenario runs.

Since our model is of a theoretical interest and is not designed to simulate some particular localities, we are using only approximate, reasonable values for parameters and variables. The purpose in this case is not simulations of some concrete systems, but investigations of some possible regimes and understanding of the relationship between the behavior of the system and the values that the parameters may take on. We assume that we have incorporated some of the properties of the real life system into the model and now try to investigate the types of dynamic behavior that the system may possibly display. This sort of analysis is a substitute to analytical study of system behavior. The model suggested is non-linear and complicated enough to be outside of the domain that may be treated by analytical methods. Running simulations with various combinations of parameters we try to cover the possibly wider range of parameter variations, limiting it by some extreme reasonable values.

We cannot claim that the results obtained cover all the trajectories of the system. However they give an idea of some of the possible modes of system behavior and already seem quite informative and stimulating.

It is quite easy to hit a set of parameters with which the system disintegrates, one or several of its variables running to infinity or zero. This means that there is a domain of parameters variation in which the system is unstable. However there is also a domain of stable system behavior – one of the most common regimes that may be observed is presented in Fig.2. After several oscillations the system equilibrates at a certain value. The amplitude of the oscillations and the equilibrium point depend upon the coefficients of the model. But the equilibrium point seems to be stable, because small perturbations of parameters or initial values do not change the overall dynamic picture.

The example in Fig. 2 was generated for a system that is assumed to start to evolve in a relatively pristine area with a low initial population of 100 people and very low initial values of economic development, capital and environmental degradation (10). The carrying capacity of the region is set at 10000 and we may observe that after several oscillations the system equilibrates at levels quite far from the carrying capacity. If we lower carrying capacity to 500 and thus make some external factors dampen the oscillations, we arrive at a stable trajectory much quicker

(Fig. 3). We view it as an external factor, because carrying capacity in this context is not a systems function, but rather an imposed condition, such as a social decision about limits on population growth. It does not intrinsically rise from systems dynamics, but is produced by a combination of cultural, traditional, educational factors specific for a particular region.

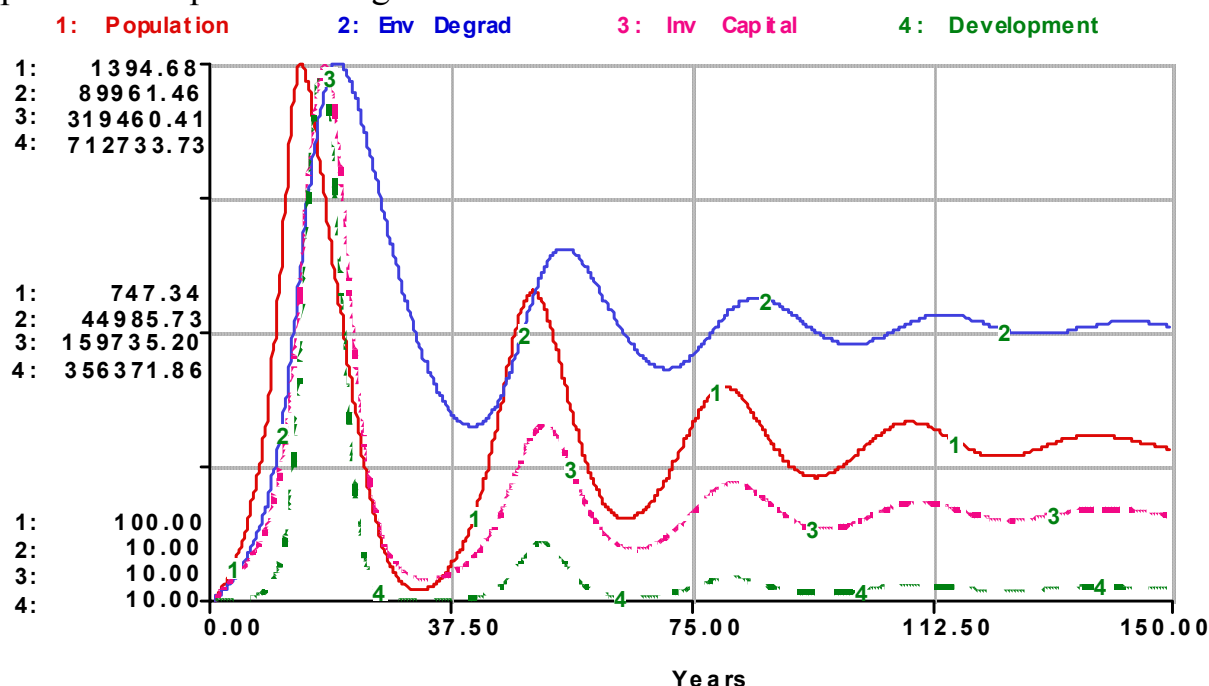


Fig. 2. Baserun – environment ally controlled population and development growth

On the contrary, another external factor that brings additional investment capital from outside of the system destabilizes it, extending the period of oscillations.

