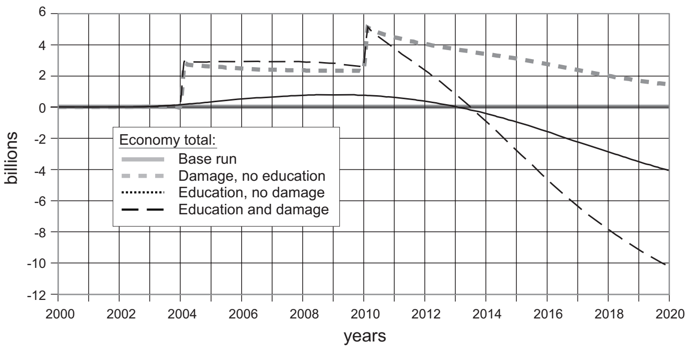
Using economic change for adaption to climate risks – a modeling study



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ISSN 0344-9629

GKSS 2003/3

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GKSS-Forschungszentrum Geesthacht GmbH • Geesthacht • 2003

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ISSN 0344-9629

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GKSS 2003/3

Using economic change for adaptation to climatic risks – a modeling study

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27 pages with 10 figures and 1 table

Abstract

The global environmental system, in particular through climate change, interacts with a globally changing socio-economic system. The risks of environmental extremes threaten life and welfare, while human activity is changing the environment. However, this human activity is undergoing significant changes. In the framework of the system dynamics model ISIS, we study the problem of how the socio-economic development can be pushed in a direction to reduce future vulnerability of society and economy to environmental risks. Obviously, such a strategy would be particularly valuable, if environmental extremes would become worse. We demonstrate in an idealized situation how to piggyback present innovation for solving environmental problems. This is analyzed for a two-region world. Region I is preferred by the traditional economy and by the economic elites, but the region is at risk through environmental factors (e.g. climate or tectonics). Region II is considerably less developed but also much less threatened by natural forces. Without environmental disasters and without the perception of environmental risk, the new economy develops in Region I while Region II remains backward. However, both, environmental disasters as well as the increased perception of risk (through experience and education) cause increased activity in Region II. This view of Region I and Region II is, for example, applicable to large parts of the Pacific Basin. Interestingly, instead of causing costs, this relocation of activity may be economically more efficient in the long run as it forces the actors to invest in the most modern technology. The underlying approach may be relevant for a much broader class of environmental problems.

Nutzung des ökonomischen Strukturwandels zur Anpassung an Klimarisiken – eine Modellstudie

Zusammenfassung

Das globale Umweltsystem steht in enger Wechselwirkung mit einem sich global wandelnden sozioökonomischen System, insbesondere auch im Bereich des Klimawandels. Leben und Wohlergehen werden durch extreme Umweltfaktoren bedroht, und gleichzeitig wird diese Umwelt durch menschliche Aktivitäten verändert. Die menschlichen Aktivitäten unterliegen ihrerseits einem erheblichem Wandel. In einer Anwendung des systemdynamischen Modells ISIS untersuchen wir das Problem, wie die sozioökonomische Entwicklung eine Richtung einnehmen könnte, die mit einer Verringerung der Verwundbarkeit von Gesellschaft und Wirtschaft durch

Umweltrisiken einhergehen würde. Offenkundig wäre eine derartige Strategie von besonderem Wert, wenn sich extreme Umweltsituationen verschärfen würden. Wir zeigen für eine idealisierte Situation, wie man die ohnehin erfolgende breite Innovation für die Lösung von Umweltproblemen ausnutzen kann. Dies wird für eine Zwei-Regionen-Welt untersucht. Region I wird von der etablierten Wirtschaft und ihren Führungskräften bevorzugt, aber diese Region wird durch Umweltfaktoren (wie Klima oder mögliche Erdbeben) gefährdet. Region II ist deutlich weniger entwickelt, aber auch weit weniger durch diese Umweltfaktoren gefährdet. Ohne Umweltkatastrophen und ohne eine Wahrnehmung der Umweltrisiken entwickelt sich neue Wirtschaft vor allem in Region I und Region II bleibt noch weiter zurück. Allerdings können sowohl Schädigungen durch Umweltwirkungen als auch ein Erkennen der Risiken (durch direkte Erlebnisse wie auch durch Aufklärung) eine Verlagerung der Aktivitäten in Region II bewirken. Die Einteilung in Regionen I und II kann beispielsweise für größere Gebiete der pazifischen Anrainer- und Inselstaaten vorgenommen werden. Interessanterweise könnte eine derartige Verschiebung der wirtschaftlichen Aktivitäten insgesamt zu einem wirtschaftlichen Gewinn führen, der die Kosten deutlich überwiegt, wenn die Situation die wirtschaftlichen Akteure dazu führt, in die neueste Technologie zu investieren. Der hier gewählte Ansatz könnte für eine breite Klasse von Umweltproblemen nützlich sein.

Manuscript received / Manuskripteingang in TDB: 18. Februar 2003

1. INTRODUCTION

The attention of wide parts of the public debate is caught by global environmental problems such as Global Warming, transboundary pollution and the like. The scientific literature is abundant with articles dealing with "what-if" questions about how society would suffer, or gain, when global warming is actually emerging as envisaged by the Intergovernmental Panel on Climate Change (IPCC). The conventional wisdom is to some extent based on the idea that environmental change would influence society, for instance by deteriorating agricultural productivity through changing precipitation patterns, or by endangering human health through different spatial distribution of dangerous insects, or would influence human settlements by more frequent climatic extremes, like windstorms or floods. Any such approach assumes that the social and economic effect to a given environmental change is more or less determined – this view is consistent with the traditional, historically discredited concept of climatic determinism (Stehr and von Storch, 1999) – even if presented in a modern and less sweeping version. The question is, of course, how different societies would respond to such changes. In fact, in parallel to climate change there are at all times changes of societal organization, people's preferences and technology, such that environmental features, unacceptably risky at present, may well be dealt with in the wake of societal change at considerably lower costs.

Thus, the useful approach of scenarios (e.g., Schwartz, 1991), envisaging plausible but not necessarily probable futures, must describe not only environmental change but social and economic change as well. Both, environmental and socio-economic change are subject to their own dynamics, which can be influenced only to a rather limited extent. Furthermore, they influence each other: Environmental factors (mainly: risks) are impacting society and economy, while societal and economic change is bringing forth regional and global environmental change. It is challenging to consider whether certain political regulations can help to steer the development into a direction of economic welfare, while environmental risks are reduced.

We see a unique opportunity to combine the achievement of economic and social benefits with solving problems related to the need for adaptation to environmental risks, in general and, possibly, climate change, in particular. This opportunity arises from the present major economic restructuring, rebuilding and new creation due to the possibilities of the new information and communication technologies (Grossmann 2001). Large amounts of information are becoming a major resource. According to Dyson et al. (1994), this is comparable to the transition from the agricultural to the industrial age when, due to the steam engine, a big supply of energy could be accessed: fossil coal. This emergence of an information society is restructuring the social fabric of the modern societies (Stehr, 2001) so that not only the economy but also the social organization will undergo significant changes in the foreseeable future (see for example, Center for Economic Development at California State University; Pine and Gilmore 1999 (with their description of the "Experience Economy"), Dent 1999; Evans and Wurster 1999; Kelly 1997 Margherio et al 1998; Shapiro 1999; TAPSCOTT 1998).

As the economy is changing rapidly and massively anyway, we will consider possibilities to use, to piggyback, this change to proactively adapt to environmental risks and possible climate change. This might greatly reduce costs for adaptation. This use of economic transformation to achieve goals in climate affairs is not yet well researched. Weyant (2000, p. 21) states: "Inventions of productive technologies or processes are, by their very nature, hard to predict. However, past experience has shown that they can be revolutionary enough to justify large expenditures in basic research in strategic areas. Innovations could be of great help in lowering the costs of reducing GHG [greenhouse gas] emissions." In our research we evaluate policies that support this "piggybacking" of economic transformation for goals in climate affairs. Weyant (2000, p. 22) states: "Thus it would be worthwhile to find an appropriate combination of government interventions and private sector incentives that encourage innovation. Thus far, however, most of the policy debate on the influence of technological change on climate change has focused not on technology policy options, but rather on how restrictions on GHG emissions affect the cost of GHG reductions over time...". The same could be said for adaptation to emerging risks from climate change. Here we will concentrate on adaptation, although it seems that our approach would also be applicable to mitigation.

