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Designing an Environmental Responsibility Institution – The Environmental Mitigation Banking System*

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ABSTRACT

While institutions are a key determinant of economic behavior and new institutions are often formed as a part of an economic policy, a systematic way to design these institutions and test their potential performance before they are created does not exist. I have attempted in this paper to create and test such a design for an environmental mitigation banking system using system dynamics modeling and computer simulation. Viewed as an environmental responsibility institution for transmitting the cost of restoration to the agent responsible for damage and assuring at the same time that net damage to the environment remains zero, environmental mitigation banking has been introduced in limited niches like forests and wetlands and operated mostly in the private sector, but at a scale that its impact on human activity and environment cannot be ascertained. Many opinions exist about how this industry should be instituted and regulated, but without a clear understanding of how proposed institutional arrangements and regulatory policies would affect its performance in terms of supporting human activity, preserving environment and minimizing organizational costs and social conflicts. Environmental restoration costs in a mitigation banking system are transmitted to users through mitigation credits, which are earned by a mitigation bank and bought by a user prior to inflicting damage to the environment. Pricing of these credits is an important aspect of the banking system and complex engineering methods connecting cost to price have been proposed as pricing criteria. Also, environmental groups often advocate subsidization of the environmental mitigation activity by the government. Experimentation with my model suggests that the market is able to yield an optimal price without inputs from engineering methods connecting price to cost, while the delays associated with engineering calculations, when they are used to determine price, would reduce growth of human activity by stifling its multiplier effects. Subsidies would indirectly support human activity by reducing the price of credits, but for the same budget, direct subsidies support human activities more than the market-based subsidies. Connecting credit requirements to environmental condition introduces instability in all cases due to the delays involved in this process. The experimental method used to test the efficacy of the mitigation banking system is seen in general to be important to the design of new institutions and improving performance of existing ones.

Keywords: Environmental economics, Institutional economics, sustainable development, environmental mitigation banking, wetlands preservation, infrastructure development, system dynamics, computer simulation.

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INTRODUCTION

While heterodox economics streams have widely recognized the role of institutions in influencing behavior of an economy, a large part of the writings in institutional economics are devoted to interpreting classical thought on institutions rather than making use of this powerful instrument in designing a policy implementation framework (Neal 1987, Bush 1987). In particular, environmental policy, which should be aimed at creating environmental responsibility institutions that influence every day conduct of business, continues to be implemented through command and control and rather arbitrary fiscal instruments, although a few market-based instruments such as tradable pollution permits have been proposed (Cropper and Oates 1992). Environmental mitigation banking has recently been suggested as an institutional innovation that should transmit restoration cost to the agents causing environmental damage while at the same time assure that net damage to the environment remains zero so there are no inter-temporal transfers of costs and benefits. Environmental restoration costs in an environmental mitigation banking system are transmitted to users through mitigation credits, which are earned by a mitigation bank through restoration of decayed environment and bought by a user prior to inflicting damage to the environment. Mitigation banking has been implemented in limited enclaves, mostly to conserve wetlands and forest areas. In United States, mitigation banks are in operation in Minnesota, California and Florida since environmental regulation in these states calls for equivalent restoration of environment to offset any damage caused by infrastructure projects, but the scale of this activity remains small (Mitigation Banking *Website*, Mitigation Banks *Website*).

Many opinions exist about how mitigation banking industry should be instituted and regulated, but without a clear understanding of how proposed institutional arrangements and regulatory policies would affect its performance in terms of supporting human activity, preserving environment and minimizing organizational costs and social conflicts. Pricing of environmental credits is an important aspect of the banking system and complex engineering methods connecting price to cost have been proposed as pricing criteria. Also, environmental groups have often advocated subsidization of the environmental mitigation activity by the government or other outside agents, but without clearly understanding the implications of such subsidies. Evidently, there is a need for perfecting design of this new institution before confidence can be placed in its successfully meeting the dual goals of maintaining environment and supporting human activity without a cumbersome and expensive command and control system in place.

Integrating concepts from economics and system dynamics, I have attempted in this paper to model the role of a mitigation bank operating with a variety of regulatory instruments and interventions imposed by a government. Computer simulation is used to discern behavior of the relationships included in the model. Experimentation with my model suggests that the market is able to yield both an optimal price and a human activity size compatible with the environmental capacity without inputs from engineering methods connecting price to cost, while the delays associated with engineering calculations, when they are used to influence price, would greatly reduce growth of human activity by stifling its multiplier effects, even though they would achieve a compatibility between the size of human activity and environmental capacity. Subsidies would indirectly support human activity by reducing the price of credits, but for the same budget, direct subsidies support human activities more than the market-based subsidies. Connecting credit requirements to environmental condition introduces instability in all cases in view of the delays involved in the process, but helps to connect human activity size to environmental capacity when market or cost-based pricing mechanisms are not instituted Most importantly, an environmental mitigation banking system operating under a variety of appropriately designed institutional arrangements appears to align human activity with ecosystem size that has been blatantly ignored in orthodox economics. Such an alignment has been emphasized by the environmentalists (Daly 1991, 1996), but the operational means for achieve it are not clear. Equations of the model programmed in *ithink*[1] software are placed in the Appendix. A machine-readable version, only for noncommercial use, is available from the author on request

The experimental process used in this paper to arrive at an appropriate design for an environmental mitigation banking system is seen in general to be of significant importance to the design of new institutions and improving performance of the existing ones since it creates a test bed for institutional design. Such a process should allow putting the many invaluable institutional economics concepts into practice.

INSTITUTIONS AS INSTIGATORS OF POLICY IN AN ECONOMIC SYSTEM

Michael Radzicki in a series of writings appearing both in system dynamics and institutional economics literature has drawn parallels between the qualitative models of how institutions create roles for the agents in an economic system and the formal models created through system dynamics modeling process (Radzicki 1988, 1990, 2003). In my observation, there is also a great similarity between how an abstract system of roles that process information and return decisions is defined around an articulated problem (Saeed 2002) and how Institutional economists define an institution – not as a manifestation of bricks and mortar, but "as a set of socially prescribed patterns of behavior" (Bush 1987), or as "activities of people in situations"... which includes: "1) people doing; 2) the rules including the situations in which

[1] *ithink* is trade mark of High Performance Systems, Inc.

they are followed, and 3) the folk views explaining the rules" (Neale 1987). My interpretation is that institutions are the role senders while agents, who may be a part of one or more institutions, are the role receivers as suggest by Katz and Kahn (1990).

Creation of institutions to act as policy agents is not new. Command and control institutions are widely used in numerous policy contexts. More recently institutions have been created that constantly monitor information to create appropriate market interventions. The Federal Reserve Bank is an example of such institutions. I have earlier proposed the creation of a Natural Resource Board to constantly monitor resource basket with respect to its regeneration rate and vary severance tax structure so what is consumed is regenerated (Saeed 1985). Herman Daly (1991) has suggested an innovative set of institutions for proper functioning of a steady state economy. In all such proposals, institutions act as agents that constantly process information derived from the system state and return decisions to alter this state if it deviates from designated goals.

Figure 1 illustrates the information processing and decision-making roles of the agents operating in a system of institutions. The decision rules in this system are formed by norms, values, expectations and sometimes explicit rules emanating over long term from institutions. The decision process is based on access of the agents to information and their manifest or informal contribution to the decisions delivered following those norms and rules. Clearly, this process constitutes a bounded rational rather than an absolute rational decision process as has been pointed out in the seminal work of Herbert Simon (1982). As Morecroft (1985) and Radzicki (1988) point out, such a bounded rational decision process is also a common construct, both in System Dynamics and Institutional Economics. An important point to note is that both, the creation of decision rules and actions occur in feedback loops that involve discerning system state, however, the former involves a long time constant while the latter a short one.

A system dynamics model constructed as a test bed for institutional design may include both the role-sending functions of the institutions involved in the process and the roles-playing functions of their agents, depending on the problem of interest. When the causes of an institutional change are to be investigated, the long-term process of changes in rules and norms must be included in the model; however, when the short-term impact of an institution is to be investigated, these long term processes need not be modeled since the activities to be addressed by the model constitute performance of the institution not the motivation for forming it (Saeed 1992).

