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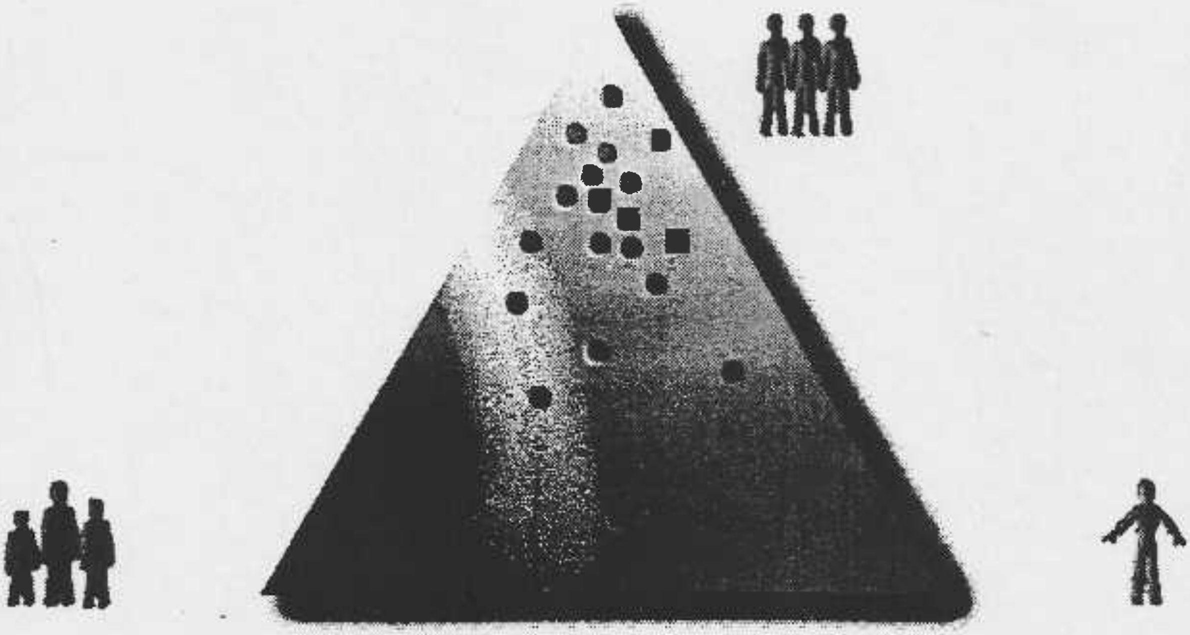

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The Battle of Perspectives*

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Abstract

Current (integrated) modelling efforts aimed at scanning the future do not allow for the learning and adaptive behaviour of agents in a world of uncertainty. In this paper, a framework is presented which might prove to provide a starting point in scanning the feasibility of coping with the dynamics of an ever-evolving interaction between the global system and the relevant agents, whereby the latter are assumed to view the global system from various perspectives. These perspectives may change over time in the event of surprises appearing in the observations. The agents' favoured management styles, which are assumed to be related to the perspectives, may therefore likewise change over time. Incorporation of the 'battle of perspectives' enables us to embark modelling the interaction of decision-making with the complex global system in a world of uncertainty.
The example which is worked out here is the climate change issue, whereby a simple dynamic system for the economy and the climate system is used. This enables us to derive images of the future which take the notion of learning and adaptation into account.

Key words

climate change, integrated assessment modelling, perspectives, learning behaviour, surprises

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1. Introduction

There is a vast body of evidence that human activities are capable of causing changes in the human and environmental system. In order to reduce the risks of harmful impacts associated with global change, such as climate change, acid rain, erosion, malnutrition and fresh water scarcity, response strategies need to be developed. To support decision-making, simulation models have been designed which describe the relations of important aspects within the global system. However, one of the main problems in model design is that the global system cannot be described in terms of deterministic laws alone, since agents can respond, react, learn, change, adapt and influence each other. Such learning and adaptive behaviour exhibited by agents mainly involves reactions to changes and surprises within their environment. In assessing future developments one is tempted to adopt the precept which states that: 'the unexpected always happens'. We can envision that in the coming decades we will discover time and time again that our impression of reality is seriously flawed. Therefore, the modelling of global change requires an approach which facilitates the incorporation of adaptation and learning behaviour, both in the human and in the environmental system. In this paper, we introduce a concept in which the learning and adaptive behaviour exhibited by agents can be explicitly taken into account.

We propose to focus on the problem of human-induced climate change, since this is a fairly well-documented example of problems related to global change, and one for which a variety of analytical methods can be adopted. The IPCC (1994) distinguish four general methods: experimentation, impact projections, empirical analogue studies, and expert judgement. The method of impact projections can be further sub-divided into those generated by biophysical models, economic models, and integrated assessment models. The latter type of model is the one used in this study.
To date, integrated assessment models have often been used to support policy-making. Integrated assessment models are scientifically-based models which describe the human and environmental system on a global scale and some of them can focus on specific economic regions. Although such models do not describe the complex system in detail since they employ simplified versions of expert models, they can nevertheless be used interactively to estimate the outcomes of various scenarios and to provide a bridge which facilitates communication between natural scientists, economists, social scientists and decision-makers. A twofold distinction can be drawn once we have recognised that while several of the models are process-based simulation models (Rotmans and Dowlatabadi, 1995), e.g. IMAGE 1.0 (Rotmans, 1990), STUGE (Wigley *et al.*, 1991) and ESCAPE (Rotmans *et al.*, 1994a), others are optimization models, e.g. DICE (Nordhaus, 1992; 1993; 1994), MERGE (Manne *et al.*, 1994) and CETA (Peck and Teisberg, 1993).

Over and above the fact that both types of model have serious limitations and the fact that a single integrated framework is required wherever process-based models are employed within an optimization framework (Janssen *et al.*, 1995; Janssen and Rotmans, 1995b), both of the approaches underpinning the models fail to address one of the main stumbling blocks in studying the climate change problem: i.e. how are surprises to be dealt with?
Those engaged in climate change research are continually confronted with new surprises. In recent years new scientific findings (IPCC, 1992; Schimel, 1994) have shown that:
- negative radiative forcing due to ozone depletion could counteract positive radiative forcing associated with chlorofluorocarbons (CFCs).

- there is a possible cooling effect due to aerosols resulting from sulphur emissions.
- the rates of increase in the atmospheric concentration of most greenhouse gases have slowed down.
- recent measurements of the CO_2 in the atmosphere show a levelling off of the concentration, while paradoxically the emission rate has not stabilized at all.