The information-based economic sector is growing dramatically, producing larger and larger shares of the socially generated wealth. The economic restructuring does not just affect production of goods such as shipbuilding or steel production or agriculture and fisheries, but most of banking, insurance, tourism and other service industries as well. This development is global as is a related social transition which brings new lifestyles. Lifestyles and economy determine land use, type of production, and use of resources. These latter factors have high environmental importance. This development of the information society and of a new economy might allow to optimize the utility of conventional resources.

Our research is based on two assumptions:

- Much of the information-intensive economy is less susceptible to environmental damage than mature industries. The new economy[1] uses smaller buildings, has smaller or no inventories and a far less bulky infrastructure. Goods of the new economy are often fairly "dematerialized". Software or multimedia products need less storage capacity; smaller factories and less material transport but instead more office space. Their value often does not lie in any good but in the knowledge incorporated in the products. For example, a car, a typical product of the mature industry, may have the same value as a few CDs with expensive software. If the car is destroyed, the capital is lost. If the CDs are destroyed, the damage may be negligible. The assets of this new economy are often "intangible" and are therefore less vulnerable. However, the results do not depend much on this particular assumption.

- It is difficult for extended mature industries to relocate into new areas whereas the new economy, as it is rapidly expanding, can much more easily grow in new regions. This allows to move away from regions which have an enhanced risk from environmental hazards.

In the following we use the concept of "Information Society Integrated Systems", abbreviated as ISIS (Grossmann, 2001). ISIS models may be used to describe different options for society to respond to

[1] The definition of new economy used here is different from the trendy "new economy" of the dot.coms. Here it is defined as all economy that is very intense in use of information and of networks.

emerging real or perceived environmental risks. Ideally, the case considered would deal with one or two decades, as on this scale ISIS models are most skillful, or on several decades, as on these time scales the contemporary climate models are most powerful. Present versions of ISIS models have little skill on more than two decades, and natural climate variability prevents climate models from being accurate on time scales of one or two decades. Therefore, we have opted for not dealing with climate change but with present climate risk. Another reason for this decision is the fact that our study is based on the use of dynamical systems and that, according to Dijkstra (2000, page xiv), "its concepts have not found widespread application in the oceanographic and climate research community". We are trying to describe the evolutionary options of a society faced with existing or emerging serious environmental risks, as for instance storm damages, flooding or also earthquakes. This approach has the advantage that it can be applied to a wide variety of problems related to climate change, natural risks and disasters.

In the following we outline in Section 2 the future of environmental risks and sketch an economic development which is based on the dynamic emergence and maturing of new information and communication technologies. Also, the ISIS concept is introduced. In Section 3, the idealized "two-region" problem is introduced with Region I being the traditionally preferred region, which suffers from increased environmental risk, whereas Region II is economically backward but less hazardous. The ISIS model used in this study is formally introduced in Section 4. In Section 5, different scenarios, in which environmental disasters and efforts in changing perceptions are free parameters, are developed with ISIS and discussed. The paper is concluded with a general discussion in Section 6.

2. FUTURE RISKS AND ENVIRONMENT

Insurance companies find that in recent times environmental damages are greatly increasing. Floods, earthquakes, windstorms and hurricanes are among the most damaging environmental factors. Most of this increase in damages is related to the organization of society and economy and only to a minor part, if any, to more severe weather events (IPCC, 2001). Society had believed that it had emancipated from the hazards of the natural environment, but it turns out that society and economy had recently become more vulnerable (Stehr, 2001), possibly because of the widespread perception of invulnerability from natural threats and because modern technology is also vulnerable to extreme environmental conditions.

We have to assume that the environmental threats will not diminish in the future; in fact some of them may, indeed, become worse, like severe rainstorms, while others, like earthquake hazards, may remain unchanged.

The dynamics of changing economy as a result of the emergence of the new ICTs is conceptualized in the "Information Society Integrated Systems Model" (ISIS), Grossmann (2001). ISIS is a concept, which takes the form of a family of simulation models (Section 4). It describes interactions between evolving economies, the physical environment, human knowledge, and human attitude. ISIS features four complex "*landscapes*": 1) *know-how*, for example in the form of the new ICTs and knowledge for their application, 2) new *attitude* in moving from a material based, resource rich economy to an information rich economy and from material products to dematerialized "information products" such as multimedia products, 3) the *economy* with two competing and co-operating sectors, the mature and a new, information-rich, economy and 4) the *physical landscape* comprising settlements, infrastructure and natural and cultivated areas. Some metaphors such as "mindscape" or "knowledgescape" convey the same images.

As part of the changes of the "four landscapes", the environment is changing. It is more and more transformed and integrated in efforts of serving society – for example in terms of areas used for outdoor recreation, shipping channels, agriculturally used land, waste deposits and aesthetic consumption of "nature". However, this use of the environment is changing the environment itself on a global scale. The most prominent example is potential global climate change caused by massive human release of greenhouse gases.

ISIS-models use seven different phases for the life cycle of a basic innovation. The first phase is the invention. Sometimes an invention can dramatically change the economy and human life. Such inventions with dramatic effects are called "basic innovations" (Senge[2], 1990). When the innovation is beginning to be successful the outside world has to adapt to it. For example, when beginning in the 1920s a higher number of cars was produced, the cars needed gas stations, traffic signs, traffic lights, new laws and so on. And the basic innovation has to adapt to the outside world as well; for example the PC needed appropriate software, good displays, the mouse and so on. This process of mutual adaptation is phase 3. Adaptation fulfills all preconditions for a massive expansion of the new basic innovation, phase 4. Phase 5 means further but slower expansion, and in phase 6 the competition becomes global and bitter. Phase 7 is the final phase of stagnation, and often disappearance of the basic innovation, like for example transatlantic passenger ships in the 1970s. The average duration of a phase is about 8 years but there is an overlap and a cycling between phases 1, 2, 3 and 4, for example, through the new products needed in the process of adaptation.

In the present case, the basic innovation is the "new information and communication technologies" (new ICTs). Some of the new economy has already passed phases 1 to 4, and is beginning to enter phase 5 and higher.

ISIS-models relate these economic phases to different types of *knowledgeable people* necessary in these phases, e.g. inventors in phase 1 and innovators in phase 2. Phase 3 needs people who know the new basic innovation as well as the outside world and who can do this mutual adaptation, which also needs diplomatic skills. Phase 4 needs expansionists for the massive expansion of production, of investments, of staff or of advertisement. Phase 6 needs people who excel in global competition and rationalization. To capture the changes in attitude that come with a new basic innovation ISIS models show interactions between these people and the respective economic phase.

The *knowledge landscape* is also modeled in these phases. The know-how in phase 1 is the invention. Research and development in phase 2 help to make this invention marketable. Much R&D is necessary in phase 3 for the mutual adaptation of the new basic innovation and its environment. Very different R&D is necessary for the mass production, financing and managing in phase 4. Different

[2] Discussions of basic innovations were already done in the 1930s; there is ample literature on this subject.

know-how is needed for the competition and rationalization beginning in phases 5 and more so in phase 6. In phase 7 much of the know-how is for marginal product improvements.

Beginning in phase 4, with the massive expansion in production, staff and production sites, the land use is dramatically affected. Beginning with phase 5 most locations have been selected, and most building has been done. Most people have moved near their place of work.