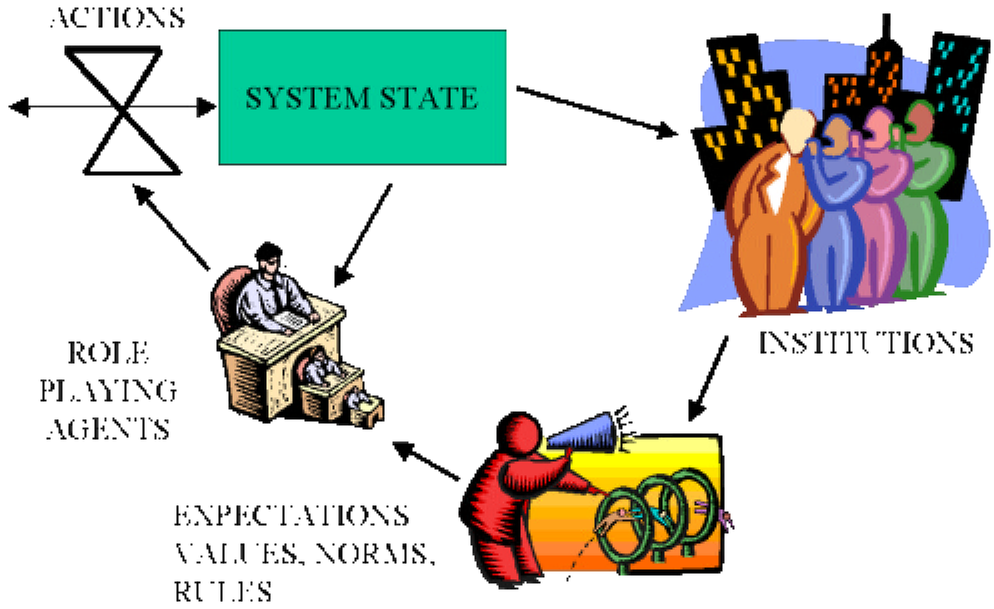


Figure 1 **Institutions as role senders and agents as role players**

ENVIRONMENTAL RESPONSIBILITY AND ORTHODOXECONOMICS

Orthodox economics excluded environment from its formal analyses until early 1970s, although Harold Hotelling expressed passing concerns about market failure in the extractive resources industry as far back as 1931 (Hotelling 1931), while Malthus postulated the relationship between population and resources in 1798 (Malthus 1926), and Ricardo stated the iron law of wages and rents in 1817 (McCulloch 1881). It should be noted that both Malthus and Ricardo apparently considered resources to be completely renewable since they equated them to land with fixed rather than depleting capacity, while Hotelling dealt with exhaustible resources with concerns that the market may not be able to return optimal rates of exhaustion, but without pessimism about the technology to bring to fore new sources as old ones are exhausted These early concerns have been followed by a blissful confidence in the ability of the technological developments and prices to provide access to unlimited supplies of resources (Devarajan and Fisher 1981, Smith and Krutilla 1984). Environmental analysis seems to have appeared as an add-on in response to the environmental movement spearheaded by the famous *Limits to Growth* study (Meadows, et. al. 1972, 1992). In this add-on, the classical economics theory has continued to assume mineral resources to be unlimited expecting prices and technological developments to continue to unearth richer mines so less profitable existing mines may be abandoned (Robinson 1980,).

Solow's 1974 Richard T. Ely lecture made a strong argument for integrating depletion of resources into the models of economic growth (Solow 1974), but the momentum of orthodox economics effort has nonetheless not deviated much from its earlier focus on optimal rates of depletion and pricing of resources (Nordhaus 1964, 1979) without concerns for environmental capacity, which are mostly expressed in passing. There have been some concerns also expressed about intergenerational equity, but its treatments remain tied to arbitrary rates of discount (Hartwick 1977, Solow 1986). Notable exceptions to this practice include the writings of Georgescu-Rogen (1971) and Kenneth Boulding (1981), and more recently, Herman Daly (1991) and Robert Costanza who have spearheaded the ecological economics movement (Costanza et. al. 1997) that emphasizes the importance of connecting the volume of human activity to the size of the environment. Barring these few exceptions, present day environmental economics texts are primarily built on micro-economic theory concerned mostly with optimal pricing of resources and environmental degradation (Tietenberg 2003, Field and Field 2002) with only passing references to intergenerational equity and environmental capacity.

In a more practical policy context, the famous Brundtland Report (1987) defined sustainable development as "development that meets the needs of the present without undermining the ability of the future generations to meet their own needs." This definition was widely applauded at the famous 1992 Rio conference on environment, but its proponents continue to be seen as activists rather than scholars and its principles are rarely incorporated into what has appeared as orthodox environmental economics in which discounting the future is a norm and policy is driven by optimal rates of consumption rather than by the principle of keeping intergenerational transfer of costs and benefits to zero. There also remain many missing links between the various theoretical threads and practice, in part because theoretical concerns, whether based on environmental pessimism or technological optimism, are difficult to translate into operational policy clearly defining goals and choice of instruments (Dietz and Straaten 1992). Hence environmental concerns have translated mostly to moral statements and activist values rather than to policy.

Mitigation Banking is an institutional innovation, developed in most part by engineers, geographers and foresters and mentioned only in passing in the texts on environmental economics. It has been put to work only in few locations and in limited contexts like preservation of wetlands and forests, although it promises to be an important institution for restoring environmental responsibility into the society that has moved away from it on the false promise of technology to make available a bigger and richer basket of resources in the foreseeable future (Saeed 1985). A new institution, however, cannot be created in a vacuum. It must be designed carefully to function and deliver its mandate in an existing system. Hence, as all institutions should be, a mitigation banking system needs to be carefully designed and tested before its scope is expanded to include a variety of environmental and regional contexts so its reliable performance is assured.

Designing and testing of prototypes is an integral part of engineering and applied sciences, but this process has not been instituted in economics for lack of our ability to construct appropriate test beds. System dynamics modeling practice creates an opportunity for us to construct such test beds. I have in the past advocated the use of system dynamics modeling to develop operational implementation instruments for normative policy statements (Saeed 1992) and have attempted to demonstrate this process by constructing a model for operationalizing the recommendations of the Limits to Growth Study (Acharya and Saeed 1996, Saeed 1998), and for designing innovation organizations (Saeed 1998a). I have attempted in this paper to extend this process to testing the performance of a mitigation banking institution working under a variety of regulatory and organizational arrangements, building on my earlier attempts presented in Saeed & Fukuda (2002) and Saeed & Fukuda (2003).

MITIGATION BANKING AS AN ENVIRONMENTAL RESPONSIBILITY INSTITUTION

As long as the scale of human settlements was small, and the resource basket used was constituted mostly by locally found renewable resources, the resource limits remained easily recognizable. It is not surprising that indigenous knowledge in traditional societies enabled them to live in a way that maintained a balance between development and environment. For example, ancient agricultural methods, such as slash-and-burn farming were restricted to small ranges, desert cultures adopted nomadic ways to assure regeneration of the oases that sustained them, planting trees was believed to earn spiritual merit, and fallow practice and diversity of crops were widely used as standard farming practices that sustained land fertility.

The indigenous knowledge and beliefs at that scale allowed the human society to live in harmony with nature and the questions of conquering it or sustaining it did not arise (Daly 1991). As technological developments allowed access to huge stocks of nonrenewable resources that seemed to be unlimited, and this together with the availability of modern transportation networks allowed the scale of the human settlements to grow, multiple societal functions had to be broken away from individual roles to become resident in specialized institutions for the sake of expediency. Unfortunately, the societal function of environmental responsibility that came naturally to small-scale societies with holistic individual roles fell through specialization cracks since institutions taking over this function were never thought about until evidence of deterioration in environment appeared. The impending danger of disaster that can be created by indiscriminate growth and resource consumption raised some thirty years ago by the famous “Limits to Growth” study (Meadows et. al. 1972, 1974) is now quite widely recognized (Boulding 1993, Cleveland 1991).

Even when the need for restoring environmental responsibility to society has been recognized, creating reliable designs for incentives and institutions cultivating responsibility functions still remains difficult. Unlike engineering where technical innovations can be transformed into prototypes and tested extensively before being put into practice, social innovations are often implemented while they are still in concept stage since the means to test their reliability have been limited. Indeed, a large variability has been widely experienced in the performance of social and economic development agendas (Saeed 1994).