The familiar approaches which employ integrated assessment models are scenario analysis and optimization. Scenario analyses may be seen as a means of scanning possible future developments, although the scenarios tend to lose their meaning if agents do not learn from, and react to, surprises. Optimization, on the other hand, is based on the assumption that rationally-acting agents have perfect knowledge about the system in question and are able to determine the optimal strategy for the next century. Although this approach may yield valuable insights into efficient strategies, it can never arrive at an optimal solutions to problems which arise, and probably will continue to arise, as researchers are confronted with new scientific insights.

Thus, there is a need for an approach which is able to address the adaptive behaviour of the numerous agents involved in climate change policy. The recognition that the behaviour of agents may change over time is not new (e.g. Thompson *et al.*, 1990). During recent years a number of studies related to climate change have appeared which investigate the concept of adaptive or sequential decision-making (Manne and Richels, 1992; Hammitt *et al.*, 1992; Peck and Teisberg, 1993; Lempert *et al.*, 1995). The first three of these studies employ a sequential-decision model in which the optimal trajectory is derived in two steps, taking account of a learning phase in the initial period. In Lempert *et al.* (1995), a simple adaptive strategy is examined whereby differing assumptions of the costs and damage functions are juxtaposed with optimal policies. Moreover, the recognition of a multiplicity of agents has filtered into integrated assessment models which address climate change (e.g. Nordhaus and Yang, 1995). In this publication they report the development of a regional dynamic general equilibrium model of optimal climate-change policy in which 6 to 11 regions optimize their climate policy.
Among the attempts to model social behaviour is the artificial society approach. An interesting example is to be found in the work of Epstein and Axtell (1995) since they designed a program which generates artificial societies by modelling simple rules for hundreds of individual agents who evolve over time. The purpose of such an artificial society is to enable the investigation of social processes within a so-called 'CompuTerrarium'.

However, a shortcoming common to all of these studies is that none of them incorporate the notion that learning and adaptation are rooted in the multiple perspectives adopted by the agents. Thompson *et al.* (1990) have pointed out that agents are forced to cast around for alternatives in the event that they are confronted with a persistent pattern of surprises, and a number of studies have tried to model such changing perspectives.
Thompson and Taylor (1986) devised a computer simulation of a so-called 'surprise game' in which used a so-called payoff matrix valued the "nice" and "nasty" consequences of various surprises. The game was implemented for an imaginary industrial enterprise with a considerable number of competitors, and simulates the number of egalitarians, hierarchists, individualists and fatalists in time.
In a set of exploratory experiments, Janssen and Rotmans (1995a) generated, various scenarios in which climate policy is changed as a result of shifts in the dominant perspective among

the agents. The dominant perspective may change if expectations about the functioning of the system fail to correspond with reality. They simply assume that scenarios would involve change and did not simulate the underlying dynamics forcing agents to change their perspectives, which is the aim of this paper. We assume that learning and adaptation can be simulated by studying changes in agents' perspectives. We recognize that this is a highly simplistic representation of reality, but are convinced that it nevertheless enables us to start implementing the concept of learning and adaptive behaviour in integrated assessment modelling.
The dominant perspective among the agents evolves over time feed by the agents' observations of the system. The agents are assumed to be abstract images of decision-makers on an international level and thus could ideally be thought of an institutional actors. In a 'competitive' environment in which adherents to a variety of perspectives all claim to provide explanations, agents try to find the best possible explanation of the observations: hence the "Battle of Perspectives" (Figure 1).

Cultural Theory as expounded in Thompson *et al.* (1990) is used to classify the impact of differences in perspectives on policy-making, and to derive a set of concomitant world views. Although such a classification consists of stereotypes, it might nevertheless prove to be useful in analyzing the dynamics of behaviour associated with changes in the perspectives adopted by agents. In fact, in our implementation of the 'Battle of Perspectives', the agents' perspectives are located in the spectrum defined by the three extreme perspectives. A brief discussion of the Cultural Theory and its applications can be found in Section 2.
We use a simple system to describe economic and climate dynamics (Section 3), suitable for implementing an initial prototype of the 'battle of perspectives'. In Section 4, we discuss the bottom-up modelling approach to simulate the behaviour of agents and how this might be incorporated within the model described in Section 3.
We propose to model the perspective changes exhibited by agents in terms of rival world views to which a set of agents adhere. Observations of the system may cause the dominant perspective among agents to be abandoned or revised. The assumptions underpinning the modelling of world views and management styles can be found in Section 5.
In Section 6, we first analyze the projections for the next century in case of a set of stereotype agents. Thereafter we perform a set of experiments in which the agents may learn and adapt to new information as derived from the system. The paper is concluded with a discussion on the limitations of our approach and profitable avenues for future research (Section 7) together with our own conclusions (Section 8).

2. Perspectives

The attitudes towards society and the environment which have evolved in the course of history have to an important extent been determined by perspectives which have been classified in various ways. In recent years, there has been increasing recognition of the usefulness of various socio-cultural perspectives within the context of sustainable development, albeit mainly in qualitative terms (Zweers, 1984; De Vries, 1989; Jastrow *et al.*, 1990; Riebsame, 1990; Schwartz and Thompson, 1990; Thompson *et al.*, 1990; Colby, 1991; Rayner, 1991; Coward and Hurka, 1993; Dotto, 1994; Rotmans *et al.*, 1994b; WRR, 1994). A contribution which provides a general description of the role of perspectives in understanding natural and human systems and social relations, is proposed by Thompson *et al.* (1990) in their Cultural Theory. Thompson *et al.* (1990) elaborate the concept by introducing the notions of cultural bias (shared values and beliefs) and social relations (patterns of interpersonal relations). Reference to these notions enables a cultural perspective to be defined as a more-or-less viable combination of social relations and cultural bias. The degree of viability of a perspective depends upon a mutually relationship between a particular cultural bias and a particular pattern of social relations. Thompson *et al.* (1990) claim that five, and only five, perspectives - namely: the hierarchist, egalitarian, fatalist, individualist and autonomous perspectives - are sufficiently viable. The adoption of perspectives is a dynamic process, whereby change occurs because of 'surprise', i.e. the discrepancy between the expected and the actual, a process which is of central importance in dislodging individuals from a previously-adopted perspective. Adherents to each of the five perspectives are in competition for new adherents to their particular perspective, but are nevertheless dependent on one another at the same time. In other words, all of the perspectives are needed to ensure each one's viability (Thompson *et al.*, 1990).
Thompson *et al.* (1990) argue that needs and resources are socially-constructed. This leads to the conclusion that behaviour is never rational or irrational in itself and that any particular strategy can only be evaluated in the light of an actor's perspective. Strategies are an expression of an actors' perspective. For example, because egalitarians perceive resources as being fixed and believe that human-beings can do nothing about them, the only available strategy is to decrease their needs so as to ensure a sustainable resource use. If it were to be effective, such a need-reducing strategy would have to be followed by everyone.