Beginning with phase 5, the new evolution has taken its final form and is no longer much adaptable. In other words: according to the ISIS concept, the present development of a new economy is providing a window of opportunity to adapt to environmental risks. Using this window of opportunity requires knowledge about how to influence the present economic and social transformation. The ISIS-models include policies for support of new economy, they include training, and policies to create awareness and influence perceptions. This allows a policy analysis on how to facilitate and support the economic and social transformation.

3. THE TWO-REGION PROBLEM

As already outlined in the introduction, the problem of simultaneous social and environmental change and ongoing or changing environmental risks is dealt with in a simplified world with two regions differing in terms of economics and environmental hazards. Regions I and II could, for example, be two valleys with a very different susceptibility to climate impacts such as floods, or differ with respect to threat from earthquakes or tsunamis. It could be different islands of a political unit, like the islands of Hawaii, or different islands of an archipelago like Indonesia or Kiribati. It could also be a coastal strip of California with its environmental beauty and its exposure to environmental risks and the adjacent inland area which is less preferred but also less exposed to environmental risks.

The two regions are assumed to differ in the attractiveness for investment and in the risk of environmental damage to the economy. In addition, it is assumed that authorities have the option of educating the people regarding the risk of environmental damage. More specifically,

- **Region I** is exposed to environmental risks, but is otherwise preferred by people because of environmental attractiveness. There, the mature industry is flourishing but the new economy is becoming ever more important.
- **Region II**, on the other hand, is not subject to environmental risks, but is considered less attractive, so that no mature industry and little new economy is located in that region.

One option is to relocate some of the economic activities into the less preferred but more secure Region II. We want to analyze whether the transformation into an information society might offer new possibilities for adaptation to environmental risk.

What makes this case more widely applicable is the capability of the new ICTs to make geographical distance irrelevant in so far as many types of work in the new economy can be done from any distance. Small businesses emerge in regions which so far did not allow much business. The new possibilities will make some areas highly attractive for business that had not been attractive before. On the other hand, most people in the new economy love regional agglomerations of like-minded people because they need close personal contacts, which means support in solving the often new and challenging problems. Accordingly, an evaluation of success regions in the U.S. (HUD, 1997) shows that all of the 114 most successful regions are embedded in metropolitan regions. Most are smaller cities in the metropolitan area with a higher quality of life than the metropolis itself.

The characteristics of regions, which are attractive for the new economy, are well known. From Atkinson et al 1999: "They tend to have a high concentration of managers, professionals, and college-educated residents working in “knowledge jobs” (...). Most have a solid “innovation infrastructure” that fosters and supports technological innovation. Many have experienced high levels of domestic immigration of highly mobile, highly skilled knowledge workers seeking good employment opportunities coupled with a good quality of life.” The California Economic Strategy Panel (1999), in its report for the Governor and Legislature, states under the heading “Policies that make California an attractive place to live and to work“: “The availability of this business infrastructure and a distinct, higher quality of life have become the key determinant for attracting and growing high-value businesses.“ Another part in this document reads: “Quality of life for employees is the main reason companies are here.” We will not look more closely at these issues of attractiveness. For our purpose it suffices to see that regional attractiveness for business and industry is changing due to the new ICTs and due to the emergence of a new economy. Regions which had before been less attractive for business may now become more attractive. Some of these regions may be less exposed to environmental risks and threats than those which traditionally had been preferred.

Environmental risks and threats could cause damage to the economy. We assume that such damage may occur. Such extreme events differ very much in the degree of damage they cause. Damage means that some fraction of the existing economy gets destroyed. This damage could be due to climate impact, but could also be due to earthquakes or other hazards and risks. We use stochastic damage terms so that damage could happen anytime within the period from 2002 to 2020, and there could be several damage events during this period. In the scenario with damage we assume damage to the preferred Region I which can destroy up to 10% of the existing mature industry and up to 4% of the new economy. Damage hits only Region I, not Region II which is assumed as much more secure with respect to such risks.

As risks and threats change, the public awareness for these new risks could change. Education increases public awareness of emerging threats. Education makes Region II more attractive for investment and Region I will have less investment. As new economy is less vulnerable to most environmental threats, less investment may go into mature industries.

There are two groups of policies:

- education on emerging environmental threats and how to avoid them, for example by shifting investments to the economy in Region II. This includes curricula of schools and universities as well as articles in newspapers and magazines, advertising and speeches by leading politicians, managers and officials, an efficient bureaucracy and taxation, laws on bankruptcy which support innovation, support of new information infrastructure, and encouragement of special interest groups for new economy and new skills.

- regional incentives for companies to move to Region II, including an increase of attractiveness of Region II. Here, the presence of attractive facilities for leisure, universities, and a favorable natural environment are relevant as well as access to consulting, job- training, venture capital, information infrastructure and low rents for office spaces are relevant.

Any of these policies have been used in some regions such that these policies are realistic and their effects can be empirically analyzed. The ISIS models allow a systematic integration of such policies, and they allow to see how and where such policies work.

4. DESCRIPTION OF ISIS-MODEL AND MODEL EQUATIONS

Formally an ISIS model is a dynamical system consisting of a system of ordinary differential equations for sociological state variables $x_1, x_2, \dots, x_m$ as functions of time:

$$dx_i/dt = G_i(x_1, x_2, \dots, x_m; k_1, k_2,\dots,k_r; p_1,p_2,\dots,p_s)$$

with initial conditions for all state variables.

There $i = 1, 2, \dots m$; $k_1, k_2,\dots, k_r$ are constants, and $p_1, p_2,\dots,p_s$ are policies.

Typically m has values between 30 and 80. In this study we are using two parallel ISIS models each with 34 unknowns. One of the models allows changes of policies $p_1, p_2,\dots,p_s$, the second model runs without policies but is otherwise identical to the first model. The second model serves as a reference to compare the effects of various policy changes.

We have put the (two times 34) ISIS equations used for this study as differential equations as well as a STELLA model on the Internet (http://coast.gkss.de/staff/grossmann).A runtime package to run STELLA models can be downloaded from the web site of HPS (http://www.hps-inc.com).

The overall structure of the model is sketched in Figure 1. Building blocks of the model include A (stochastic climate impacts), B (basic innovations of the 1930s), C (basic innovations around new ICTs), D (markets and new IC technologies) and E (policies).

Subsystems B and C interact through markets and know-how with competition and cooperation. Things emerge, mature, and become obsolescent. "Aging chains" (Sterman 2000, pp 470) describe the phases of the evolution of know-how, economy and knowledgeable people (key people). These knowledgeable people also represent the new attitude mentioned before as one of the four landscapes as described by the ISIS model. These aging chains are linked through so-called cross-catalytical networks (CCNs, Clarke 1980), indicated by ellipses in Figure 1. Eigen and Schuster (1978) developed the first CCNs, calling them "hypercycles", to explain the origin of life.

A CCN consists of two or more subsystems, α and β, Figure 2, such that at least two of them are capable of exponential growth on their own ("autocatalytic" growth) and, in addition, they are linked so that they can support each other and mutually increase their growth. Fränzle and Grossmann (1999) analyzed about 40 highly successful companies, regions and innovations. All of them turned out to be structured as CCNs.