Many institutional concepts have been proposed to restore environmental responsibility in society once its need was recognized. Examples of these include the creation of private national trusts that would purchase and maintain historical heritage and reserves; the imposition of environmental taxation on production of commodities so their price is modified in accordance with the environmental burdens they create; the trading of emission rights so cost of environmental degradation can be borne by the responsible parties with the help of the market, and mitigation banking so environmental degradation is off set by a compensatory restoration effort while the cost of mitigation is borne by the parties who consume environmental resources (MITIGATION BANKING *website*). Whether these concepts can reinstate the environmental responsibility function in society cannot be ascertained, since designs based on these concepts have not been tested adequately to allow us to guarantee their success.

The compensatory mitigation concept supports the notion that the net environmental value of an area lost to development is maintained at zero. When mitigation is carried out within the developed area, a complete status quo in environmental resources can be maintained, but this may not always be a feasible solution. When development and mitigation areas can be geographically separated, the net environmental loss might still be maintained at zero while the loss and gain areas are different, and the parties carrying out mitigation may also be different from the parties consuming environmental resources. However, if the cost of mitigation must still be borne by the party consuming environmental resources, while an equivalent value of environmental resources consumed is restored, the mitigation process may unify the objectives of avoidance, minimization and mitigation of environmental damage.

If the development and compensatory restoration areas must coincide, each developer must be required to mitigate the environmental damage she has caused. However, when development and mitigation areas may be different, mitigation banks can be formed to carry out the mitigation work and sell the credits so earned to a developer. Such a mitigation process creates a trading system whereby deposits can be credited in advance of development by means of ecosystem creation or restoration. Since restoration effort might be concentrated in a selected area, this process can also help to alleviate ecosystem fragmentation. Also, since a bank can specialize in particular types of restoration work, restoration activity would be more reliable and ecosystem restoration failure may be avoided. Furthermore, unforeseen costs in case of direct restoration by the developers may be avoided since failure rate is progressively reduced as a mitigation bank develops technical expertise in its work. Last, but not least, since the regulation accompanying mitigation banking creates a cost for projects that degrade environment, they are likely to be implemented in a way that this cost and hence the accompanying environmental damage are minimized.

A mitigation banking system may function under a variety of organizational and regulatory arrangements. It can be established in the public or private sector. The price of mitigation credits it creates can be fixed, tied to cost using engineering methods, supported by subsidies, determined by the market or influenced by all combinations of those factors. Furthermore, the regulation governing the requirement of mitigation credits for formation and operation of built environment may be fixed or tied to the condition of the environment. Many views exist on what might be an appropriate way for a mitigation bank and mitigation regulation to function. Currently, the establishment and use of mitigation banks are being promoted in many countries. In the United States, active mitigation banking systems are in place in Minnesota, Florida and California. In all cases, the implementation of the concept is in a nascent stage and its efficacy under a variety of arrangements needs to be carefully evaluated (Mitigation Banking *Website*, Mitigation Banks *Website*).

MODELING AN ENVIRONMENTAL MITIGATION BANKING SYSTEM

Key agents in an environmental mitigation banking system include 1) human activity that creates built environment or man-made capital, 2) ecosystem that is consumed by the building and operation of man-made capital, 3) mitigation banking that engages in environmental restorations creating and banking mitigation credits, 4) a regulatory process creating and modifying credit requirements, 5) a regulatory compliance process that enforces credit requirements on developers, 6) pricing norms imposed on mitigation banks – including price fixing by an authority, engineering models connecting price to cost and the market mechanisms connecting price to supply and demand considerations, and 7) government and foundation subsidies to speed up restoration activity. Some of these agents were included in models presented earlier in Saeed & Fukuda (2002) and Saeed & Fukuda (2003), which assumed constant damage costs and restoration costs with fixed requirement of credits for each unit of construction and operation. These assumptions have been relaxed in the model I have developed in this paper to represent the interaction between environment, conservation and development. I have also attempted in this paper to more clearly define decision rules at two levels for each agent: those for interaction between agents and those for making decisions with each agent.

a) Interaction between system agents

Figure 2 shows a map of the model at the level of interaction among its various agents. These agents are grouped according to the functions they perform. Thus, Human Activity represents creation and operation of infrastructure and built environment, including man-made capital and the production carried out with them. The Ecosystem represents natural capital that is consumed by human activity. These are the only two agents in the system before the mitigation banking institution is introduced and there exists a unilateral relationship between them in which Human Activity may only consume the Ecosystem.

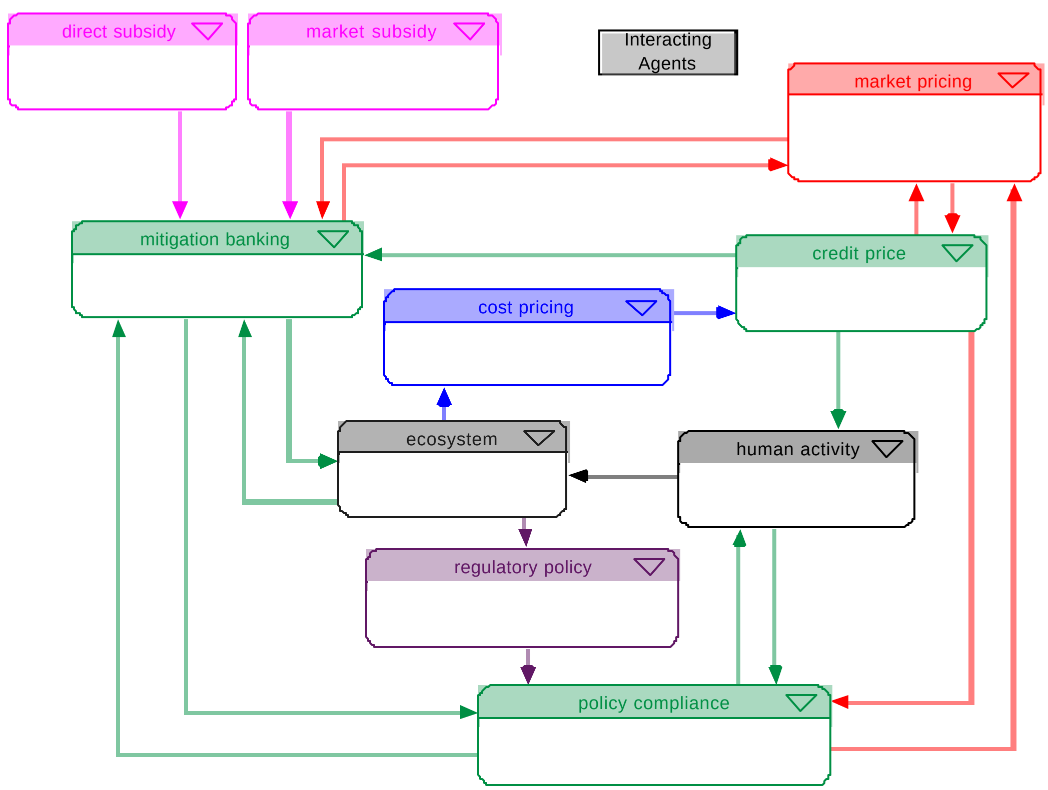


Figure 2 Agents created with introduction of mitigation banking and interaction between them.

The introduction of mitigation banking creates at the outset four new agents: 1) Mitigation Banking that undertakes to restore environment, earn and bank mitigation credits in the process and sell them to the Human Activity agent; 2) a Regulatory Policy that defines the requirement of credits for any human activity to go on, 3) a Compliance Process that enforces regulatory requirements on human activity; and 4) a Credit Pricing process which returns a constant price in default unless influences from market and restoration cost considerations are activated.

Ecosystem restoration cost depends on the condition of the ecosystem, a better condition returning a lower cost. When price of credits is linked with the restoration cost, ecosystem condition influences price, but after some delay representing the perception and engineering evaluation processes. Market influence on price, if in place, depends on the other hand on demand for credits arising from policy compliance and their supply created by mitigation banking. Mitigation banking, if influenced by market, in turn responds to price in forming its expectations of profit, while price also influences policy compliance through a similar expectation process, a high price creating deferment of credit purchases, a low price calling for purchase for future use. Regulatory policy determines the requirement of credits either autonomously or on basis of ecosystem condition. Compliance of regulatory policy affects the demand for credits, which creates an input to the market based pricing agent as well as to the mitigation bank through purchase of credits, which in turn facilitates compliance. Credit price also affects human activity, a high price drains cash resources of the agent carrying out human activity creating a constraint to growth, a low price conserves those resources and supports growth.