We propose to use Cultural Theory as a heuristic framework, and thus a means by which to incorporate the notion of perspectives into the modelling context, since previous studies have demonstrated the usefulness of Cultural Theory in applications applied to integrated assessment models for global climate change. A first attempt to introduce the use of cultural perspectives as an approach enabling an uncertainty analysis of integrated assessment models has been made by Janssen and Rotmans (1995). In this study, cultural perspectives were used in determining distributions of parameters and future scenarios in order to allocate emission rights of CO_2. Van Asselt and Rotmans (1995) delineated a general uncertainty analysis framework based on their perspective based approach. In this study, alternative model routes for the fertility issue and the climate change issue were mapped out.
Following Rayner (1991), Janssen and Rotmans (1995) and Van Asselt and Rotmans (1995), we propose to study the 'active perspectives' alone, i.e. the hierarchist, the egalitarian and the individualist, thus disregarding the autonomous and the fatalist perspectives. The active perspectives are considered as being located at the extremes of a continuum which is used to describe all possible points of view (Figure 2).

Trisoglio *et al.* (1994) conceptualize the cultural perspectives in two dimensions (Table 1):
1) how the world is seen (the totality of views of physical and human nature).
2) management style (the totality of preferred strategies)
The combination of each perspective's world view together with its respective favoured strategy is used to assess the utopias. We refer to agents' utopia to describe the management style which corresponds with the agents' view of the world. The dystopias describe what would happen to the world if the agents' favoured strategy were to be applied while reality more closely corresponded to another world view.

The utopia/dystopia approach as adopted by Trisoglio *et al.* (1994) and Van Asselt and Rotmans (1995) is essentially static. Their approach relies upon an agents' current conception of the future, which in turn determines the present policy which agents might adopt in the form of a set of rules which guide decision-making. In this paper, we attempt to simulate the agents' perspectives in time, so we can model the manner in which they learn, change their opinions and adapt in the face of surprises, and respond to new evidence which will surface in a changing system. We recognize that the present understanding of why and how agents may change their behaviour is limited. The crucial issues are whether agents ignore surprises, whether changes of management styles are restricted by social factors, and whether we can assume that changes in perspective and management style going together?

Nevertheless, if we start with a 'surprise game', we may able to illustrate some aspects of learning and adaptive behaviour. In a sense we are seeking to simulate society as a swarm flying above the triangle spanned up by the various perspectives attracted by information as derived from the unknown underlying world.

	individualist	hierarchist	egalitarian
world view			
idea of nature	skill-controlled cornucopia	isomorphic nature	accountable
myth of nature	Natural Benign	Nature Perverse/Tolerant	Nature Ephemeral
concept of human nature	self-seeking	sinful	born good, malleable
management style			
driving force	growth	stability	equity and equality
type of management	adaptive	control	preventive
attitude to nature	laissez-faire	regulatory	attentive
attitude towards humans	channel rather than change	restrict behaviour	change social environment
attitude to needs/resources	expand resource base	rational allocation of resources	need-reducing strategy
economic growth	preferred: aim to create personal wealth	preferred: aim to avoid social collapse	not preferred
risk	risk-seeking	risk-accepting	risk-aversive

Table 1: Characteristics of Cultural Perspectives (based on Van Asselt and Rotmans (1995)).

3. The Model

For the purpose of this study, we employ a simple dynamic system which describes the basic dynamics of the economy and the climate system. The model is based on existing economy-climate models such as those found in: Nordhaus (1992; 1993; 1994), Manne *et al.*, (1994), Hammitt *et al.* (1992) and Lempert *et al.* (1995). We recognize that this model yields a highly simplified representation of the problem, but its dynamic framework serves well to illustrate the 'Battle of Perspectives'.

Economic output Y(t) is given by a standard constant-returns-to-scale Cobb-Douglas production function in the levels of technology a(t), capital K(t) and labour, which is assumed to be proportional to population, P(t), for which a future projection published in Bulatao *et al.* (1990) is used, while γ represents the elasticity of output with respect to capital which is taken to be 0.25. The impact of emission reductions and global climate change on output is represented by the scale factor S(t).

$$Y(t) = S(t) \cdot a(t) \cdot K(t)^{\gamma} \cdot P(t)^{1-\gamma} \tag{1}$$

Technological changes are regarded as being exogenous, although such development is assumed to proceed at a declining rate

$$\frac{da}{dt} = e^{\delta_a^{rate} \cdot t} \cdot a$$
$$\frac{d\delta_a^{rate}}{dt} = -\delta_a \cdot \delta_a^{rate} \tag{2}$$

Total consumption C(t) is equal to economic output minus gross investments,

$$C(t) = (1 - I(t)) \cdot Y(t) \tag{3}$$

where I(t) is the fraction of the economic output which is reinvested in capital stock.

The capital balance equation for the capital stock K(t) is defined in terms of investments minus depreciation:

$$\frac{dK}{dt} = I \cdot Y - \delta_k \cdot K \tag{4}$$

where δ_k is the rate of depreciation of the capital stock, i.e. 10% per annum, reflecting an average lifetime of capital of ten years on a declining balance method.