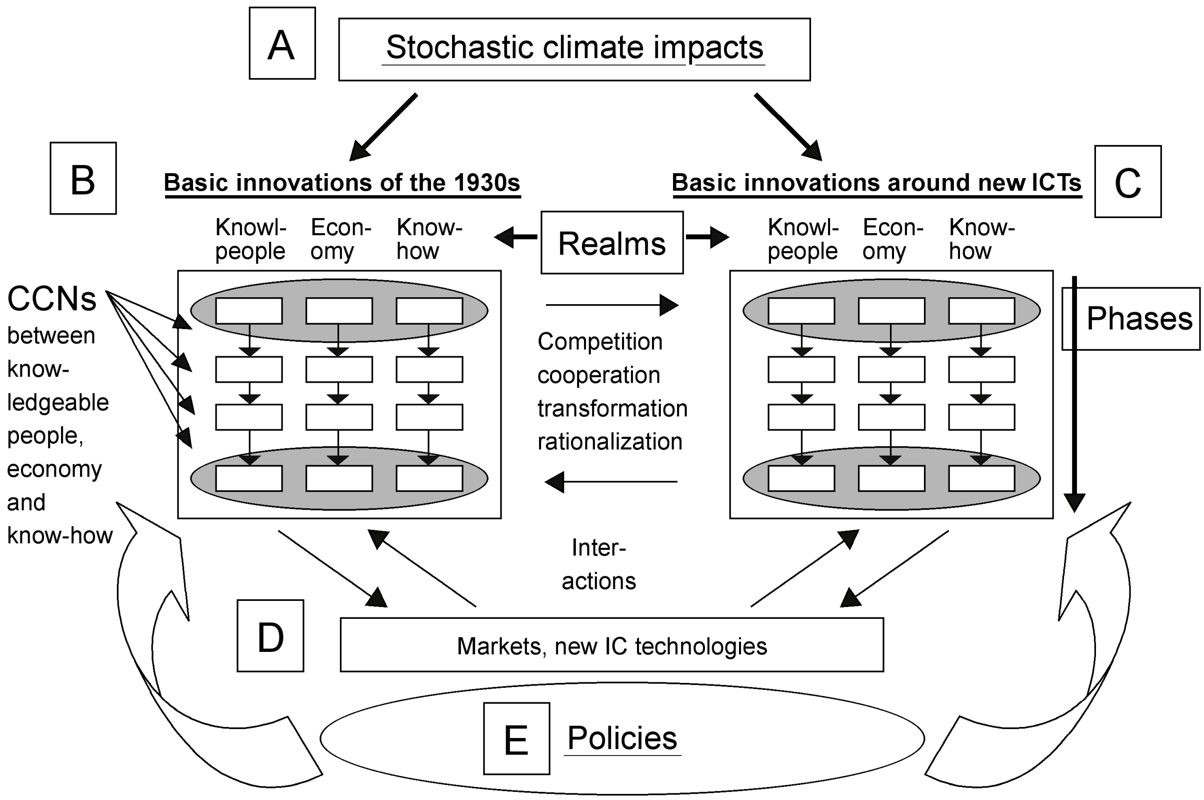

Figure 1. Basic configuration of the ISIS-model for environmental impacts and societal change

In Figure 2, α could be one of the three "landscapes" (key people, economy or know-how); β could be another of the three landscapes. Examples of autocatalytic growth of α or β include: (1) knowledgeable people can train more knowledgeable people; (2) the economy can grow exponentially, if its revenues are proportional to its production rate and its production rate is proportional to the invested capital; (3) more know-how allows to produce even more know-how. Examples of positive effects from α on β or vice versa include: (1) economy can grow better when there are more knowledgeable people; (2) R&D effects can increase with financing from the economy; (3) economy can grow better with more know-how; (4) economy provides jobs for knowledgeable people; stronger economy means more jobs; (5) knowledgeable people produce more know-how; (6) knowledgeable people are better off when there is more know-how.

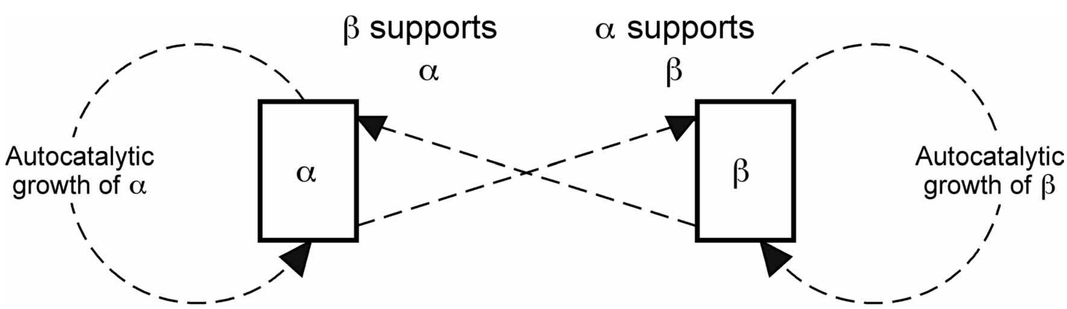

Figure 2. Structure of a CCN with two members

The ISIS-models contain CCNs between the economy, knowledgeable people, and know-how. The simplest form of a CCN between the number of key people (KP) and the invested capital in the economy under consideration (Econ) is:

$(d/dt)(Econ) \quad = f_{11} * Econ + f_{12} * Econ * KP$

$(d/dt)(KP) \quad = f_{21} * KP + f_{22} * KP * Econ$

There, the coefficients f_{ij} are empirical functions of KP and Econ (and usually not explicit functions of t) and usually, we have $f_{ij} >= 0$.

In ISIS models some of the coefficient functions are so-called logistic functions that can be approximated by analytical functions of the form $a_{ij} x^{n(ij)}/(b_{ij} + x^{n(ij)})$ where a_{ij}, b_{ij}, n(ij) are constants, x is a state variable such as Econ or KP and n is chosen to approximate the steepness of the slope of f_{ij} at its inflexion point. Such functions show low efficiency in the beginning of a new basic innovation followed by an increase to then slowly approaching a maximum.

The terms f_{11}* Econ and f_{21}* KP represent autocatalytic growth of Econ and KP, respectively. The terms f_{12} * Econ * KP and f_{22} * KP * Econ express the mutual support between Econ and KP. A CCN can produce hyperbolic growth: state variables can go to infinity within finite time. This is in contrast to exponential growth that remains finite in finite time.

The development of the 7 phases of new economy, NE_1, NE_2, …,NE_7 is modeled as an aging chain:

$dNE_1/dt = NE_1\_formation – NE_1\_transition – NE_1\_failure$

$dNE_2/dt= NE_1\_transition + NE_2\_growth – NE_2\_obsolescence – NE_2\_transition$

…

$dNE_7/dt= NE_6\_transition + NE_7\_growth - NE_7\_obsolescence$

The terms NE_j_transition describe the transition of the j-th element in this aging chain from phase j to phase j+1. Additionally, there is company formation in phase 1 and the disappearance of companies in phase 7. There is also failure and obsolescence in all phases, i.e. loss of invested capital. Growth in each phase is due to CCNs in the early phases and increasingly lower exponential growth in later phases (little effect in CCNs beginning with phase 6).

Aging chains as specified for the NE_j j= 1, 2,...7 also describe the development of mature industries, of key people, and of know-how. In the aging chain for mature industries there is no longer much invested capital in the early phases; most of the capital is in phases 5, 6 and 7, as our model starts in the year 1980, and the mature industries developed from the basic innovations which became strong in the 1930s. A basic innovation is strong for about 60 years and then declines in relative, but not necessarily also in absolute, importance.

Our model introduces environmental damage as a loss of invested capital in both, mature industries (MI) and new economy (NE): dMI/dt= ... - a MI, and dNE/dt = ... - b NE where a and b depend on the location and type of the economy. In general, a and b are random functions of time. For repeatability we have fixed a and b to cause 10% and 4% damage to mature industries and new economy, respectively, in years 2004 and 2010.

In this application of ISIS models we are using two policy parameters: (1) the amount of money invested in education about emerging environmental threats and how to avoid them by using opportunities from the present economic restructuring; (2) the amount of investments in regional incentives to increase the attractiveness of Region II. In practice we introduce the percentage of actual education of the maximum possible education thus using a non-dimensional parameter, p_1, varying between 0 (no education) and 1 (maximal education). Likewise we introduce a non-dimensional parameter, p_2, for the attractiveness of Region II as measuring the relative attractiveness of Region II as compared to the ones of all its competing regions, in particular Region I. Hence the parameter p_2 indicating the attractiveness of Region II can vary between 0 and 2. This means, Region II can be totally unattractive to twice as attractive as Region I. As mentioned earlier our concept of Region II implies that in the beginning it is less attractive than Region I. In a later development we might extend this study to include the up to 25 locational factors which allow innovative regional policies for well-being, economic growth and environmental objectives.