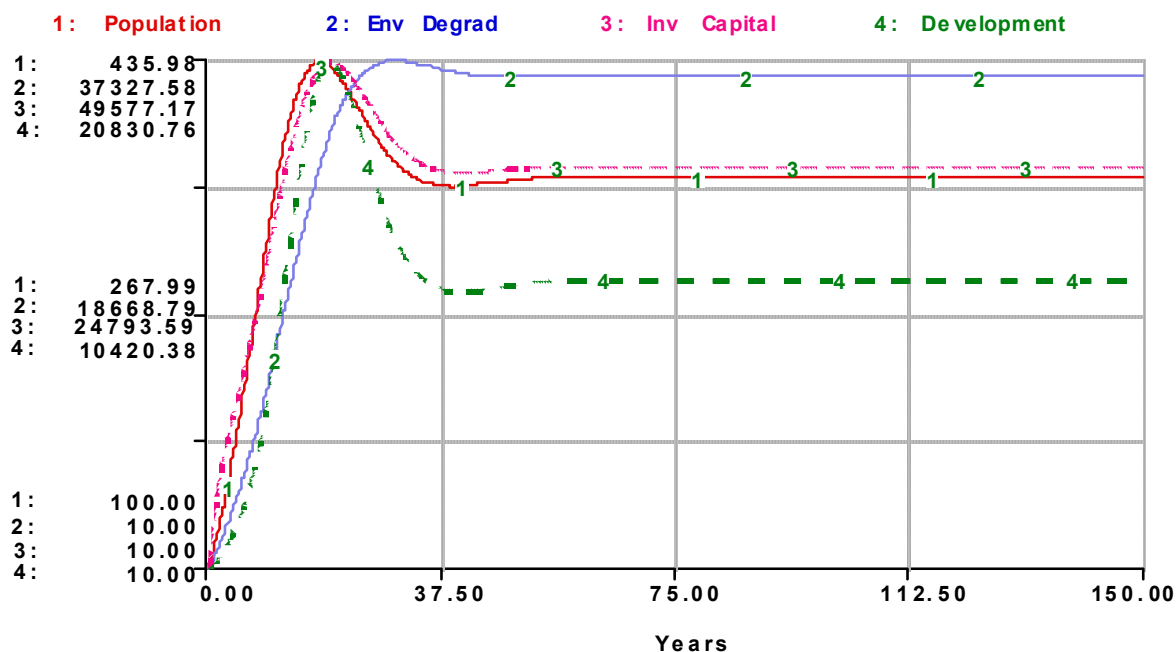


Fig. 3. Population controlled by non-environmental constraints – fast equilibrium

Another sensitive parameter is the productivity coefficient C_{P_D} . Its increase makes the oscillations much sharper, rapidly bringing the system to values above the environmental capacity. Degrading environment results in rapid decline of population and decay of the economy (Fig. 4). At a certain level the rate of po-

population decline seems to level out, but the economy is no longer viable, the life support system turns out to be no longer in place and depopulation continues practically devastating the region. After a certain period of time another outburst of development occurs, once again wiping out the natural capital so that the system is brought to self-destruction.

The most unexpected dynamics occurs when we start shifting the **C_pol_1:2** parameter, that represents at what values the environmental degradation is no longer tolerated by the population and drastic changes in the investment policy are initiated. In fact this parameter controls two functions, both of them have the form as in Fig.5, and one of them, **F_EP_factor**, triggers the population reaction to the environmental situation and the other one, **F_EC_factor**, defines the investment policy. At low enough values of **C_pol_1:2** we get the damped oscillations and approach to a stable state of the system, as above.

However when the population does not mind essentially high values of environmental degradation and **C_pol_1:2** is high, instead of damped oscillations we get a picture of steady growth to fairly high values of economic development and investment capital, while the population is limited by the carrying capacity of the region and environmental degradation is managed at reasonable levels by sufficiently high investments into clean up and restoration programs. In Fig.6 we may see that first the economy rapidly grows, but then the system drops into dramatic oscillations of a chaotic type.