The level of fossil CO_2 emissions is the result of: the transition towards alternative fuels, M(t), the energy conservation transition, σ(t), economic output, Y(t) and a coefficient α (=0.32 GtC/bil$):

$$E(t) = \alpha \cdot M(t) \cdot \sigma(t) \cdot Y(t) \tag{5}$$

where M(t) is one minus the percentage of emission reductions and is defined as a logistic function, where R is number of years which would be required to reduce the share of fossil fuels within the energy mix by 50%, and ε, in conformance with Lempert *et al.* (1995), is taken as being 0.01, reflecting an autonomous trend in decarbonisation. Thus:

$$M(t) = \frac{1}{1-\varepsilon} \cdot \frac{1}{1+\exp(\rho_M(t) \cdot (\frac{R(t)}{R(t-1)}(t-1995)-R(t)))}$$

$$where \quad \rho_M(t) = \frac{-1}{R(t)} \cdot \ln(\frac{\varepsilon}{1-\varepsilon}) \tag{6}$$

The energy intensity decline is described by a logistic function, where δ is the contribution of available low-cost conservation measures and where the number of years required to double energy efficiency is assumed to be 50 years:

$$\sigma(t) = (1-\delta) + \frac{1}{1-\varepsilon} \cdot \frac{\delta}{1+\exp(p_\sigma \cdot (t-1995-50))}$$

$$where \quad p_\sigma = \frac{-1}{50} \cdot \ln(\frac{\varepsilon}{1-\varepsilon}) \tag{7}$$

The atmospheric CO_2 concentration (pCO_2) is modelled using the reduced-form carbon cycle model developed by Maier-Reimer and Hasselmann (1987). Carbon emissions (E) are divided into 5 classes (fractions $c_{1\text{-}5}$), which have different atmospheric lifetimes $al_{1\text{-}4}$. Thus:

$$pCO_2(t) = pCO_2(t_0) + \int_{t_0}^{t} 0.47 \cdot E(\tau)\{c_1 + \sum_{i=2}^{5} c_i \cdot \exp[\frac{\tau - t}{al_{i-1}}]\}d\tau \tag{8}$$

where $c_{1\text{-}5}$=0.13, 0.20, 0.32, 0.25, and 0.1, and $al_{1\text{-}4}$=363, 74, 17, and 2 yrs.
Equation (8) was fitted by least squares to the computed response of a full-scale ocean carbon cycle model and yields a good approximation for small changes, although it underestimates the amplitude and time-scale of the response for higher concentration levels (Maier-Reimer and Hasselmann, 1987).

The radiative forcing of CO_2 is modelled in conformance with the IPCC (1990) in the following way:

$$\Delta Q_{CO_2}(t) = \frac{\Delta Q_{2XCO2}}{\ln(2.0)} \cdot \ln\left(\frac{pCO_2(t)}{pCO_2(t_0)}\right) \tag{9}$$

where ΔQ_{2xCO2} is the radiative forcing associated with a doubled CO_2 concentration (4.3 W/m^2)

Aggregated radiative forcing is assumed to have the following impact on the change in the global mean surface temperature (ΔT^P):

$$\Delta T^P(t) = \frac{\Delta T_{2XCO2}}{\Delta Q_{2XCO2}} \cdot \Delta Q_{CO2}(t) \tag{10}$$

where ΔT_{2xCO2} is the global mean surface temperature change in the event of a doubled CO_2 concentration (best guess 2.5 °C, see Section 5.2).

Since oceans take a long time to warm up, the actual temperature increase (ΔT) will lag behind the potential increase, which is modelled as follows:

$$\frac{d\Delta T}{dt} = \beta \cdot (\Delta T^P - \Delta T) \tag{11}$$

where ß is assumed to be 0.05.

The scaling factor S(t) is the ratio of one minus the percentage of abatement costs to one plus the percentage of damage costs. The (market) damage costs are quantified as a relation between global temperature $\Delta T(t)$ increase and income loss, where θ_1 represents the scale of damage and θ_2 the non-linearity in the damage function. The costs of reducing emissions of greenhouse gases are related to (1-M), the fractional reduction of greenhouse emissions, while b_1 and b_2 represent the scale and non-linearity of the cost function. Thus:

$$S(t) = \frac{1 - b_1 \cdot (1 - M(t))^{b_2}}{1 + \theta_1 \cdot \Delta T(t)^{\theta_2}} \tag{12}$$

4. Integrating Bottom-up with Top-down modelling

4.1 Selecting a tool

In this section we propose to discuss our decision to model the agents in a bottom-up fashion and how this can be integrated with the usual top-down approaches employed in integrated assessment modelling. Our purpose in modelling agents is to simulate their learning and adaptive behaviour associated with changes in their environment. The main problem we are now confronted with is that of the choice of a suitable approach to integrating simulations of changing behaviour among agents with a top-down model of the global system, such as that described in Section 3.

One of the most salient problems in studying social dynamics is that human history is an experiment which only runs once. Unlike physical science in which many kinds of experiments can be conducted over time, such a tool is lacking in social science. Due to individual differences and complex interrelations with other individuals, general laws which enables us to model human behaviour can scarcely be found.
The term complex adaptive systems here refers to systems of numerous agents which interact with their environment and can adapt to changes. These kinds of systems organize themselves, learn and remember, evolve and adapt. During the past decade, the use of computers as laboratory tools with which to study complex adaptive systems has been increasing. Such evolutionary modelling has been applied in various disciplines in attempts to study, for example: economies, ecologies, immune systems and nervous systems (e.g. Langton, 1989; Arthur, 1990; Kauffman, 1991, Holland, 1992; Waldrop, 1992; Ruthen, 1993; Epstein and Axtell, 1995). Such a modelling approach embraces a whole range of modelling tools such as: genetic algorithms, cellular automata, artificial life and nonlinear dynamic systems. Because such bottom-up modelling seems to be appropriate for simulating the behaviour of a set of agents, it is this kind of modelling which has been chosen as a tool within our framework of the 'Battle of Perspectives'.

This bottom-up approach is not in itself sufficient, since another condition has to be met before making the choice of which modelling tool to use, namely the question of integrating changes in agents' behaviour in a top-down dynamic system, the type of modelling framework which is most frequently used in integrated assessment modelling.
For the following reasons, we have chosen the genetic algorithm:
- it simulates the state of a set of agents who have individual characteristics;
- it is based on the mechanics of the survival of the fittest and is therefore able to simulate adaptation to a changing environment;
- thanks to its stochastic characteristics, each experiment with the system is unique;
- it can be integrated with the dynamic system.
The genetic algorithm will be further described in the next Section.

The genetic algorithm and the dynamic system are integrated in the following manner. Instead of scenario analysis whereby a model as described in Section 3 simulates the effects of assumptions made for the control rates I and R, or an optimization model with which the optimal values of the control rates I and R are determined, for the purposes of our 'the Battle of Perspectives', the control rates are a function of the state variables. The values I and R are the (weighted) averages of I_i and R_i the individually preferred values for the control variables.

These preferences may change in time due to changes in the system. For example, if the dominant perspective of the agents concerned is individualistic at the start, it may change as a reaction to a persistent series of surprises into a more hierarchistic or egalitarian perspective if the agents are confronted with serious impacts of climate change.