Markets

The markets are simple: production is equal to income, so everything is sold, and income gives demand and allows new investment. Production per year is a fraction of the invested capital multiplied by productivity. As invested capital grows through the interactions within the CCNs, these CCNs indirectly specify production functions of the model. Production functions give the level of economic production depending on input factors. Input factors are the three landscapes of Figure 1, i.e. knowledgeable people, economy (the invested capital for the respective phases) and know-how. The knowledgeable people provide an input of highly qualified labor and additionally they represent a new attitude and world-view. In this latter respect they describe the landscape of attitude mentioned above. Productivity grows through the information potential (see below). Productivity increase causes economic growth.

Important for the model behavior is the variable "comparative attractiveness of information offers" that, due to growth of the information potential, shifts demand away from mature industries to new economy. Due to this shift the markets are not in equilibrium as long as the growth in demand for products of the new economy is faster than the build-up of new economy. The decrease in demand for products of the mature industries causes another disequilibrium if it is faster than the decrease of production capacity in the mature industries[3]. The assumption in the present model runs is such that, at around the year 2020, 95% of all demand will be for new economy. This, of course, depends on the definition of new economy which here is all economy that is very high in the use of information and of networks. For about five years most of the goods producing sector has adopted such a transformation, so that it will eventually also become new economy. This assumption could also be based on the historic precedent that, due to industrialization, the share of agriculture in gross domestic product has dropped to a few percent in almost all developed countries although agricultural production is higher than ever. But there is no simple trend, and the assumption here is one of many possible hypotheses on the future development which will have to be tested.

Information Potential

In the consulting sector, the increase of all capabilities in the sector of the new information and communication technologies (new ICTs) is described by a collection of so-called "laws". Foster (2002) describes the base of his decisions how to provide maximum computing power for his institute: "A useful metric for the rate of technological change is the average period during which speed or capacity doubles or, more or less equivalently, halves in price. For storage, networks, and computing power, these periods are around 12, 9, and 18 months, respectively. The different time constants associated with these three exponentials have significant implications." These "laws" have been valid for most of the last 20 years and experts say that present prototypes and new technological processes seem to allow their validity for about 10 more years. The ISIS-version used in this paper

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[3] In a model run of 200 years, there is a decline in production and an approach to equilibrium. This decline occurs because the model shows the past and the present basic innovation. With the impending decline of the present basic innovation after 2030 there is a decline of all phases of new economy.

simulates the aggregate capability of the ICTs over time for values of t ≤ 2020 as the “information potential”:

information_potential = $e^{(2(t-1980))}$, and e^{80} for t > 2020.

This variable doubles every year, which is lower than the present increase.

Modeling of the transition to Region II

Economy in Region II is modeled by one additional aging chain, which is connected to markets and key people in exactly the same way as the aging chain for Region I. For all phases, the initial values in the aging chain for Region II are 10% of those of Region I.

Region II can become more attractive than Region I through both, education on emerging environmental risks and by environmental damage to economy in Region I. This increased attractiveness of Region II causes a decline in investments in Region I and an increase in investments in Region II. In the case of damage, as in real life, additional capital may come from outside of the total system (Regions I plus II) to alleviate damage. If the attractiveness of Region II is lower than that of Region I, then investments which are not done in Region I due to risk or damage will not automatically go to Region II but might go elsewhere and leave the total system.

This shift of capital investments is described by three functions, which all look like but differ in their values on the y-axis:

1. propensity sf_1 to redirect investments away from mature industries to new economy in Region I and even more so to Region II. The assumption is that the new investment will be done in new economy, not in mature industry. The propensity is zero, if there is no damage in mature industry, and can grow up to 50% of planned investments per year immediately after damage has occurred, Figure 3

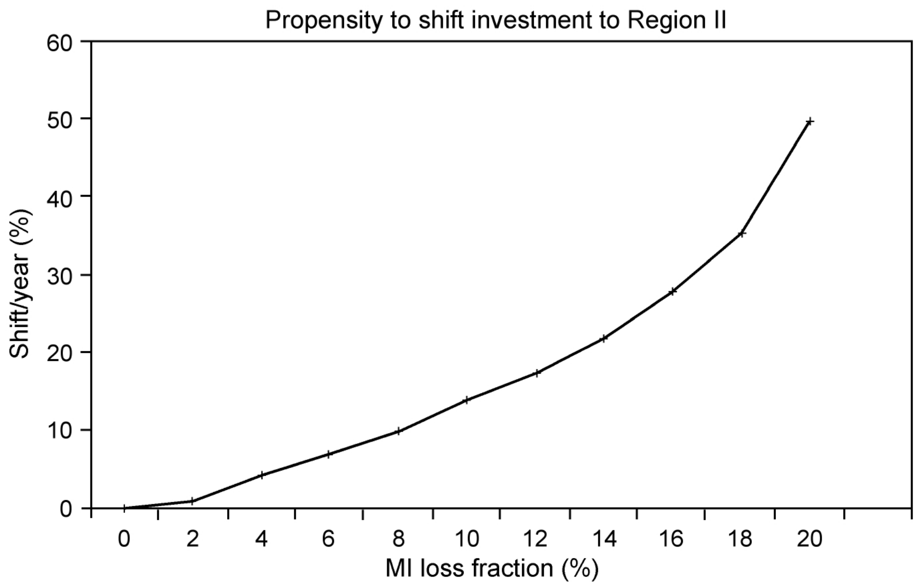

Figure 3. Typical propensity for redirection of investments

2. propensity sf_2 to redirect planned investments in new economy from Region I to Region II. This propensity is zero, if no damage to new economy occurs; its maximum value is 30%, not 50% as for the function in Figure 3

3. education on the emerging environmental risks. This education could have two components: one precautionary to move investments away from Region I and a proactive to invest in new economy and how to do it. A slider can bring the shift function sf_3 to a maximum value of 50%, like the function in Figure 3. This function, if activated, grows during the four years from 2002 to 2006 to assume the maximum value as prescribed by the slider. Therefore the effect of education can be slower than the effect of damage.

Mathematically, these three shift functions sf_i, $sf_i \geq 0$, (i=1, 2, 3) decrease investments in Region I according to:

(investment actual in Region I) = (investment planned in Region I) / $((1+sf_1)*(1+sf_2)*(1+sf_3))$

whereas investments in Region II increase according to:

(investment actual in Region II) = (investment planned in Region II) * $(1+sf_1)*(1+sf_2)*(1+sf_3)*p_2$.

If the attractiveness p_2 is low, then the whole system is no longer attractive after damage and will not recover – something which has happened to many regions of the world.

If, due to the education, people or companies begin to understand new opportunities from new economy, they might increase investments above the amount planned for both Region I and II. This expresses the propensity of investors to use opportunities where they see them. In this way education could do good even if no damage would occur.

5. THE MODEL RUNS

In the following we present results from a series of model simulations of the 2-regions problem for 1980-2020 (Table 1). The simulations are not done to produce fully realistic quantitative results but to explore plausible responses of the 2-regions system to real and perceived environmental risks.

Table 1. List of simulations

No.	Attractiveness p_2 of Region II	Damage in Region I	Education
1	1	No	No
2	1	Yes	No
3	1	No	Yes
4	1	Yes	Yes
5	0.92	Yes	Yes

In simulations 1-4 the secure Region II is as attractive as Region I. It is assumed that people are used to Region I, but Region II is about as attractive and has just been neglected. Increasing concern about environmental hazards causes people to become aware of the risk in Region I and the safety in Region II. In simulation 5 the attractiveness of Region II is perceived as inferior to that of Region I. Education is going on in simulations 3 to 5, and actual, severe damages occur in simulations 2, 4 and 5. Simulation 1 is a "base" run without damages and without education. In simulation 2, society is hit by severe damages without having been prepared. In simulation 3 warnings about impending disasters are voiced and education has been done about how to decrease risks, but no such disaster actually happens. In simulations 4 and 5, disasters happen and the public is prepared through education.