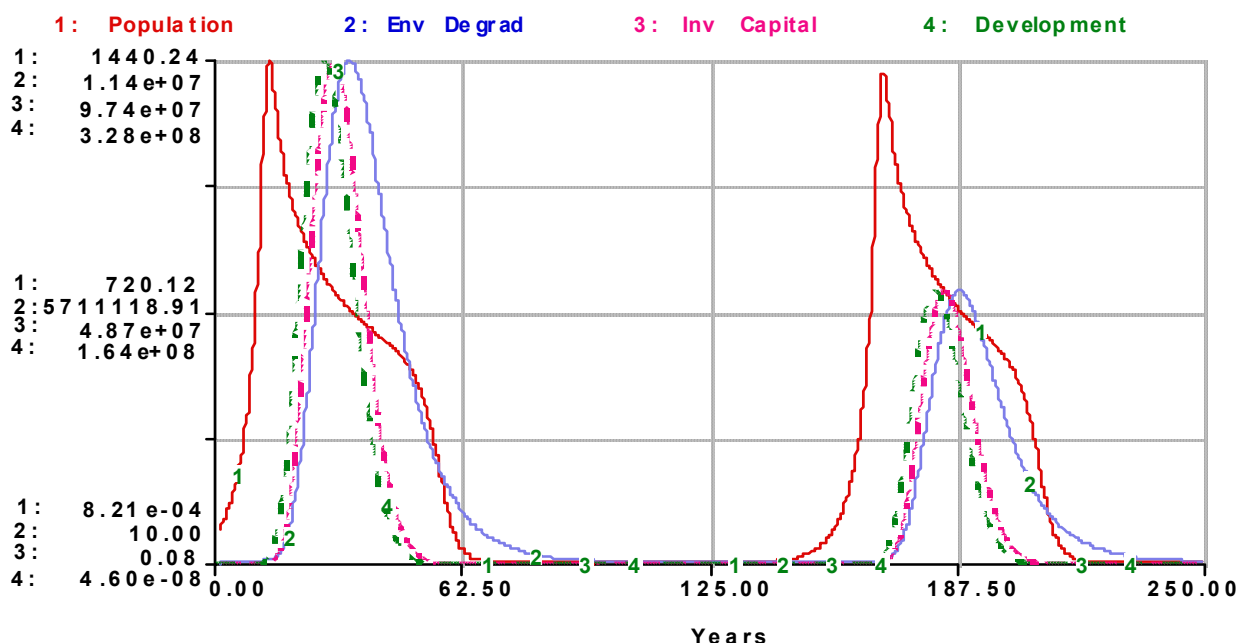


Fig. 4. Model dynamics for high growth rate coefficient

On the one hand we should realize that this is totally a modeling artifact and we could smooth out the trajectories once we could adjust the integration time step to accommodate the increasing flow rates. On the other hand, we may note that in our real-life decisions we are usually basing on some non-perfect discrete information. In many cases especially when the rates of the processes are high and the flows of material or capital or information are high, decisions are made when the information is obsolete or uncertain. We may also note that one of the premises

of the model is that capital is available to fix environmental degradation. Very few social systems really have the governmental structure or the political will to achieve that (Smith, 1994). Time needed to put the capital to work for improving the environment may be considered as one such source for the time lag in the system. In Fig.7 we display the **F_EC_factor** function, that presents how the investment policy has been set for the system. After a period of smooth change from economic priorities to environmental ones the system suddenly plunges into rather chaotic decisions when the measures taken often overshoot the set targets and this continues further on. Interestingly the system still manages to follow quite a reasonable trajectory of development neither going extinct, nor running to infinity.

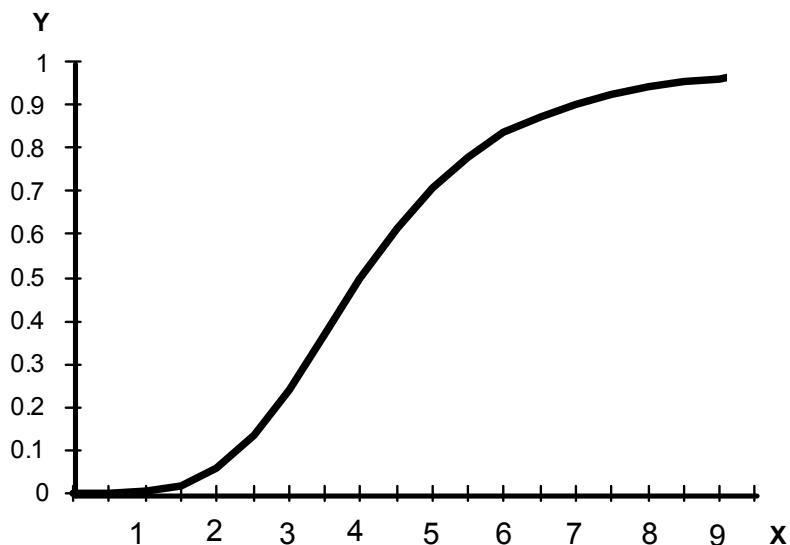


Fig. 5. Investment control function with threshold coefficient $C_pol_1:2 = 4$. X is the amount of pollution (in relative units), Y is the fraction of investment spent for environmental purposes or the factor of environmentally induced population decrease.