4.2 The genetic algorithm

The genetic algorithm has been developed by Holland (1975) in order to try to abstract and explain the adaptive processes of natural systems. The basic construction is to consider a population of individuals in which each individual represents a potential solution to a problem. The relative success of each individual vis-à-vis that problem is considered to be an indicator of the individuals fitness, and is used to selectively reproduce the most fit individuals to produce similar, albeit not identical offspring for the next generation.

Consider a population of N individuals, each represented by a chromosomal string of L allelic values (Figure 3). An initial population is constructed at random on a specific range; call this generation g_0. Each individual is evaluated by a fitness function. The evolutionary algorithm then performs two operations. First, its selection algorithm uses the population's N fitness measures to determine how many offspring each member of g_0 contributes to g_1. Second, a set of genetic operators is applied to the offspring to make them different from their parents. The resulting population is now g_1, these individuals are again evaluated in the next time step according to the new situation, and the cycle repeats itself.

We can now formulate the genetic algorithm in a more formal way:

(1) An individual can be characterized by a binary bit string of fixed length L, which is denoted as *a*, and $a \in B^L$ where $B = \{0,1\}$. The bit string can be separated into n segments of equal length l_x, thus implying that $L = n * l_x$. Each segment is interpreted as the binary code of the object variable $x_i \in [u_i,v_i]$ which can be redecoded by applying:

$$\Gamma_i(a_{i1}...a_{il_i}) = u_i + \frac{v_i - u_i}{2^{lx} - 1} \cdot \left(\sum_{j=0}^{l_i - 1} a_{i(l_i - j)} \cdot 2^j \right) \tag{13}$$

where $(a_{i1}...a_{ilx})$ denotes the i-th segment of an individual $a \in B^L$. Then $\Gamma = \Gamma_1 x..x\Gamma_n$ yields a vector of real values on the desired range $[u_i, v_i]$.

Example: $a = 10011$, $u = 0$, $v = 1$

$\Gamma = (1*2^4 + 0*2^3 + 0*2^2 + 1*2^1 + 1*2^0)/31 = 0.613$

(2) Mutation is a bit reversal event that occurs with the small probability of p_m per bit. This mutation can explore new genetic information and is a powerful operator in discovering ways to adapt to a changing environment.

Example: Suppose we have the following bit string: 11111

At random, roughly one in every 1000 symbols flips from 0 to 1 or vice versa; in our example from 1 to 0: 11011

(3) The algorithm uses a crossover operator that exchanges substrings arbitrarily between two individuals with a probability p_c. The length and position of these substrings are

chosen at random, but are identical for both individuals.

Example: Suppose we have the following bit strings: 11111 and 00000
A point along the strings is selected at random and the offspring contain a mixture of the parents: 11000 and 00111

(4) The probabilistic selection operator forms the next generation by copying individuals on the basis of fitness-proportionate probabilities

$$p_i = \frac{F(a_i)}{\sum_{j=1}^{N} F(a_j)} \tag{14}$$

where $F:B^L \rightarrow \mathbf{R}$ is the fitness function. The less fit individuals are therefore less likely to reproduce their genetic information.

According to Goldberg (1989), genetic algorithms are successful robust algorithms in optimization because they are able to select strings with useful blocks of information, and concentrate their search (selection) on variations which include those blocks. The genetic algorithms test and exploit large numbers of regions in the search space while manipulating relatively few strings and without using specific information about the functional forms. Instead of using the genetic algorithm purely as an optimization routine, we propose to illustrate the power of the algorithm as an optimizer within a changing environment.

5. Modelling agents who learn and adapt

5.1 Introduction

Modelling human behaviour is an ambitious, enigmatic and perilous task, and we do not harbour any pretention to being able to model perspectives of agents and their dynamics in their full richness. However, we hope to be successful in developing a framework to simulate a number of interesting topics related to the interactions between human activities, the environment and the responses of relevant agents. The agents are assumed to be abstract images of decision-makers on an international level, responsible for climate change policy and determine the level of investments and emission reductions. Each agent adheres to a world-view which is located within the perspective triangle (Figure 4). By considering a set of similar agents who adopt various perspectives with respect to the climate change problem, we believe we will be able to simulate a learning process for the agents and their adaptation of their behaviour in terms of policy measures. Of course, we would not claim that empirical agents actually learn and adapt in a way which closely resembles the 'Battle of Perspectives'. We do however conjecture that there might be a sort of 'weak isomorphism' between the 'Battle of Perspectives' and the ways in which actual agents adapt to their changing environment.

Although the perspectives of the agents may change over time if they are confronted with surprises, the underlying system is assumed to follow the assumptions of one of the three extreme perspectives. We will first discuss the world-views of the adherents to the three active perspectives, and then go on to discuss management styles adopted by the agents concerned. The Section is concluded with a discussion on the modelling of the changes in perspectives.

5.2 World-view

Taking the model described in Section 3 as representing the global system, we assume that the values of several parameters within the model vary according to the three perspectives. In conformity with the construction of the uncertainty space in Lempert *et al.* (1995), and sensitivity analysis in Nordhaus (1994), we distinguish the following issues as being subject to uncertainty:
- climate sensitivity,
- technological improvements,
- mitigation costs,
- damage costs due to a climate change.

Choices are mainly based on the work of Schwarz and Thompson (1990), Rayner (1991) and Van Asselt and Rotmans (1995). We should stress that we only change parameter values, although differences in perspectives principally also affect the mathematical system. For practical reasons, we have hitherto excluded this, assuming that it will not influence our conclusions significantly.

The Individualist

According to the individualists' view of a benign natural system, climate change will be

mitigated by known and hitherto unknown dampening feedbacks. Speculative negative feedbacks are therefore taken into account, whereas uncertain positive feedbacks are neglected or considered to have negligible impacts on the climate system. Consistent with the lowest estimate of ΔT_{2xCO_2} in the literature, we adopted a value of 0.5°C for ΔT_{2xCO_2} (Lindzen, 1990). Individualists, believing in a stable system, assume that no economic damage will be suffered as a result of climate change. In the event of a climate change occurring, technical solutions will balance out any negative effects.
Technological development is a difficult phenomenon to capture with Cultural Theory. Technologies which have been created in the past extended life expectancies and enhanced affluence, bringing with them in addition incremental pollution, technological risk and climate change. On the other hand, technological development also generates numerous solutions for dealing with the unwanted by-products. In choosing the parameter values, we assume that the individualists are desirous of an appropriate technological development which as cheap and cheerful as possible, and therefore we assume a high rate of technological development. However, on the other hand, individualist are assumed that the amount of low-cost conservation of energy is low, while the market will not stimulate this kind of development. Their self-interest and short-term reasoning imply a low rate of technological progress in finding expensive ways to decarbonize economic production.