Another important instrument affecting system performance is the subsidization of mitigation banking activity, which will indirectly support human activity by increasing credit supply and lowering the price of credits. This subsidy can be provided as direct support to the mitigation bank in the form of tax rebates or cash for operation, or through the market by purchasing a designated amount of credits and retiring them so mitigation activity is supported while at the same time the shortage so created enhances credit price and further improves financial incentives for mitigation activity.

Structuring model as shown in Figure 2 allowed testing its behavior with different combinations of agents for understanding the impact of their roles on human activity and environment. It also provided an overall map of the interactions between various agents in the system and the feedback loops formed through it as shown in Figure 2.

As a reality check, the first experiment with the model is conducted by connecting only the human activity and the ecosystem agents, with human activity proceeding oblivious of the ecosystem and consuming it in the process. Figure 3 shows the simulated behavior of the model As would be expected, human activity grows while ecosystem declines, which should be expected since human activity size is not controlled in any way by the ecosystem size as has been emphasized by ecological economists repeatedly. Further simulation experiments with the model described in the next section attempt to understand implications of establishing a mitigation banking system in an attempt to impose size considerations on human activity, with different institutional, pricing and regulatory arrangements to arrive at an appropriate combination of policies that should support both human activity and environment.

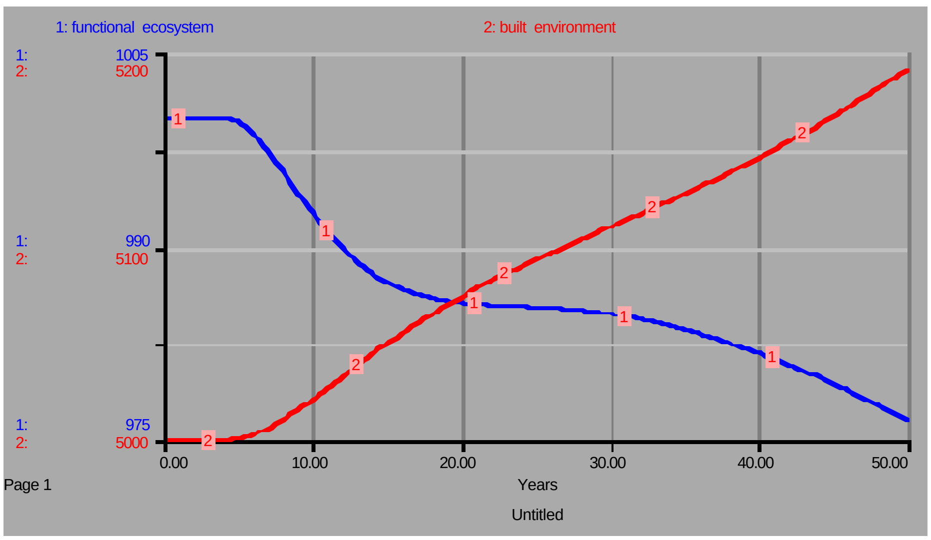


Figure 3 **Growth of human activity in a declining ecosystem in the absence of an environmental responsibility institution.**

PERFORMANCE OF MITIGATION BANKING INSTITUTION UNDER VARIOUS PRICING AND REGULATORY POLICIES

Many experiments were performed with the model with different combinations of pricing and regulatory conditions. The limitation of space would not allow description of all of them, but I'll attempt to describe key experiments that help to identify the best policy set from the stand point of linking the size of human activity to environmental policy with minimal institutional overhead and without transient instability. The experiments described here include testing the model with different pricing, subsidization and credit requirement policies.

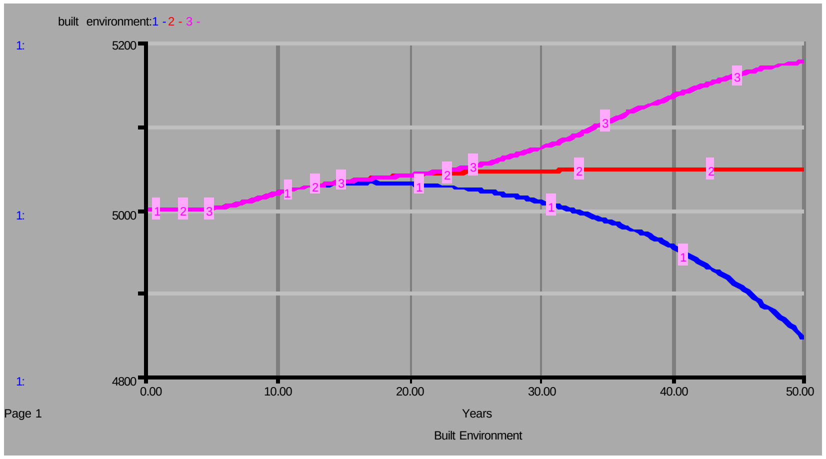
a) Performance of a mitigation banking system with fixed price of credits

A mitigation banking agent charging a fixed price for credits and devoting all its resources to environmental restoration will essentially be a public sector organization without any profit motives. Graph 1 in Figure 4a shows the behavior of such a system.

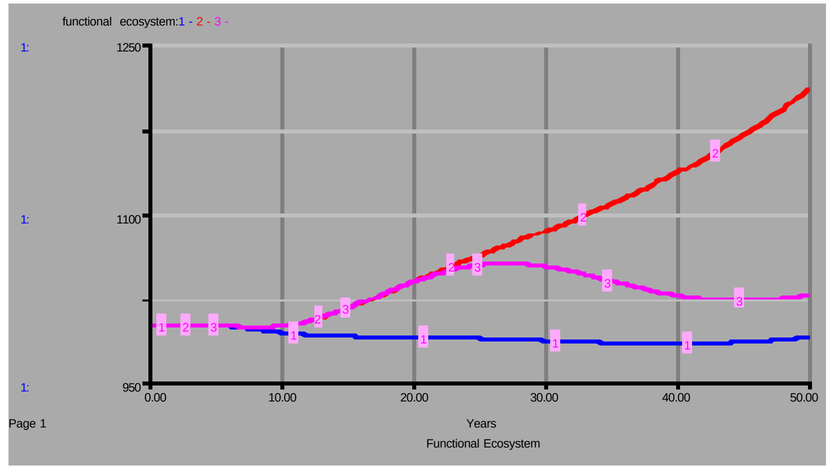
When growth rate of human activity is stepped up, it increases the gain of the positive feedback loop 1 shown in Figure 4b representing the simplified causal structure of such a system. A slowdown occurs, however, in this growth from the cash drain caused by the negative feedback loop 2 created by the purchase of credits needed for new construction and maintenance. This feedback loop progressively decays the gain of the positive feedback loop 1, connecting human activity and development cash. Purchase of credits also supplies bank cash for mitigation work that slows down environmental decay. However, as growth creates mode decay, the cost of mitigation rises above the fixed price of credits, causing the bank cash resources to drain, which reduces the number of mitigation credits it can create. The shortage of credits imposes another constraint on the growth of the built environment through the negative feedback loop 3. Hence it goes into a tailspin, bringing down mitigation banking with it since the mitigation bank cash depends on the sale of credits to support human activity.

Subsidization of such a banking agent can support mitigation activity to a level that prevents credit supply constraint from stifling human activity, that can grow to a sustainable level, mostly consuming mitigation credits for maintenance rather than for new construction. A fixed subsidy budget was experimented with and the resulting behavior is shown in the graphs labeled 2 in Figure 4a. Such a budget lifts the credit supply constraint created by loop 3 to the extent determined by the subsidy budget. Improvement of the environment in the process, however, brings restoration costs down, generating surplus cash for the bank to continue its mitigation work so the ecosystem continues to improve. However, a cash drain created by the credit requirement for operation, constrains further growth in human activity.