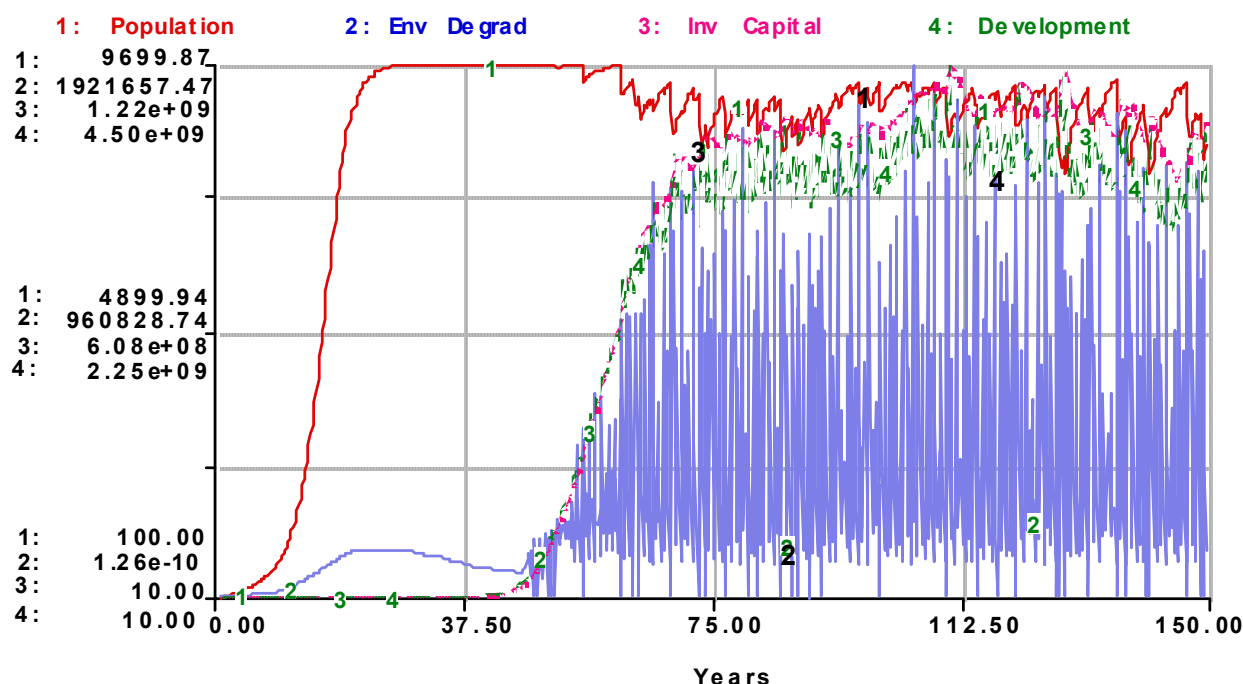


*Fig. 6. Model dynamics for environmentally tolerant population
Non-negativity constraint for Environmental Degradation*