The results of the simulations are displayed by a set of curves, showing the total sum of invested capital in the economy for both, mature and new economy in both regions, the invested capital in the mature economy in both regions, the invested capital in the new economy in both regions, and the invested capital in the total economy in Region I and the capital invested in the total economy in Region II.

5.1 Base simulation 1

In the base simulation 1, both regions have the same attractiveness. No damage occurs, no education regarding risks of environmental damage is done.

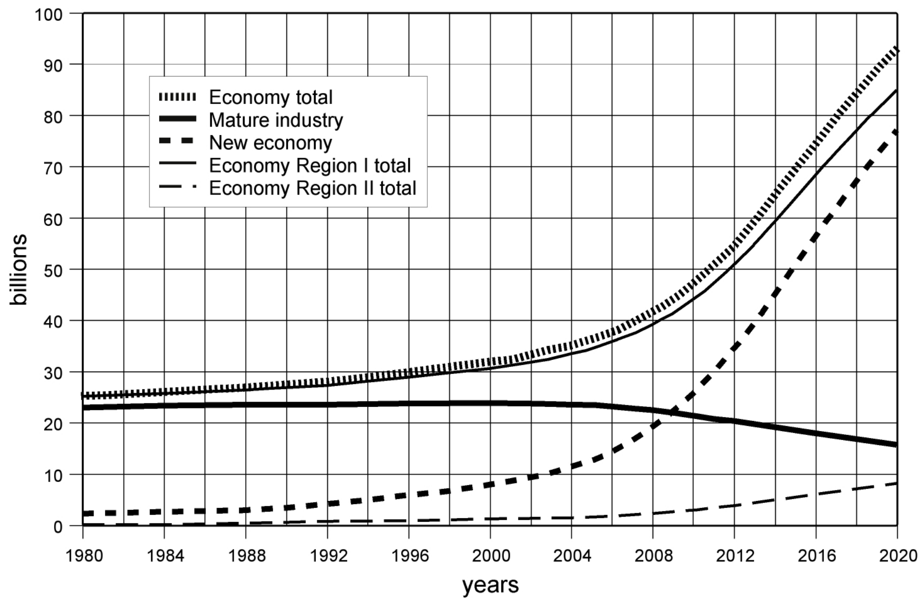

Figure 4. Base run of ISIS model for 2-Region system

Figure 4 shows the economic development from year 1980 to year 2020 as simulated by ISIS. The mature industry is barely growing in the first years and declining in the last years. At the same time the new economy is growing. Most of the activity is going on in Region I. Region II is, in absolute terms, ever more falling behind, even if the invested capital in that region is growing as well. The slow decline of the mature industry is accompanied by the loss of jobs, while the success of the new economy is associated with the founding and growth of new companies "from scratch". This is the normal process of substituting mature industry by new economy. For example, between 1980 and 2000 the U.S. created an average of 4.5 million new jobs per year minus 2.5 million lost per year, which gives a net job creation rate of 2 million per year (US Census 1995, 2000).

Overall, the growth of the economy seems to be quite smooth in spite of dramatic structural change. This is not only a characteristic of this model run, but has been visible in the published statistics for the 1990s. Since the year 2000 the economy is undergoing a period of unrest with lower growth, which may be business cycle related (J. Marsh). But also in this present period of economic unrest those processes are going on which are crucial for our argumentation, the transformation of the mature and the growth of a new economy.

5.2 Simulation 2 with severe damage without education

In simulation 2 the two regions have again the same attractiveness. No education regarding risks of environmental damage is done, but environmental damages occur in the years 2004 and 2010. Each damaging event destroys 10% of the mature industries and 4% of the new economy in Region I. There is no risk and no damage in the secure Region II. The timing of impact is not predictable; it would also be possible that Region I will be hit several times. We show only one such simulation. When redone with different random timings of the damages similar results are obtained.

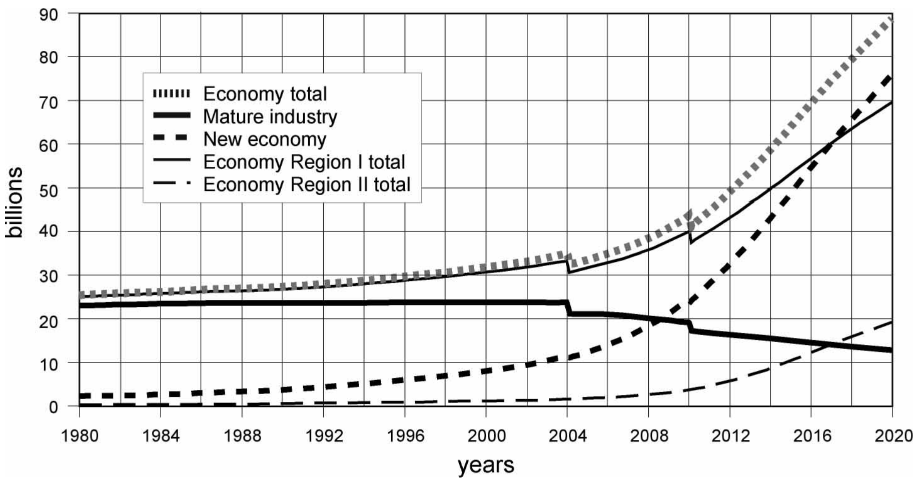

Figure 5. Environmental damage, but no education

Figure 5 and Figure 9 (which is explained below) show, in comparison to Figure 4, that ISIS describes the economy to recover slowly after these dramatic damaging events; in the year 2020 the value of invested capital is still behind the value in the model run without damage. The mature economy declines more rapidly than in the base simulation 1. This is to be expected as few managers would rebuild old economy. (There are exceptions when state subsidies are given for rebuilding of old industries.) Experience shows that severe damage - due to whatever origin and type of impact - often leads to a thorough economic modernization afterwards. Therefore, new economy grows faster in this model run than in the preceding without damage. This is visible by the "new economy" overtaking mature industry a little bit earlier than in the base run.

In this model run the economy in Region II grows to more than twice the value it had in the base run. This is due to the fact that people perceive the damage as a new threat to their preferred Region I and put more investments into Region II and less into Region I. According to ISIS, damage could be an effective teacher.

Is it plausible to assume that the new economy settles in regions which have not been used by the mature industry. For many companies and many sectors of industry the new information and communication technologies allow a vastly improved co-operation through the Internet. This makes geographical distance and bulky infrastructure often less relevant than before.

5.3 Education on environmental risk but no damage

In simulation 3 again both regions share the same attractiveness. In contrast to simulation 2 no damages occur, but people are educated about the emerging risk of severe environmental damages. It is not relevant, if this risk is real or just the result of an incorrect assessment of the hazards.

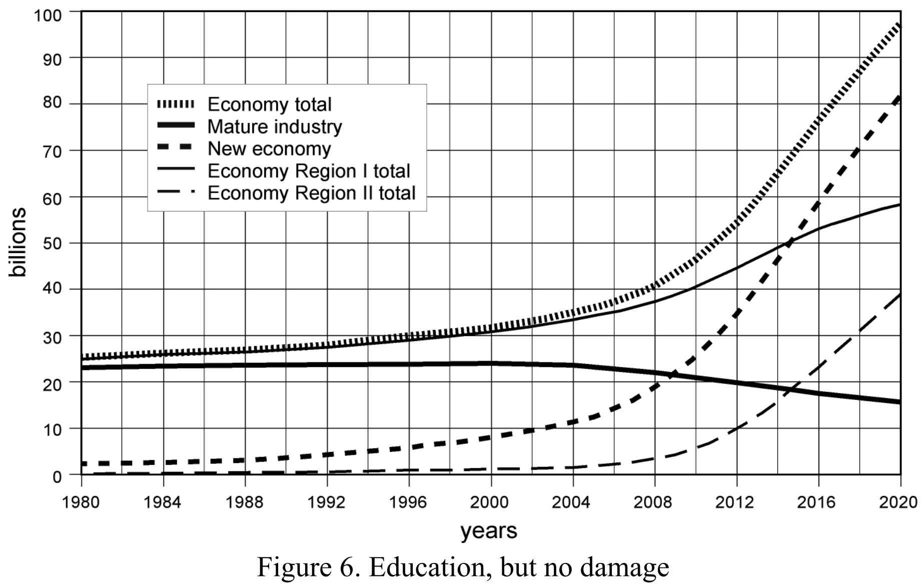

Figure 6. Education, but no damage

Like in the base simulation the mature industry declines, and the overall economy grows exponentially. Here again, the economic development is smooth. Education has a visible effect: the economy in Region II is growing much faster than in the base simulation without education, whereas the economy in Region I is growing considerably slower, Figure 6.