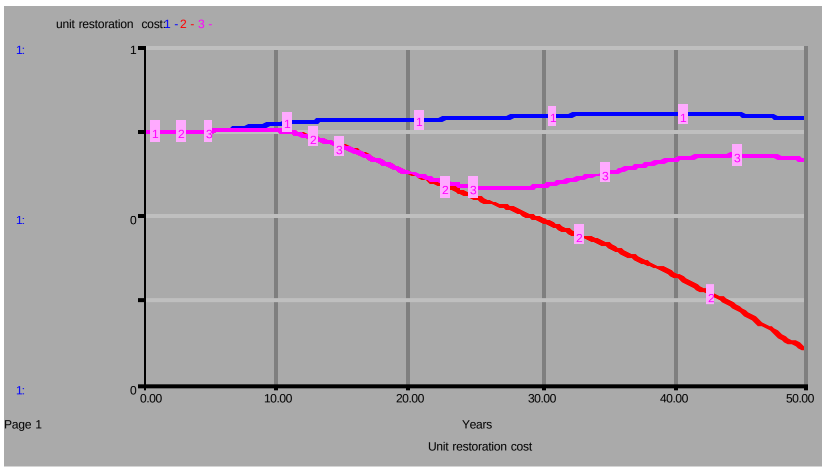
In such a system, the growth of human activity can be further supported by varying the requirement of credits depending on environmental condition. Such a change would require establishment of an ecosystem monitoring institution that would continuously modify credit requirement, increasing it when ecosystem condition declines and decreasing it when this condition improves. This process, represented by the negative feedback loop 4 in Figure 10b, should however be expected to involve considerable delays, which would create some instability in the adjustment of prices and costs since measurements and decision making in the presence of consumer and producer lobbies will prevent instantaneous adjustment of credit requirements.

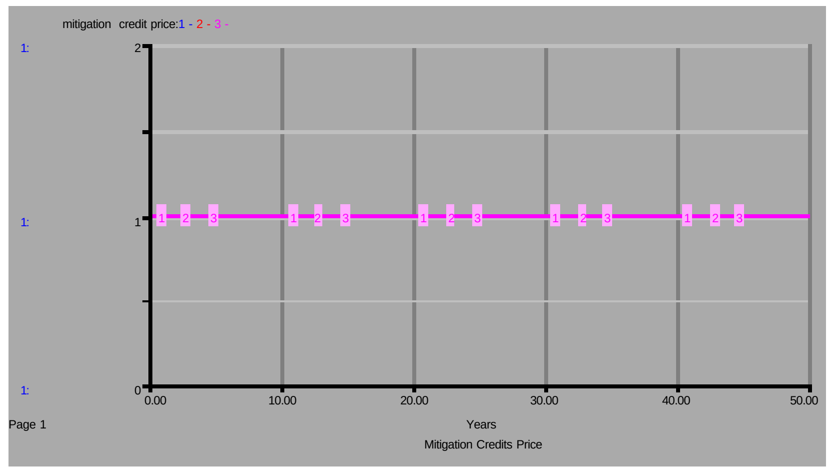


Human activity



Ecosystem





Price of credits

Unit mitigation cost

Figure 4a Behavior of human activity, ecosystem and unit mitigation cost with fixed price of credits.

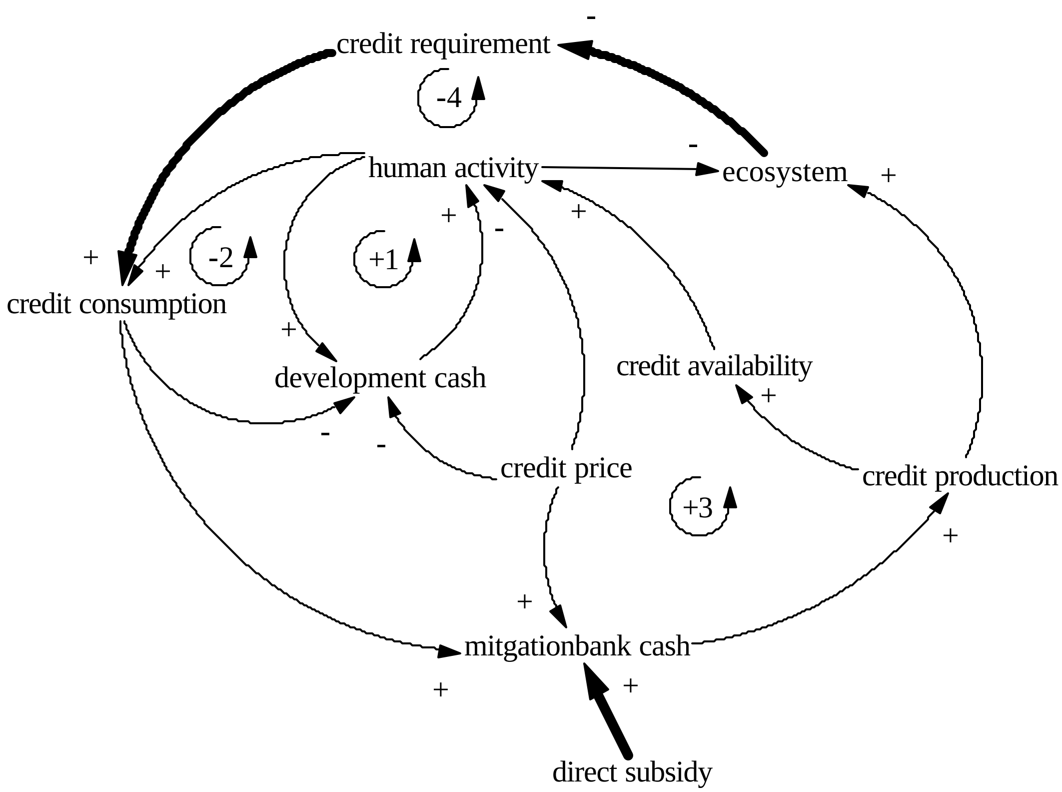
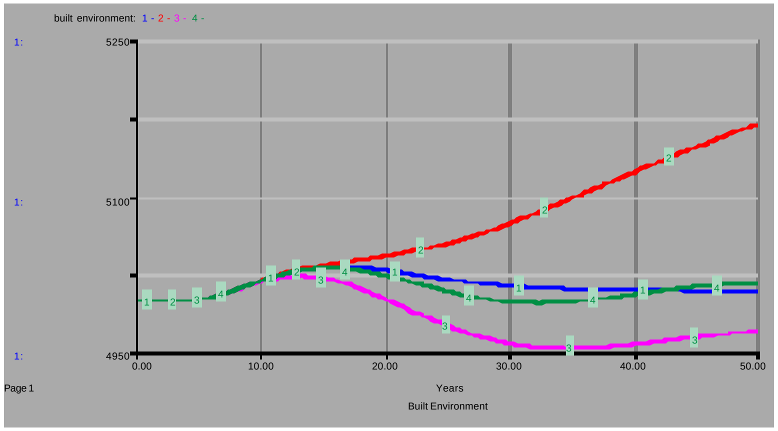


Figure 4b **Causal structure for the case of a mitigation bank operating with fixed credit prices.**

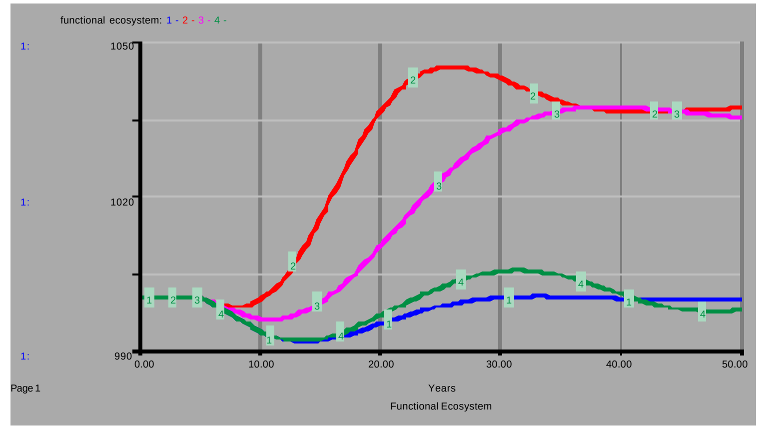
The presence of such a mechanism will, however, align mitigation costs with the price of credits and help create a level of mitigation activity that can support growth of human activity, depending of course on the subsidy budget as shown in the graphs labeled 3 in Figure 10a, which also exhibits the expected instability.

b) Performance of a mitigation banking system with price of credits tied to restoration costs

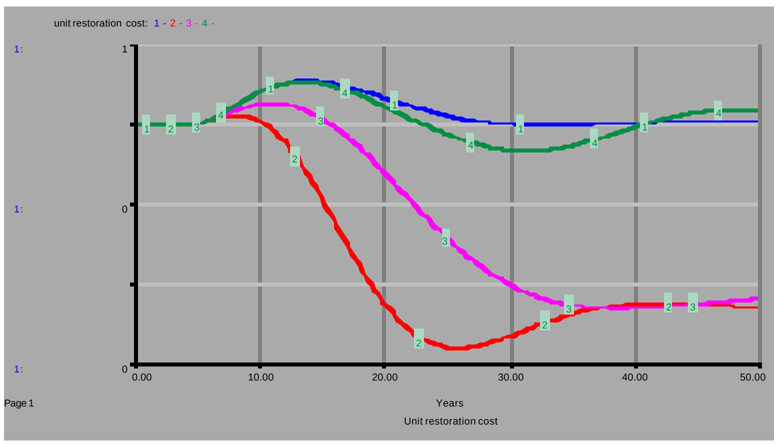
A mitigation banking agent working with a variable price of credits tied to restoration cost can take the form of a public sector monopoly or highly regulated private sector agents or NGOs. Figure 5a shows the behavior of such a system under different conditions. Figure 5b shows the simplified causal structure. Please note two new negative feedback loops labeled 5 and 6 are created by connecting credit price to restoration cost. Graphs labeled 1 in Figure 11a show the model behavior in the absence of any subsidies and with constant credit requirement.