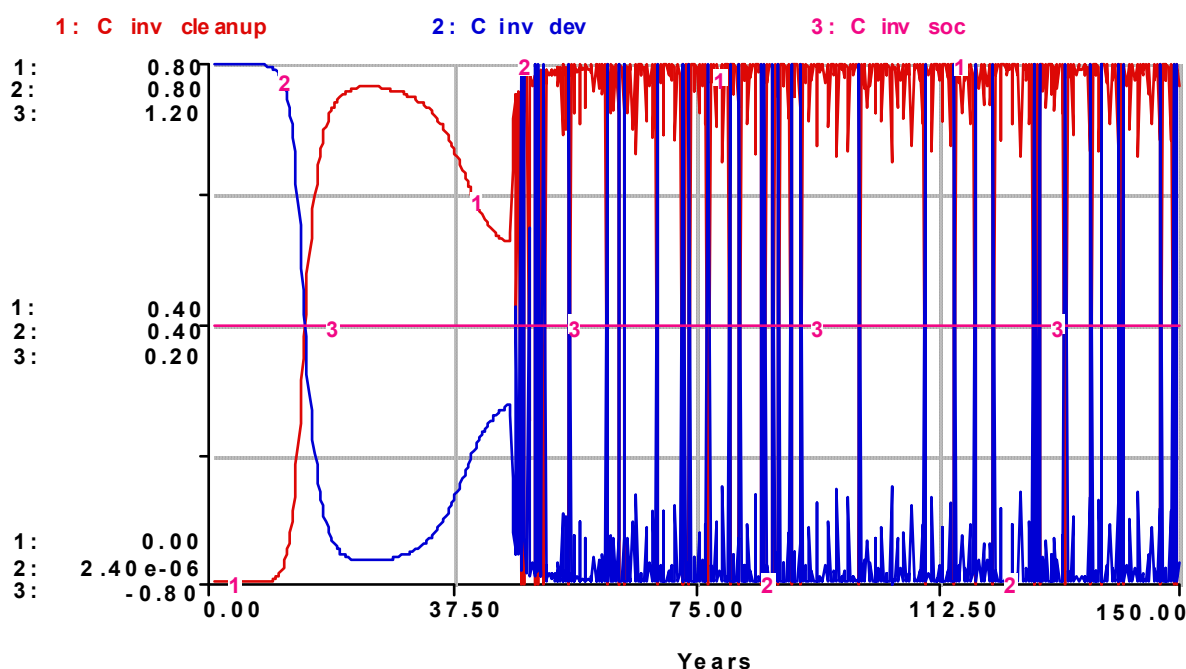


Fig. 7. Investment function at high environmental tolerance of population

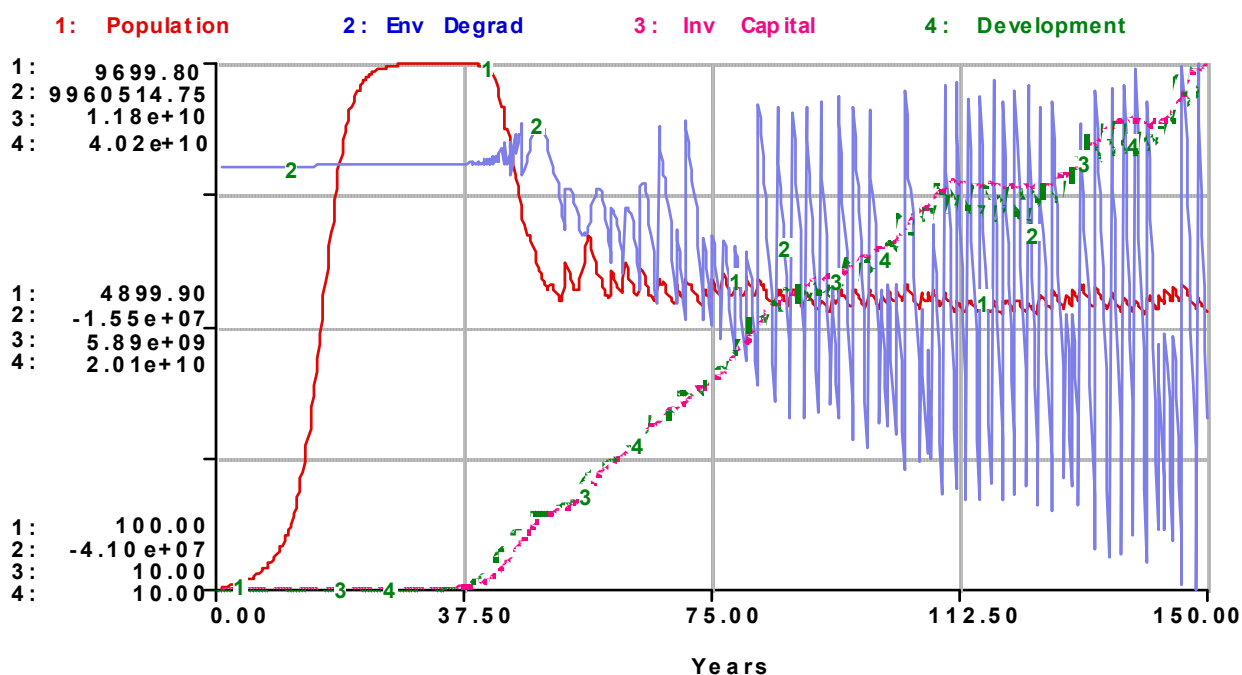


Fig. 8. Dynamics with environmentally tolerant population and no non-negativity constraint for Environmental Degradation

Moreover if we allow environmental degradation to be negative, we get the dynamics in Fig. 8 that provide for a steady growth of economy even further on. Negative environmental degradation may be understood as an accumulation of natural capital above the initial conditions or a clean-up of the environment beyond the set requirements. The natural capital in form of some resources or additional pollution permits may be either stored for the future or traded to the external systems. In both cases an additional reserve of stability is created, that allows for further economic development of the region.

Furthermore, running the same model with a smaller timestep, we may delay the plunge into oscillations and thus prolong the period of growth in the model. Also the smaller the timestep, the higher the level at which population stabilizes. Thus the timestep may be considered as another model parameter and interpreted as the time delay in the decision making process. In a way this parameter can be related to the technological progress, that enhances the controllability of the system. Ideally with the technology and management in place that allow right decisions to be made instantaneously, we can achieve infinite growth in the system. The question is whether this is possible in reality.

Sustainability designs

Describing the ecological and economic components within one and the same system, we may try to analyze sustainability looking at stability of system trajectories (Voinov, Smith, in press). In fact, an integrated ecological economic system should have the intrinsic values and social priorities embedded into it. Therefore if a trajectory of such a system turns out to be stable, we may think of the system as of a sustainable one. The model presented above is an attempt to present both the ecological and economic components within one system, even though in a very simplified way. Some of the terms explicitly correspond to certain value sets dominant in the system. Hence we may interpret the long term quasi-stable behavior of the system as a sustainable one.