The Hierarchist

We assume that hierarchists interpret uncertainties in a similar manner to prominent scientific experts and institutions (such as the Intergovernmental Panel on Climate Change (IPCC)). We have adopted the central estimate of the IPCC, 2.5°C, for ΔT_{2xCO_2} (IPCC, 1990; 1992) which is consistent with their trust in institutions; hierarchists thus are assumed to follow the best-guess estimates of the scientific community. Following Nordhaus' (1994) central estimate, a quadratic relation between temperature increase and damage cost results in a 1.3% loss of economic growth if temperature increases by 3°C.
Expectations of technological progress which stimulates economic development are based on technological improvement rates in the past. In balancing the risks, hierarchists stimulate research for alternative solutions. We assume that the hierarchist stimulates decarbonisation of economic production and therefore a moderate value of δ is assumed. Furthermore, we assume a best-guess estimate of the mitigation cost as used by Nordhaus (1994) who based his estimates on a survey of energy models (Nordhaus, 1991).

The Egalitarian

The egalitarian myth of nature suggests that minor changes disproportionately influence the behaviour of the system. Consistent with their view of climate change as a catastrophic threat they consider all uncertain processes and feedbacks as having amplifying effects on the human-induced disturbance of the global climate. Speculations about amplified feedbacks or catastrophic impacts, which are strongly disputed within the scientific community, are also taken into account, whereas potential negative feedbacks are ignored. Therefore we have adopted a value of 5.5 °C for ΔT_{2xCO_2}, this being one of the highest estimates to be found in the literature (Dickinson, 1986).
The egalitarian myth of an ephemeral natural system results in high cost estimates of the impacts on the human system. We assume that egalitarians believe in a highly nonlinear damage curve, resulting in a 32% loss of economic output if temperature increased by 3°C

in the course of the next century, these values being based on the high range estimates offered by Nordhaus (1994).
The increasing level of technological development is not stimulated by egalitarians insofar as it leads to greater pressure on the environmental system. Therefore, a low rate of technological development (δ_a) is assumed. Technology enabling decarbonization of the economy is stimulated by the egalitarians and they are optimistic about the rate of improvement. Although cost considerations are not important to egalitarians, we assume a low mitigation cost per unit of reduction which reflects their optimism about the efficacy of clean technology.

The assumptions associated with the various perspectives which affect a number of crucial parameters within the model can be found in Table 2.

Table 2: Parameter values in which the perspectives differ in their world view.

	Individualist	Hierarchist	Egalitarian
Climate sensitivity	low	best-guess	high
ΔT_{2xCO_2}	0.5	2.5	5.5
Damage costs	low	moderate	high
θ_1	0	0.0014	0.004
θ_2	0	2	4
Technological development	high	moderate	low
δ_a	0.004	0.012	0.024
Mitigation costs	high	moderate	low
b_1	0.25	0.11	0.05
b_2	3.5	2.9	2.3
δ	0.4	0.5	0.6

5.3 Management Style

The so-called management styles are modelled as a set of simple decision rules. During the simulation period, the preferred management style of each perspective is determined every year. The individual agents, however, adhere to management styles which lie within the perspective triangle (Figure 4). We assume that the average perspective adhered to by the agents determines the implemented policy (I and R), which is the (weighted) average of the preferred policies of the three active perspectives. Thus:

$$
\begin{aligned}
I &= \frac{1}{N}\sum_{i=1}^{N} a_i^E \cdot I^E + \frac{1}{N}\sum_{i=1}^{N} a_i^I \cdot I^I + \frac{1}{N}\sum_{i=1}^{N} a_i^H \cdot I^H \\
R &= \frac{1}{N}\sum_{i=1}^{N} a_i^E \cdot R^E + \frac{1}{N}\sum_{i=1}^{N} a_i^I \cdot R^I + \frac{1}{N}\sum_{i=1}^{N} a_i^H \cdot R^H
\end{aligned}
\qquad (15)
$$

where the relative shares are equal to one, $a_i^E+a_i^H+a_i^I=1$.
We assume that agents lack perfect knowledge of the system both in the present and in the future. Decisions are made on the basis of the agents' expectations of the future, their beliefs, wants and needs, and their observations of the system. The assumptions which are made in framing decision rules are mainly based on Schwartz and Thompson (1990), Thompson *et al.* (1990) and Rayner (1991).

The Individualist

Consistent with their characteristics, individualists prefer an adaptive management style. While they assume that a new equilibrium in the natural system will provide new opportunities for smart individualists, no active climate policy is advocated. In the event of negative effects on economic development occurring, technological innovation will cancel these negative impacts of climate change out. In line with their ambition for economic growth, at least a minimum level of economic growth is desired. We assume a simple adaptive strategy such that in the event of realized economic growth falling below a certain minimum level, investments in economic development will be increased. Thus:

$$
\textit{if } dY(t) < \min[dY] \textit{ then } I^I(t) = \min\left(1.0, \min[dY] \cdot \frac{I(t-1)}{dY(t-1)}\right) \textit{ else } I(t) = I(t-1) \qquad (16)
$$

where min[dY] is the minimum economic growth preferred by the individualist. The value of the minimum growth rate is determined by experiments on the utopian world for the individualist (see Section 6.2). Assuming that in such a world a collapse in consumption per capita is not desired, our experiments arrive at a minimum growth rate of 2%.

With regard to emission reduction, the individualist will similarly advocate an adaptive strategy. We assume that, although individualists do not believe in economic risks due to climate change, if damage costs exceed a certain threshold value, of for example 1% of economic output, fossil fuel transition will be accelerated, while assuming a minimum half-life time of 20 years. This approach is somewhat similar to that adopted by Lempert *et al.* (1995). Thus:

$$R^I(t) = 20 + (R^I(t-1) - 20) \cdot 0.99 \tag{17}$$

If no significant economic damage is detected, the half-life time of a fossil transition is assumed to be the longer period of 1000 years.