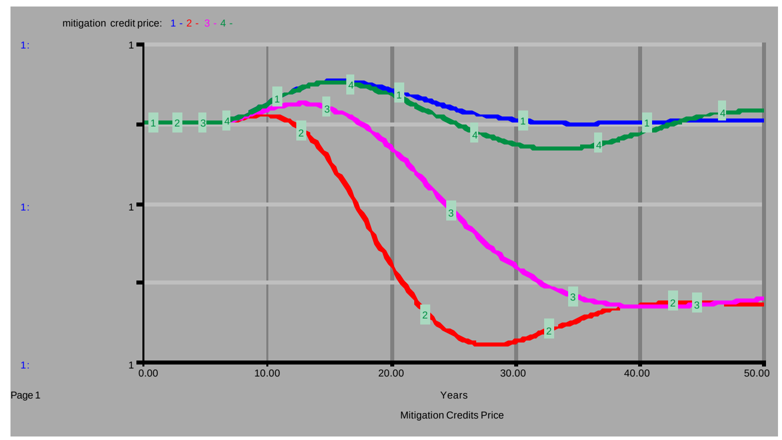
Human activity



Ecosystem



Unit mitigation cost



Price of credits

Figure 5a Behavior of human activity, ecosystem, unit mitigation cost and price of credits with price of credits tied to restoration costs.

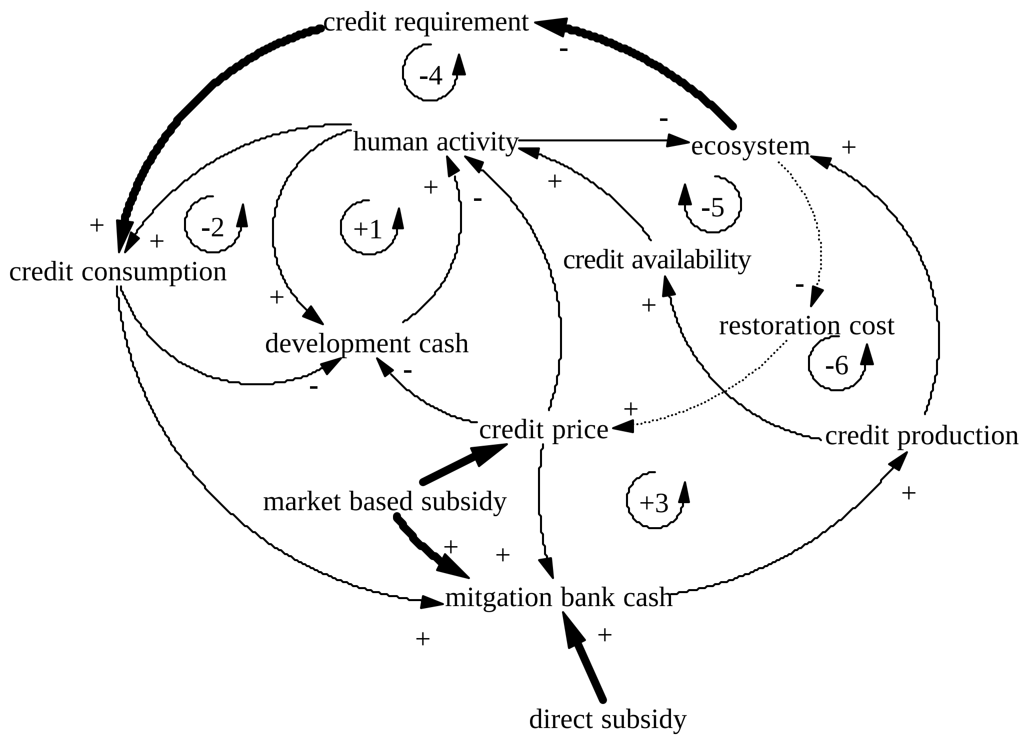


Figure 5b **Causal structure for the case of a mitigation bank operating with restoration cost-based credit pricing policy.**

Evidently, this pricing arrangement very nicely links human activity size to the ecosystem size, bringing both to a compatible equilibrium, even without having a regulatory body to change the credit requirements. Negative feedback loops 5 and 6 provide the necessary controlling mechanisms needed to accomplish this.

A fixed subsidy budget directly added to the mitigation bank cash allows growth of human activity while also improving ecosystem condition and lowering both credit price and mitigation cost as shown in graphs 2 in Figure 5a. Such a subsidy provides additional cash for mitigation, improving environment and consequently reducing mitigation costs, which also lowers the price of credits. Low cost credits promote growth in human activity, which generates more mitigation bank cash. In the process, both a better environmental quality and a modest growth rate can be accommodated. A similar subsidy budget can be given to the mitigation bank through purchasing credits and retiring them, which I have called market subsidy. Graphs labeled 3 in Figure 5a show how a market subsidy performs along with a cost-based credit pricing policy.

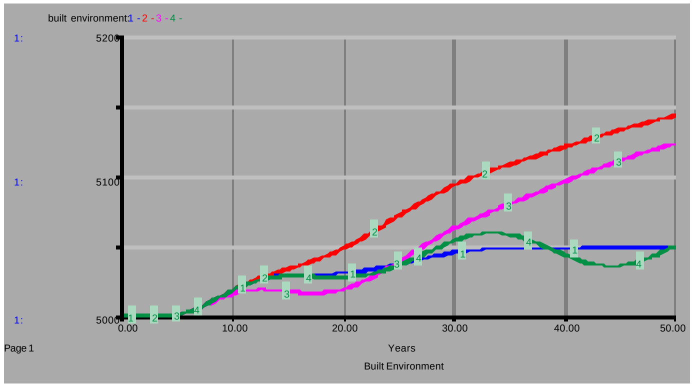
This type of subsidy increases bank's cash resources, while also simultaneously creating a credit shortage in the system. Since credit price is not determined by the market, credit shortage does not increase price or fuel further production of credits. This shortage, however, stifles human activity when enough credits cannot be found for new construction. As building activity slows down, the growth created by feedback loop 1 is greatly weakened. Hence human activity suffers because of this subsidy while it is supported by a direct subsidy. The environmental quality, restoration cost and the price of credits in both types of subsidization end up to be similar, although their transient paths are different. It should be noted that while we might favor a market-based subsidy over a direct subsidy because of our faith in market, the former would create adverse affects if it goes not gel with the other mechanisms in the system.

Finally, activation of negative feedback loop 4 by creating an institution to vary requirement of credits for operation and new construction implemented along with a cost-based credit pricing policy further assists with to creation of compatibility between human activity and ecosystem size. However, cost-based pricing process already delivers such a compatibility, and the delays involved in further linking credit requirement to environmental condition also lead to some instability, which might exacerbate the business cycle activity widely found in market based economies.

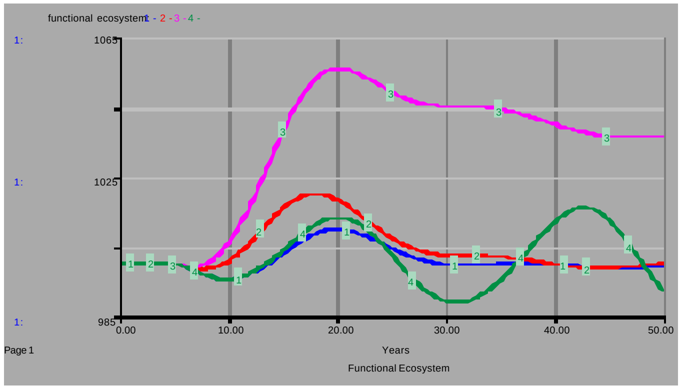
c) Performance of a mitigation banking system with credit price determined by the market

A mitigation banking agent working with prices determined by free market would be located squarely in the private sector. Such an institution would respond to high prices by raising its profit expectations and investing more in restoration activity. It would likewise limit this activity when prices were down even when it had cash resources. Figure 6a shows the behavior of the mitigation system working in a free market with various subsidization and credit requirement determination policies. Figure 6b shows the simplified causal structure of such a system. Please note negative feedback loops 5 and 6 which linked price to restoration cost are now substituted by negative feedback loops 7 and 8 which represent influences of supply and demand of credits on their price.