Interestingly we may observe two rather distinct organizations of sustainability. On the one hand we have the quasi-stability of the less economically developed system (Fig. 2). We shall be referring to them as Type 1 sustainable systems. In such systems sustainability may be seen as a natural property of the system, sustained primarily by some natural mechanisms of self-support. This is possible only while the human population is small and economic development is low. We may look at this type of sustainability as at a stable development of a natural ecosystem with humans, in terms of natural capital consumption and energy cycling, playing a role of just another species.

The other type of sustainability (Fig. 6), or Type 2 sustainability, on the contrary, is provided by active involvement of humans. Population and economy are growing rapidly. In fact, economy is growing efficiently enough to reinvest sufficient amounts of capital into environmental restoration. In this case sustainability is a result of human interference, in contrast to natural sustainability, it is artificially maintained by humans and totally depends upon effective decision making and economic development.

The major difference between the two types of sustainability is in the social accord about what are the levels of environmental degradation that are acceptable for humans. If the environmental requirements are high, the only acceptable sustainable course is the natural sustainability of pristine ecosystems, where humans tend to play an appropriate role of a top predator, keeping their interference with the natural biogeochemical cycles to a minimum and controlling their population at a sufficiently low level.

Increasing this tolerance level, humans allow reshaping of the environment according to their economic needs. They create artificial sustainable systems,

which may be totally different from the original natural settings. Sustainability in this case is provided by constant management, control, adaptation, readjustment. This sort of sustainability is possible only if economy is doing well enough. It needs to be efficient enough to set aside sufficient resources for rebuilding natural capital, for cleaning up the environment.

We should not, however, forget that the artificial sustainability is associated with increasing risks and uncertainties. As we have observed, higher development rate and more intensive cycling of energy and capital in the system, is associated with higher prices of wrong or untimely decisions and therefore with higher stakes and risks. This is the kind of behaviour, that Holling (1986: 294) describes as surprise "when action produces a result opposite to that intended, ... when perceived reality departs qualitatively from expectations". He also stresses the discontinuous nature of development, that always generates views beyond their time, resulting in greater surprise and need for larger adjustments.

It should be also stressed that this avenue of sustainability is heavily dependent upon the assumption that natural capital can be regenerated due to appropriate investments into environmental clean up, restoration, mitigation etc. Again, in many cases the reconstructed environments, even performing the necessary ecological functions, will hardly be the same as the initial pristine systems and will hardly serve the same purposes and meet the same demands (deer in the backyard or bears in the park are different from animals in a forest – both ecologically and socially).

Realizing this important distinction, one may explain much of the controversy that currently exists in discussions around sustainability issues. The problem is that oftentimes people are simply implying different types of sustainability. The well known Simon – Ehrlich argument is one such example (Tierney, 1990). While Ehrlich expressed his deep concerns about the future of this planet and was proving that the living conditions are declining and we are moving away from sustainability, Simon on the contrary was arguing that the technological progress can cope with all the newly arising problems and humans are doing only better, with the life standards improving and economic systems gaining more and more sustainability. In terms of Simon it would be probably consistent to view the Environmental Degradation variable in the model not as the cost of regeneration of the environment, but rather as the cost of providing necessary resources. In this case we totally forget about the possible other functions of the biosphere, but concentrate on its purely utilitarian economic function.

Looking at this argument from the standpoint of the two types of sustainability we may note that basically they were speaking about different things. Simon was discussing the sustainability of the second type (Fig.6), Ehrlich was concerned with systems of the first type (Fig.2). It is important to realize that both of them are possible. But obviously Type 2 sustainability implies a very different environment than Type 1. In Simon's world there will be very limited space for pristine ecosystems, wildernesses. The Type 1 sustainable systems will be gradually displaced or reorganized. Obviously for some of the human value sets this will be hardly acceptable, but this becomes an issue of different perception of the role of humans in this biosphere. And what we should be mostly concerned with is the increasing cost

of possible miscalculations and human errors. The higher the development rate, the larger the human population, the steeper may be the fall, the higher the risk of total extinction as a result of such a fall. Up till that point everything may be developing in a sustainable way, along the trajectory we see in Fig. 6 or 8, coping quite successfully both with economic and ecological problems, exactly as Simon sees it.

Another example of this sort of misunderstanding is found in a paper by Grizzle (1994). He argues with Norton (1991), that a new environmentalism should be created, that would take into account human needs and "explicitly include all major human occupations" (p.263). He tends to prioritize human needs (though realizing that there will be always a problem in separating them from wants), basically thinking in terms of Type 2 sustainability only. Stating that "few people will seriously ignore their ecological needs in favour of protecting some yet-to-be-agreed-on ecosystem characteristics" (p.267), he does not explain what are these "ecological needs" that need to be sacrificed. Trying to protect human needs from some vicious environmentalists, he seems to ignore that there is also another avenue of sustainability possible, and that it may also correspond to needs of some other people and requires far more protection than the Type 2 sustainability assumed by the majority.