The Hierarchist

Consistent with the general characteristics of hierarchists, their preferred management style is one of control. It envisages a balance between the levels of anthropogenic pressures on the climate system and the level of structural changes in the economic system which are tolerated to meet environmental targets. Such a cost-benefit approach is adopted in our simple rules for the hierarchistic management style.
We assume that to meet the needs of the society a stable economic growth is desirable D[dY]. The preferred level of investments is therefore the one which leads to an expected growth of D[dY]. While abrupt changes in the investment levels need to be avoided, we assume that the preferred level of investments is a function of the level of investments of the previous year, to some extent corrected to meet the desire for a stable growth path of the economy, thus:

$$I^H(t) = 0.9 \cdot I(t-1) + 0.1 \cdot \frac{D[dY]}{dY(t-1)} \cdot I(t-1) \tag{18}$$

where

$$dY(t) = \frac{Y(t) - Y(t-1)}{Y(t-1)} \tag{19}$$

Experiments with the utopia case for the hierarchist (see Section 6.2) yield a figure for desired growth of 1.5% a year. A higher growth rate is not desirable since consumption per capita collapses in the event of higher desirable growth rates which is avoided in a utopian world.

Hierarchists prefer to avoid acting under extreme uncertainty. Therefore, we assume that measures to reduce emissions are embarked upon when temperature change is far from dangerous levels. We assume an upper level of a temperature increase of 2 °C relative to 1900, a figure based on the UNEP's Advisory Group on Greenhouse Gases (AGGG, 1990). Given the temperature increase of about 0.5°C over the past century, the maximum temperature increase for the next century would be 1.5°C. If measured temperature is below the threshold value of 0.5°C, we assume that R is equal to 100 years. Emission reduction measures are slowly implemented when the measured temperature increase M[ΔT] exceeds the 0.5°C increment. The implementation of measures is reinforced once the 1.0 °C level and the 1.5 °C level is violated. Furthermore we have assumed that R cannot fall below a period of 20 years.
The levels of changes as listed below have been determined by experiments in the utopian case whereby the maximum increase is 1.5 °C (Section 6.2).

$$if\ M[\Delta T(t)] < 0.5\ then\ R^H(t) = 100$$

$$if\ (M[\Delta T(t)] > 0.5) \wedge (M[\Delta T(t)] < 1.0)\ then\ R^H(t) = 20 + (R^H(t-1) - 20) \cdot 0.995 \tag{20}$$

$$if\ (M[\Delta T(t)] > 1.0) \wedge (M[\Delta T(t)] < 1.5)\ then\ R^H(t) = 20 + (R^H(t-1) - 20) \cdot 0.99$$

$$if\ M[\Delta T(t)] > 1.5\ then\ R^H(t) = 20 + (R^H(t-1) - 20) \cdot 0.98$$

The Egalitarian

Egalitarians prefer a preventive management style. In order to guard our society against a full-blown catastrophe in the long term, drastic structural social, cultural and institutional changes are necessary, notwithstanding any short-term disadvantages and costs which may result. Insofar as climate policy is concerned, a rapid transition towards a fossil free society is the ultimate goal of the egalitarian, which implies the choice of a low half-life time of 20 years (R^E=20). The level of investments is determined by the assumption that no more investments are made than these required to compensate for the depreciation of existing capital goods (dK/dt=0 in equation 4):

$$I^E(t) = \frac{\delta_k \cdot K(t-1)}{Y(t-1)} \tag{21}$$

Economic output (Y) will only grow as a result of an increase in the labour force and a low technological development.

5.4 Evaluating perspectives

According to Thompson *et al.* (1990) we may assume that people abandon their perspectives in the event of surprise, i.e. observations differing from expectations. Perspectives are assumed to shift towards world-views which can better explain the observed behaviour of the system. Therefore, we simulate this learning and adaptive behaviour of agents as a 'battle of perspectives' using a genetic algorithm. Defining a fitness function for measuring the fitness of an agents' perspective is almost an impossible task. We assume that the fitness function is required to measure the likelihood of the perspectives being adhered to. This likelihood may be expressed in terms of the difference between the measured values in the real world and the expected value associated with the view of the agent. In the simple world as constructed in this paper, the agents perspective only deals with temperature change. The fitness function is therefore a function of expected temperature change due to measured CO_2 concentration and the measured value of temperature change for a historical period. A simple model is used to quantify the expectation of perspective i as given below:

$$E^i(\Delta T)(t) = 0.05 \cdot \frac{\Delta T_{2xCO2}}{\ln(2)} \cdot \ln(\frac{M[pCO_2](t)}{pCO2-in}) + 0.95 \cdot E^i(\Delta T)(t-1) \tag{22}$$

where ΔT_{2xco2} is the climate sensitivity according to the perspective of the agent and $M[pCO_2]$ is the measured concentration of CO_2. Although we recognize the shortcomings of this approach of this approach, in order to render an initial implementation as clear as possible, we assume that one of the 'extreme' agents has a perfect picture of the system.

We tend to assume that the measured temperature change is equal to the observed global mean temperature change. We assume that if the difference between the measured and the expected value is less than a tolerance level, the fitness of the agents' perspective is maximal; i.e. the agents concerned have no reason to alter their perspective. This tolerance level is included to take account of the ignorance of agents. Although expectations may differ from measurements, ignorance prevents agents from changing their perspectives. Therefore, ignorance of surprises may delay the learning and adaptive behaviour of the agents.

In mathematical terms, this enables us to write the following equations; in the event of the difference between expected and measured levels being greater than a tolerance level, the agents may be surprised and be moved to alter their perspective. The resulting fitness function is shown in Figure 5.
In the event of the measured value M(ΔT) being smaller than the expected value minus the tolerance level (E(ΔT)-tol), the fitness function is defined as:

$$f_i = e^{-(E(\Delta T) - M(\Delta T) - tol)^2} \tag{23}$$

while in the event of M(ΔT) being greater than E(ΔT)+tol, the fitness function is defined as:

$$f_i = e^{-(M(\Delta T) - E(\Delta T) - tol)^2} \tag{24}$$

6. Exploratory Experiments

6.1 Introduction

In this section we will first analyze the utopias and dystopias for the three perspectives. The utopias and dystopias are a static view of a single global commoner, but can be used to scan the space of possible futures. In the second part, we assume that a set of agents exists with perspectives located at various places within the triangle spanned up by the three active perspectives. Due to learning via observations of the system, the favoured climate policy may change over time among the agents. This may lead to a set of possible images of the future. Finally, we attempt to analyze the influence of surprises on the change in perspectives.
Before starting, we need to emphasize the fact that the results should not be considered as outcomes of any 'truth machine', but rather as examples of how a tool which serves as a heuristical device can be used.