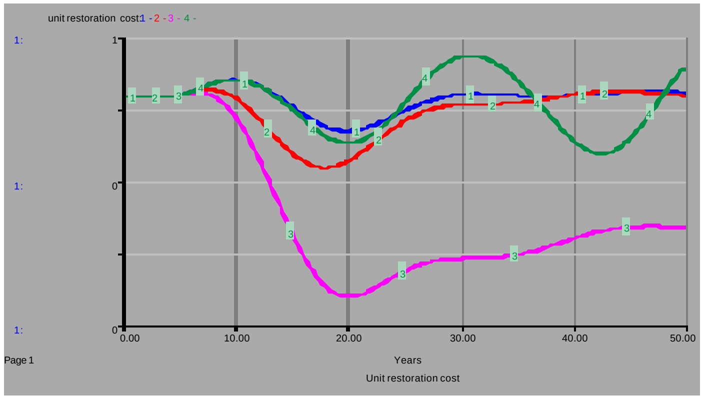
Graphs 1 in Figure 6a show behavior of the model with market pricing of credits, with fixed credit requirement for operation and new construction and without any type of subsidy in place. Apparently, the market related control mechanisms in feedback loops 7 and 8 are able to align growth rates of human activity and ecosystem so there again appears a size compatibility between them. The price of credits and mitigation costs also equilibrate although at different levels since restoration cost as modeled excludes administrative overhead of mitigation banking.



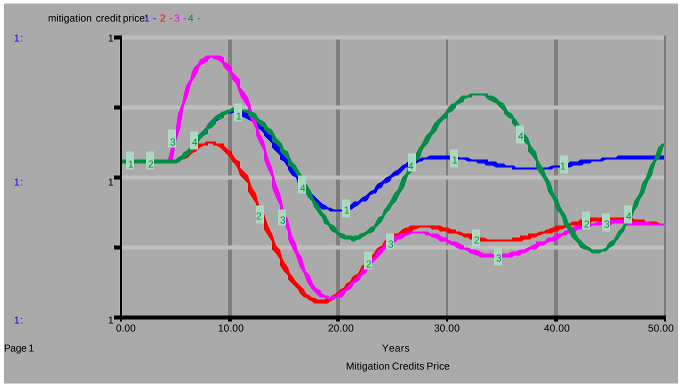
Human activity



Ecosystem



Unit mitigation cost



Price of credits

Figure 6a **Behavior of human activity, ecosystem, unit mitigation cost and price of credits with credit price determined by free market.**

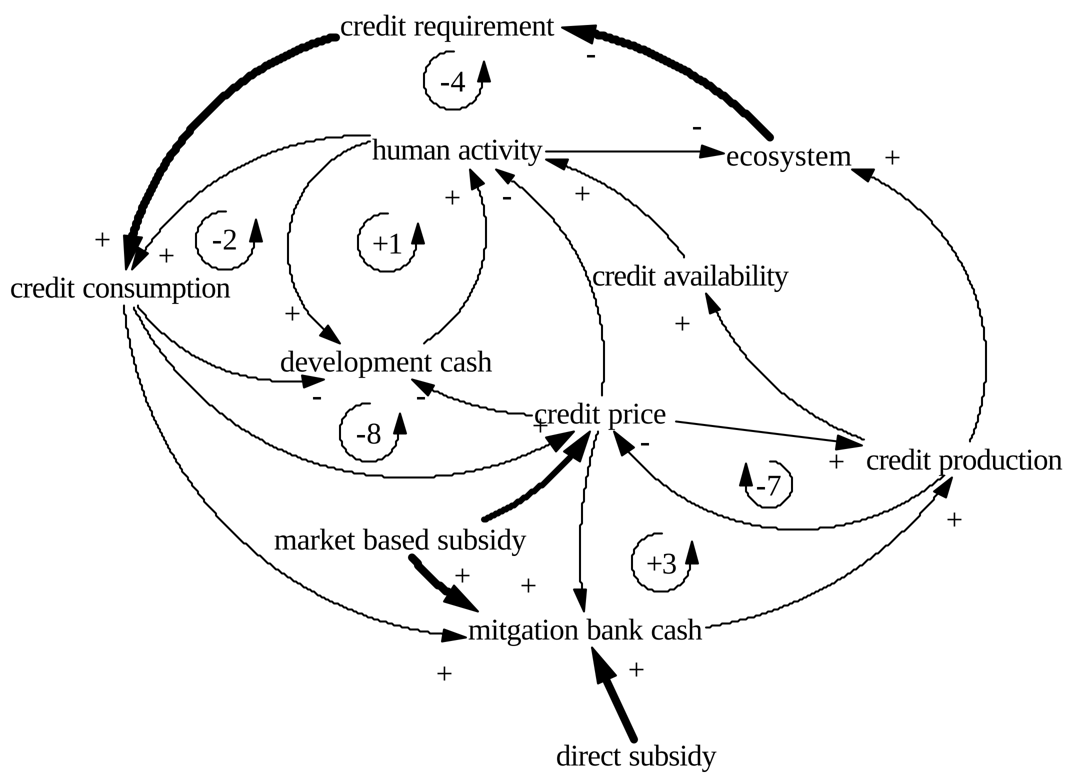


Figure 6b **Causal structure for the case of a mitigation bank operating with credit price determined by the market.**

Provision of a fixed and direct subsidy budget in this system leads to the graphs labeled 2 in Figure 6a. Such a subsidy at first fuels restoration, increasing credit supply and lowering credit price. Consequently these two factors support growth of human activity, which generates further cash for credit production, further increasing their supply and lowering their price. While enlarged human activity also increases ecosystem decay rates, a lower price of credits decreases profit expectations of the mitigation bank, which slows down credit production. Hence ecosystem declines to equilibrate at its original level. However, the growth impetus provided by the profit expectations of the mitigation bank creates high economic growth rates allowing for a high level of human activity along with a high level of mitigation activity until the two activities come to a balance.

A market-based subsidy implemented together with a market-based credit pricing system lead to the graphs labeled 2 in Figure 6a. Please note this type of subsidy creates a lower human activity growth rate together with a much higher ecosystem level than the direct subsidy. Market subsidy would increase credit price simultaneously with adding to the mitigation bank cash. This would stifle growth of human activity while restoration work is fueled. Hence, the system would end up with better environmental quality with slower growth in human activity.

Finally, graphs labeled 4 in Figure 6b represent the presence of a monitoring system that continuously adjusts credit requirements in relation to the ecosystem condition. Apparently, this adjustment process adds considerable instability to the system, while the mean values around which this instability occurs are the same as with only a market-based credit pricing system in place. In case of market-based pricing of credits, an institution for monitoring credit requirements may in fact be counter productive, as it would lead to instability without improving compatibility between the size of human activity and the ecosystem capacity.

LIMITATIONS OF THE STUDY

The model developed in this paper has, however, several limitations.

First, infrastructure development is modeled as a supply-side activity while in reality the demand for infrastructure is generated by the economy while infrastructure availability influences economic growth. While this feedback is approximately captured by the dependence of infrastructure growth on infrastructure stock, the delays in the process are not captured. A simple model of the economy should be added to the existing model to represent. Second, the quality of restoration is assumed to be always satisfactory, whereas in reality it might be influenced by financial, organizational and technical considerations, which need to be investigated. Third, the extent of damage a developer may cause might be sensitive to the price of credits, which will create more careful construction techniques, if it is high. This aspect of development needs to be further investigated. Fourth, government intervention can be implemented in a variety of ways, including general support of mitigation organizations, support of selected projects, allocation of general taxation to general or earmarked support of mitigation, remedial taxation of infrastructure, price support for mitigation credits, etc. Likewise, private organizations might also be involved in the finance of mitigation activity in a variety of ways. The impact of all such options needs to be further investigated. Fifth, when mitigation area is geographically separated from development area, there appears the issue of costs and benefits accrued to the various cross-sections of the population, which should determine the bounds for the operation of the mitigation system. This needs to be carefully delineated. Last, but not least, the mitigation banking concept has to date been applied largely to wetlands and forests. Its relevance to other types of environment needs to be investigated.