ISIS describes an increased growth in Region II because we expect managers to evaluate the new situation and decide that Region II is becoming a good location for new economy as it is safer than Region I. There is always investment and reinvestment in the economy, and investment in a new economy occurs at all times. At present investment in new economy is high due to the emergence of an economy with qualitatively different characteristics. Companies all over the world are forced to adopt the new information and communication technologies to stay competitive. This means dramatic qualitative and quantitative change as is visible in the U.S. economic data from the last 20 years. Our motivation for this model run is to determine whether this rebuilding of the economy, which is happening anyway, can be "tapped" to achieve another legitimate economic objective: to improve the safety of the investment by a growing preference for Region II.

5.4 Damage and education on emerging environmental risk

Simulation 4 combines the two influence factors on the economy, namely randomly happening severe damages and education preparing the public for such disasters. In simulations 2 and 3, the effect of only one of the two was simulated. Here again the attractiveness of both regions is identical.

The economic development, as envisaged by ISIS, is displayed in Figure 7. The development of the economy in Region II is faster than in the simulations 1 to 3. Already in the year 2016 the new economy in Region II would overtake the total economy of Region I.

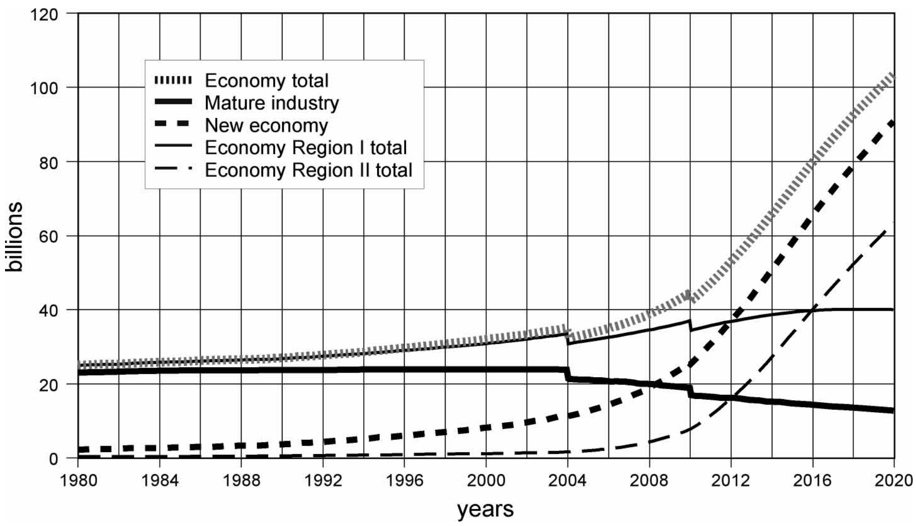

Figure 7. Damage plus education

5.5 Comparison of the simulations 1 to 4 with equal attractiveness of the two regions

Figure 8 is a comparison of the development of the total invested capital in both economies in the four preceding ISIS simulations, and in Figure 9 we compare the costs and losses of the model runs with each other.

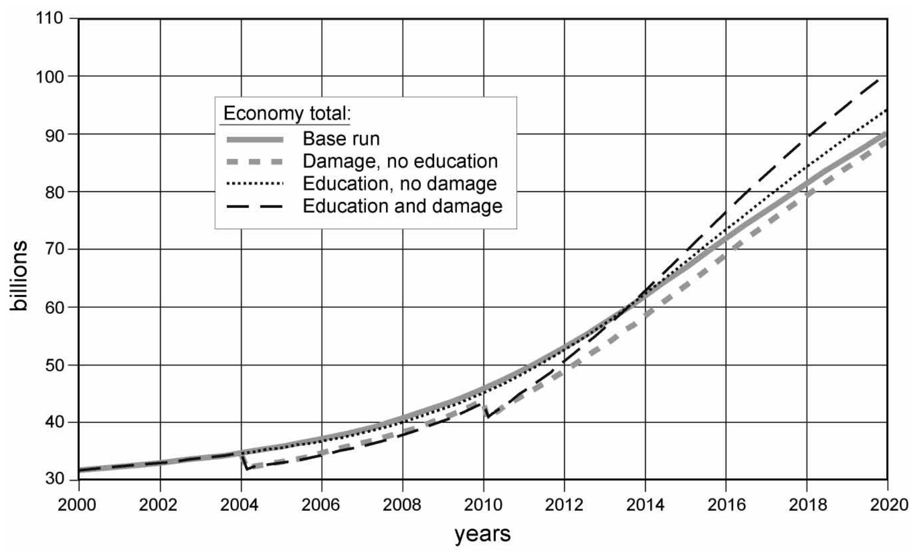

Figure 8. Comparison of the variable "economy total" for all four runs shown above

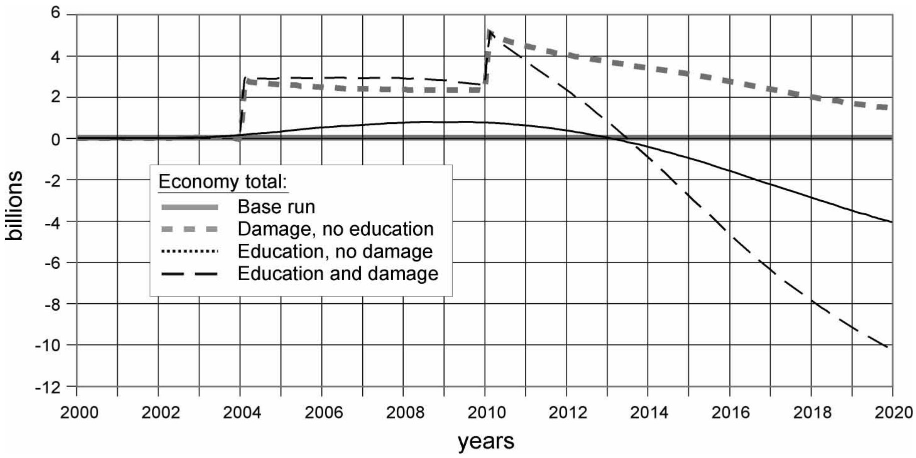

Figure 9. Comparison of costs of the four runs shown above. In both cases with education, the costs become negative so that there is a gain for this region

There are a number of interesting features:

- In simulation 2 with severe damages the economy needs a long time for recovery, which is not fully achieved at the end of the simulation time. In fact, after adjusting to the damages, the economy is larger than in the base simulation. In the first damage 7.1% of the total economy is lost, in the next catastrophe in the year 2010 the loss is lower at 5.1%. At the end of the run, in year 2020, the costs are almost written-off.

- When no damage occurs but if education is done to convince people of serious environmental risks (simulation 3), the economy grows more than without this education (simulation 1). The reason is that the new economy has, on average, a higher growth rate than the mature economy. If people shift a higher fraction of investments to Region II, they will not invest into rebuilding or improving mature economy but will put their capital into modern, new economy. As more money is put into a faster growing economy, the overall result is better.