It may be interesting to see how the two sustainability types identified above are related to the strong and weak sustainability that have been discussed in literature. According to Pearce and Atkinson (1993) weak sustainability allows for unconstrained elasticities of substitution between 'natural' and 'man-made' capital, while a strong sustainability would not allow for such substitutions and a positive depreciation of any 'critical' natural capital would be a sign of non-sustainability. In our case the criterion for the sustainability type is quite different. Type 1 sustainability is provided by the natural function of the system, with the human component being limited and insignificant for the persistence of the system. On the other hand Type 2 sustainability is a creation of human and is dependent upon the efficiency of his economic system. The indicator that decides between the two types is the tolerance of the population to the state of environment, humans awareness and ecological consciousness. For providing Type 2 development we most probably will have to assume flexible enough substitutions for the natural capital in order to provide steady economic growth, especially in the periods of drastic falls of in the quality of environment corresponding the peaks of environmental degradation indicator in Fig. 8. Type 1 sustainability may be associated with strong sustainability, since it will not be straining the ecological component of the system, keeping all the necessary components of the natural capital well within the required limits.

Probably the only fair and reliable arrangement can be if there will be a merge of the two types of sustainable systems (Fig. 9). This may be possible only if there will be strict control over the development of the Type 2 systems, which always tend to expand. The naturally sustainable systems in this case will serve two purposes. On the one hand they will provide sites and habitats for that smaller part of the human population whose priorities and value sets are better suited by this type of environments. On the other hand, they may serve as a refuge, at least a potential one, in case something really goes wrong in the systems of the other type. However it should be understood that there are very limited chances that naturally

sustainable systems will be able to cope with the perturbations produced by the disrupting artificially sustainable systems and will be able to accommodate even a minuscule part of the humans seeking refuge in them.