CONCLUSION

The analysis of this paper first of all provides a way to test the design of institutional reforms before they are implemented so their impact has fewer surprises. A system dynamics model of a mitigation banking system is developed and experimented with under different organizational and regulatory conditions. Experiments with the model show that market pricing of the credits might be the easiest and the most effective way to assure reliable functioning of the mitigation banking system that should support growth of built environment to a sustainable level while the functionality of physical environment is preserved. Government subsidization of mitigation may create a more rapid growth in built environment, which in certain instances might create an overshoot and decline. The model seems to perform satisfactorily in these preliminary experiments. Many more extensive experiments need to be conducted with the model to understand the role of the government, the modes of its support for mitigation activity and the impact of various regulatory policies. Furthermore, the model has many limitations that are outlined in the paper. Further work should address those limitations.

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APPENDIX: MODEL EQUATIONS

cost pricing

effect_of_cost__on_base_price = SMTH1(unit_restoration__cost/normal_unit__restoration_cost,1)

credit price

mitigation__credit_price(t) = mitigation__credit_price(t - dt) + (change_in_price) * dt

INIT mitigation__credit_price = 1

INFLOWS:

change_in_price = (indicated_price-mitigation__credit_price)/1

base_price = normal_base_price*effect_of_cost__on_base_price

indicated_price = base_price*elasticity_of__credit_price

normal_base_price = 1

price_elasticity_of_credit_demand = GRAPH(mitigation__credit_price/base_price)

(0.00, 2.00), (0.2, 1.94), (0.4, 1.82), (0.6, 1.59), (0.8, 1.27), (1.00, 1.00), (1.20, 0.8), (1.40, 0.64), (1.60, 0.53), (1.80, 0.45), (2.00, 0.4)

direct subsidy

direct__subsidy_budget = 0+STEP(5,4)

ecosystem

functional__ecosystem(t) = functional__ecosystem(t - dt) + (restoration_completions - ecosystem__decay) * dt

INIT functional__ecosystem = 1000

INFLOWS:

restoration_completions = restorations_in_progress/restoration_delay

OUTFLOWS:

ecosystem__decay = (built__environment*normal_damage__per_unit__infra_operation+building_in__progress*normal_damage_per__unit_construction)*marginal__damage_index

restorations_in_progress(t) = restorations_in_progress(t - dt) + (restoration__starts - restoration_completions) * dt

INIT restorations_in_progress = 500

INFLOWS:

restoration__starts = desired__restorations__

OUTFLOWS:
restoration_completions = restorations_in_progress/restoration_delay
desired_functional_ecosystem = 1000
funtionality__index = functional__ecosystem/desired_functional_ecosystem
normal_damage_per__unit_construction = .1
normal_damage__per_unit__infra_operation = .01
normal_unit__restoration_cost = .5
restoration_delay = 5
unit_restoration__cost = normal_unit__restoration_cost*(effect_of__functionality_on__restoration_cost)
effect_of__functionality_on__restoration_cost = GRAPH(funtionality__index)
(0.00, 5.00), (0.2, 3.25), (0.4, 2.20), (0.6, 1.64), (0.8, 1.25), (1.00, 1.00), (1.20, 0.75), (1.40, 0.62), (1.60, 0.54), (1.80, 0.5), (2.00, 0.5)
marginal__damage_index = GRAPH(funtionality__index)
(0.00, 0.00), (0.25, 0.0525), (0.5, 0.18), (0.75, 0.413), (1.00, 1.00), (1.25, 1.33), (1.50, 1.45), (1.75, 1.49), (2.00, 1.42), (2.25, 0.997), (2.50, 0.667), (2.75, 0.535),(3.00, 0.5)

human activity
building_in__progress(t) = building_in__progress(t - dt) + (building__starts - infra__completions) * dt
INIT building_in__progress = 500

INFLOWS:
building__starts = built__environment*fr_growth__rate*cash_constraint_on_development*eco_credit__constraint_on__development
OUTFLOWS:
infra__completions = building_in__progress/infra_constr__delay
built__environment(t) = built__environment(t - dt) + (infra__completions - infra_decay) * dt
INIT built__environment = 5000

INFLOWS:
infra__completions = building_in__progress/infra_constr__delay
OUTFLOWS:
infra_decay = built__environment/infra_life
developer_cash__balance(t) = developer_cash__balance(t - dt) + (developer__income - developer__expenditure) * dt
INIT developer_cash__balance = 400

INFLOWS:
developer__income = built__environment*infra_usage__fee_rate
OUTFLOWS:
developer__expenditure = building_in__progress*infra_constr_unit_cost+credits_acquired*mitigation__credit_price+unit__operation__cost*built__environment
cash_coverage = 2
developer__desired_cash_balance = SMTH1(developer__expenditure,2)*cash_coverage
fr_growth__rate = .02*(1+STEP(.1,4))
infra_constr_unit_cost = .1
infra_constr__delay = 5
infra_life = 50
infra_usage__fee_rate = .04
unit__operation__cost = .01
cash_constraint_on_development = GRAPH(developer_cash__balance/developer__desired_cash_balance)
(0.00, 0.00), (0.2, 0.28), (0.4, 0.5), (0.6, 0.7), (0.8, 0.86), (1.00, 1.00), (1.20, 1.13), (1.40, 1.24), (1.60, 1.32), (1.80, 1.37), (2.00, 1.40)

mitigation banking
mitigation_bank__credits_balance(t) = mitigation_bank__credits_balance(t - dt) + (mitigation__credits_earned - mitigation__credits_sales - subsidy_credit_sales) * dt
INIT mitigation_bank__credits_balance = 100

INFLOWS:
mitigation__credits_earned = restoration_completions*credits_per_restoration
OUTFLOWS:
mitigation__credits_sales = MIN((mitigation__credit_demand),mitigation_bank__credits_balance/1)
subsidy_credit_sales = market__subsidy_budget/mitigation__credit_price
restoration_company_balance(t) = restoration_company_balance(t - dt) + (restoration__company__income - restoration_company__expendutire) * dt
INIT restoration_company_balance = 200

INFLOWS:
restoration__company__income = value_of__credits_sold+direct__subsidy_budget
OUTFLOWS:
restoration_company__expendutire = (restorations_in_progress*unit_restoration__cost)/restoration_delay+overhead

credits_per_restoration = 1
desired__restorations__ = ((restoration_company_balance*fr_balance_for__restoration)/unit_restoration__cost)*price_elasticity_of_credit_supply
fr_balance_for__restoration = .25
overhead = restoration_company_balance*overhead_fr
overhead_fr = .25
value_of__credits_sold = mitigation__credit_price*(mitigation__credits_sales+subsidy_credit_sales)

policy compliance

developer__credit_balance(t) = developer__credit_balance(t - dt) + (credits_acquired - credits_used) * dt
INIT developer__credit_balance = 200

INFLOWS:
credits_acquired = mitigation__credits_sales
OUTFLOWS:
credits_used = built__environment*unit__operation__credits+building_in__progress*unit__construction__credits
credit_coverage = 2
developer_desired_credit__balance = SMTH1(credits_used,2)*credit_coverage
developer__credit_balance__adjustment_time = 5
mitigation__credit_demand = ((SMTH1(credits_used,2)+(developer_desired_credit__balance-developer__credit_balance)/developer__credit_balance__adjustment_time))*price_elasticity_of_credit_demand
unit__construction__credits = .1*unit_credit__requirement__modification
unit__operation__credits = .01*unit_credit__requirement__modification
eco_credit__constraint_on__development = GRAPH(developer__credit_balance/developer_desired_credit__balance)
(0.00, 0.00), (0.2, 0.29), (0.4, 0.51), (0.6, 0.7), (0.8, 0.86), (1.00, 1.00), (1.20, 1.11), (1.40, 1.21), (1.60, 1.29), (1.80, 1.33), (2.00, 1.35)

regulatory policy

unit_credit__requirement__modification = GRAPH(SMTH3(funtionality__index,5))
(0.00, 4.00), (0.2, 3.06), (0.4, 2.26), (0.6, 1.70), (0.8, 1.30), (1.00, 1.00), (1.20, 0.74), (1.40, 0.46), (1.60, 0.26), (1.80, 0.1), (2.00, 0.00)