- In year 2020 the overall economy is about 4% bigger than in the base run. This is due to education. In other words, education leads to increased growth by 4% as compared to the policy of doing nothing.

- Even more intriguing is the case of damage and education (simulation 4), Figures 8 and 9. The costs of the first damaging event in year 2004 are about the same as in the case without education (simulation 2). But the recovery is much faster with education than without education. The effect of the second damaging event in year 2010 is markedly lower due to education and due to higher investment in the secure Region II with accompanying lower investments in Region I. Overall the positive result of this case is an economy which in 2020 is 10% larger than in the case of no damage and no education. In Figure 9 the overall costs of the damaging events and of education become negative (i.e. that is a gain), as the additional economic growth triggered by education and damage more than offsets the losses and the costs for education.

We did not expect this last result and have discussed it with economists from the Hamburg Institute of International Economics, among them one adviser to the German federal government[4], who are experts in using macroeconomic models of the German economy. They say that it is known that severe damage to old industries can favor economic reconstruction at the most advanced level. Examples are the German and Japanese "economic miracles" of very rapid economic growth after World War II as described by an unknown member of Duke university: "After the destruction of Germany's capital resources, the nation had the rare opportunity to revitalize its entire capital base. The implications of this for its production abilities were both unexpected and phenomenal. With foreign aid, the German government was able to develop works projects to foster growth and development through investment in capital and infrastructure. Expansion of capital facilities grew at an incredible rate, and in just under four decades, turned West Germany into one of the premier nations in industrial production. Because of the large number of production industries and the diversification of capital allocation among them, even the nation's largest production sector (industrial) could enjoy positive returns to scale in many instances. However, this was not the greatest advantage. Because practically all of the nation's capital resources were state-of-the-art, industry had the unprecedented advantage of significantly greater efficiency of production without the sunk cost of previously-used, less efficient capital. For this reason, the German companies were able to sell goods at much lower per-unit prices than any other nation's industrial producers." (http://www.duke.edu/~hhayes/econrecon.html). In the economic literature a wide variety of reasons are named to explain these economic resurgences after World War II, and many of them would contribute to justifying our present results: a) more capital is invested in the faster growing new economy due to education, b) the loss of some mature industry makes people more willing to put their money in the new economy instead of using it for maintaining a mature industry. This, in the present

[4] Dr. Wohlers, Dr. Danckwerts, Dr. Henne

context, is an appealing idea due to the increasing environmental risks to the mature industry. Investments in the new economy of Region II are bringing better results.

5.6 Region II with lower attractiveness

The final simulation, Figure 10, is combining damage and education like in simulation 4 but with Region II being less attractive than Region I.

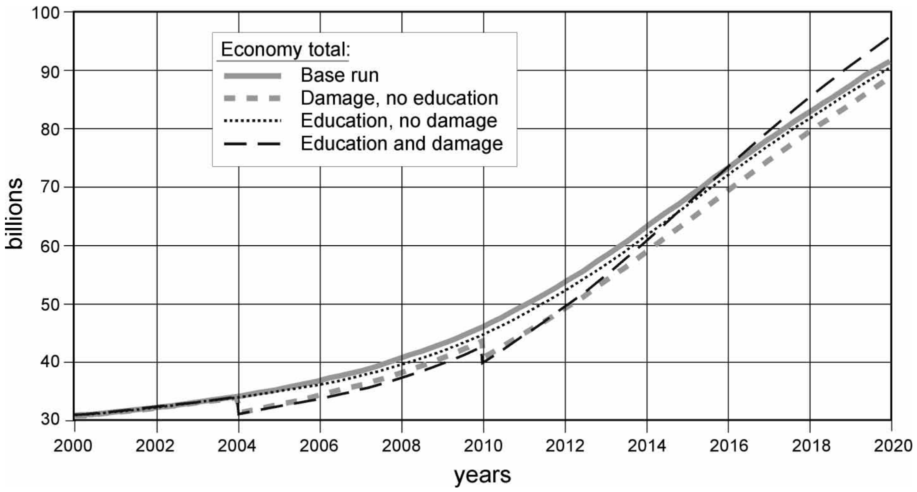

Figure 10. Model run with damage and education for attractiveness 0.92 of Region II

The attractiveness chosen here with a value of 0.92 means that Region II gets 8% less investments per year than before. Still, a considerable increase of investment in Region II occurs after the damages, but the overall gain is significantly smaller than in the case of two equally attractive regions. Here the costs of education are not recovered, if no damaging event occurs as people, in spite of all education, are not sufficiently inclined to invest in a rather unappealing region. When the attractiveness of Region II is further decreased, no gain is achieved at all.

6. DISCUSSION AND CONCLUSION

The main result of our analysis of the two-region problem is that adaptation to climate change, which piggybacks economic transformation, may enhance economic growth. This result is reasonable and is in line with what is known in economic sciences concerning large-scale destruction of mature industries. We could have arrived at this result from studying economic literature without use of a model. Still, there are advantages of using the ISIS model: 1) it gives illustrations on what recovery might look like, 2) it shows how shifting innovations link with a specific environmental threat, 3) it allows to test a variety of policies on how to combine a shift of investments with avoiding a specific environmental threat.

Policies as elaborated here aim at increasing the attractiveness of a secure "Region II". Depending on the nature of the problem, this property of being a secure "Region II" could be very different for different threats. If flooding is a problem, then "Region II" comprises those areas, which have a higher elevation and so on. All policies have in common that they favor "Regions II" by piggybacking the present social evolution so as to get both, favorable economic and environmental results.

Of course, our result is not meant to say that *damage is positive*. In fact, damage is often disastrous for the generation suffering it, and it may only be on the long term that gains are achieved. But, when damages occur, the conclusion of our study is, then it is best not to rebuild the old economy but to strongly modernize and combine the economic reconstruction with solving some environmental problems at the same time. Sometimes those who suffer the damage are the ones who also benefit; but at other times those who suffer are not those who are going to benefit. Damage may imply loss of human life. All things considered, the problems addressed here need much more research. Our results are encouraging a systematic research on how proactive policies, which take into account the present large-scale social transformation, may decrease risks and, additionally, give a larger payback than what they cost.

Such policies can come in the form of interventions by the government (incentives and disincentives) and through market mechanisms. Governmental interventions are sometimes essential. Markets can be ingenious "finding instruments" for new policies. For example, insurance companies could evaluate changing regional risks and new opportunities by using tools as outlined here in combination with a Geographical Information System. Such a combination would allow innovative offers in the insurance market.

Our analysis differs from the conventional analysis on how to deal with environmental threats in the framework of cost-benefit-analysis (which has a long tradition, see e.g. Nordhaus, 1991, Hasselmann, 1990, Weyant 2000). In such analysis, this development is described by assuming "business-as-usual" on the economic side: growth of output is related to innovations and improvements of efficiency. Associated with the growth in affluence and production is an increase in emissions of greenhouse gases and other damages of the environment. The degree of environmental change may be controlled by certain policies, redirecting the use of resources from consumption to mitigation measures. An efficient economic policy would prudently balance costs of abatement and those of adaptation, for example through a cost-benefit analysis. However, such an analysis is not taking into account the dynamical economic processes which will allow society and economy to respond flexibly to changing risks.

To conclude: According to the ISIS concept, the adaptation to an emerging threat through use of the ongoing transformation and innovation could combine two advantages: achieving environmental goals and increasing economic growth. We think that taking into account these dynamical processes could be developed and extended to a wide spectrum of problems and objectives such as mitigation or also safety, security and beauty of human habitats – issues which are becoming ever more important in the light of present developments.

ACKNOWLEDGMENTS

This study was supported by the University of Hawaii (SOEST/IPRC) at Honolulu, Hawaii, U.S.A. and the GKSS Research Center at Geesthacht, Germany. This support, that resulted in several research visits of the first and the third author at the IPRC and of the second author at the GKSS, is gratefully acknowledged. The ISIS-model was initially developed in two projects, one financed by the German Federal Ministry of Education and Research, the other by the EU.

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