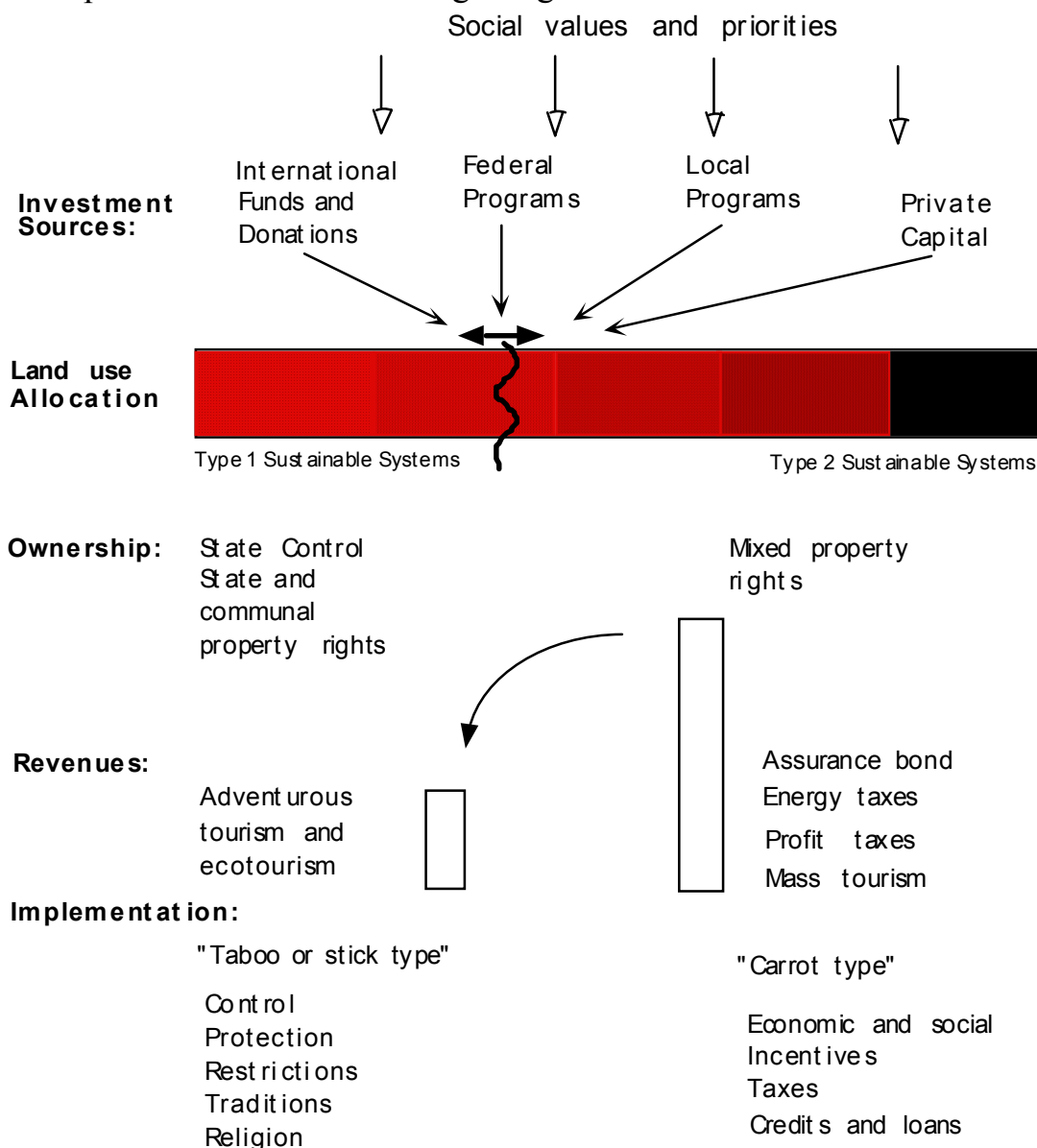


Fig. 9. Merging the two types of sustainability

In all cases there should be a decision about what parts of the area should be preserved as pristine ecosystems for conservation not only of wildlife and vegetation, but also of cultural and traditional ways of life for indigenous peoples. And it should be determined which regions will be designated for sustainable development within artificially designed and managed ecological and socioeconomic systems, within the conventional tourism industry, and within development that will invest sufficiently in the cleanup procedures, and thus ensure healthy ecological conditions in the region at the larger scale.

The proportions of the two types of systems are prescribed by social agreement very much dependent on the economic resources available. Type 1 systems at present cannot be preserved on their own—they need additional investment to perform their protection. There may be different mechanisms to provide protection, but hardly any that would be free. It should be also realized that the majority of

strategies for this type of sustainability are best based on centralized control and public property rights, which is a loss in the accounting balance and an additional burden for the budget.

The two sustainable systems should interact closely. The Type 2 systems would be serving as a buffer for the other type. The paradox is that even though "more" sustainable in essence, based on some natural control mechanisms and therefore seemingly more self-sufficient, the Type 1 systems are more vulnerable to external invasions, and they have less intrinsic mechanisms to protect themselves from unfavorable human-made perturbations. Therefore, they need the additional investments to protect themselves. Type 2 sustainability is capable of generating revenues and becoming cost effective, and it may also partially support the protected Type 1 regions.

Social values and priorities in local, national and international levels define the amount of investment that the societies are ready to make for sustainability. It also defines what fraction of the whole territory can be set aside and protected as a Type 1 sustainable system and what fraction will be developing in a Type 2 manner, serving as a buffer for the former both in geographic, social, and economic terms. Geographically and ecologically, Type 2 sustainability provides clean environment. Economically, it shares a portion of its revenues to protect Type 1 regions from direct effects (poachers) and indirect effects (perturbations due to global climate change or regional fallout of contamination) of the rest of the world. Socially, it will create the necessary cultural and educational backgrounds that will ensure and expand sustainability in the longer term.

The model runs indicate that there are no intermediate regimes in the system. The merge suggested in Fig.9 can be organized geographically by combining the sustainability types in different localities, but there can be no merge within one and the same locality: either the system takes the Type 1 trajectory or it follows the Type 2 avenue of development, either it is based on natural sustainability mechanisms, or it employs artificial human induced control mechanisms with all the associated risks and uncertainties.

Conclusion

Theoretical models like the one presented above hardly provide any constructive measures or indicators of sustainability; they are not intended for making predictions or decisions for particular sites and systems. Their major value is in promoting *understanding* of some of the mechanisms underlying the system operation, showing some of the *possible* modes of system behavior. We do not claim to cover all the details of the system and do not think that we reproduce all the variety of system dynamics. However, there may be similarities in behavior of the system and the model based on some of the most important features of and processes in that system, and we may investigate the dynamically possible regimes of the system looking at the dynamics of the model.

The model above shows that there may be two distinct modes of behavior that can be interpreted as sustainable. It also describes the processes and functions that drive the system either to one of the sustainable modes or sets it towards unsustainable development. The driving factor that defines the type of sustainability

that the system is to approach has a distinct interpretation in terms of social values and priorities and can be understood as the environmental tolerance or environmental requirements of the population.

We may note that much of the controversy in the discussions around sustainability arises from the misunderstanding of the fact that there may be two different modes of sustainability. People tend to argue about general sustainability without explicitly defining which of the two types they are talking about. At the same time the underlying mechanisms and the driving forces of sustainability tend to be very different in these two settings.

Designing regional systems, we should decide on the patterns of merging the two types of sustainable development. There are certain advantages in both of them and both of them should be present to satisfy the full scope of social demands and ecological diversity. The dominance of one or the other type of sustainability is mostly a function of the existing social choice, traditions, cultures, and religions.

The model suggested seems to have potential for further studies. Other dynamic regimes may result from a more mathematically rigorous analysis. It would be most interesting to look at the behavior of the system when coupled to other similar models, presenting adjacent territories or regions linked together by economic, demographic ties.

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