6.2 Utopias and Dystopias

The concept of utopias is used to determine a number of variables in implementing the management styles (Section 5.3). Utopias and dystopias can be simulated by running the model for a case in which a global commoner is in charge, i.e. an agent who adopts a perspective which is located at a corner of the triangle of perspectives (Figure 6a,b,c and d). Furthermore, we assume that the global commoner does not learn from the information he derives from the system. In the case of a utopia, the world fits very well with its expectations, but in case of a dystopia there is a mismatch of expectations and measurements. In order to investigate the potential consequences of such a mismatch, we are obliged to assume that the global commoner does not learn and adapt.

Utopias

The utopias are used to fill in a number of parameters of the management styles as discussed in Section 5.3. The derived results therefore correspond to subjective ideas of perspective utopias:
In the egalitarian utopia (Figure 6a,b,c and d), emissions of fossil CO_2 are phased out within a few decades, leading to a modest temperature increase of 1°C. Economic growth is approximately 1% a year which implies a stable growth of consumption per capita.
In the hierarchistic utopia the economy grows at a stable rate of 1.5% a year. Due to timely implementation of emission reductions the temperature increase stabilizes at around 1.5 °C above present values which is assumed to be the upper bound of acceptable temperature change.
In the individualistic utopia, economic growth is greater than 2% a year leading to an increase of fossil CO_2 emissions to 40 GtC in 2100. However, due to the stability of the natural system a human-induced climate change is rather modest, leading to a 0.5 °C increase in 100 years. This temperature change has no significant impact on economic activities so that the use of fossil fuels need not be restricted.

A more interesting situation is a difference in management style and world view:

Dystopias

In the event of the system functioning according to the egalitarian perspective, a hierarchistic management style leads to lower economic growth than population growth and thus to a decline in consumption per capita. An individualistic management style may lead to an absolute collapse in economic development due to excessively high economic growth aspirations together with severe impacts of climate change. The growth aspirations of both management styles are too high, leading to a collapse of consumption per capita because technological progress is less pronounced than hierarchists and individualists have assumed, while the economic damage due to a climate change hits economic activities harder than expected. The emission reductions measures are implemented a too late a juncture to avoid a temperature increase of more than 2.5 °C.
In a system which functions according to the view of the hierarchist, an egalitarian management style implies to a low economic growth. The reduction of CO_2 emissions leads to a stabilisation of the temperature increase. In the event of the individualistic management style being implemented the consumption per capita collapses and fossil CO_2 emissions increase to about 30 GtC. However, temperature increases to a level of 2.5°C.
In a stable system functioning according to the world-view of the individualists a phase out of fossil fuels would be a waste of money, since this would suppress economic growth while despite the absence of control, temperature change would not harm economic development. The management style of the egalitarians and hierarchists is associated with low economic growth.

If the global commoner adopted an egalitarian management style, the temperature increase would be lower than expected in the event of the world functioning according to the hierarchistic or individualistic world-view, and thanks to accelerated technological progress, economic growth would be higher than expected.
A hierarchistic management style, however, leads to a collapse in consumption per capita and will exceed the 1.5°C maximum increase of temperature if the world functions according to the egalitarian world view. If the world functions according to the individualistic view, higher economic growth and a lower temperature increase will occur.
An individualistic management style may lead to a collapse in terms of consumption per capita if the world functions according to the egalitarian or hierarchistic world-view. In the egalitarian world, the economy would seriously damaged by climate change.

6.3 Changing Perspectives

We include the rather arbitrary number of 50 similar agents in the 'battle of the perspectives'. We analyze, by way of a sensitivity test, the adaptive behaviour in the case of three different initial mixes of perspectives in which in each case a different perspective dominates. The dystopias showed that a mismatch between management style and world-view does not necessary lead to collapses. However, if expectations are not met (for example, a high temperature increase), preferences associated with other perspectives (for example, high economic growth) will secure a more dominant position in the event of agents adapting.

In order to analyze the consequences of the various perspectives among agents, we performed the experiments for three sets of assumptions of the global system according to the perspectives. We started in from a situation which is comparable with the matrix of utopias and dystopias as discussed in the previous section: a dominating management style X in a world which functions according to perspective Y. However, the agents' perspectives may now change in time, and none of the perspectives fully determine the climate change policy (Figure 7a,b,c and d). A tolerance level of 0.5°C is used as a measure for ignorance[1].

In the event of the world functioning according to the egalitarian world view, the temperature increase will exceed the 2°C level, although in the event of the egalitarian or hierarchist dominating in the initial years the temperature increase will stabilize. However, learning and adaptation operate too slowly to prevent a collapse in economic development in the event of an individualistic management style dominating from the start.

In a world which functions according to the hierarchist, starting with an individualistic 'high growth' management style leads to a collapse in consumption per capita, although due to high investment the economy itself remains growing. Irrespective of the initial management style, the temperature increase just exceed the 1.5°C level.

If an egalitarian management style dominates at the start, reductions in emissions would only be temporary in a world which functions according to the individualistic world view. The revival of the individualistic management style leads to an increase in emissions which in turn results in a temperature just below 0.5°C by the year 2100. Starting with a hierarchistic or individualistic management style both lead to a high level of economic development.

If, at the start, the egalitarian perspective predominates, most of the agents seem to be able to adapt their management style to a perspective which is in line with the functioning of the global system, although the resulting economic growth paths are somewhat lower than if they started with another dominating perspective.

A dominance of the hierarchistic management style at the start, may lead to a decline in economic growth due the severe impacts of climate change. The dominance of a hierarchistic management style at the start within an individualistic world does not prevent the agent from developing to a world which is largely similar to the individualistic utopia.

If an individual management style dominates at the start while the underlying system fails to function according to the individualistic management style, a collapse in consumption per capita can occur due to high investments in capital compared with technological innovation and due to severe high economic impacts of climate change.

Thus, although agents learn and adapt and the projections for each world-view are less dependent on the initial mix of perspectives compared with the utopias and dystopias listed in Section 6.3, collapses can not be avoided.

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1 Including a noise in the temperature projections does not significantly affects the trends of the results. The assumed symmetric variance seems not to lead to structural surprises which force agents to other thoughts more so than without noise in the records.

6.4 Surprises

Suppose it is the case that observed mean temperature is masked by an additional cooling effect, and this mask falls off in the middle of the next century such that the cooling effect is diminished; then various agents are confronted with a surprise. The cooling surprise may be explained in two ways:
- over the next 50 years, global warming is masked by a cooling effect which disappears after 2050.
- over the next 50 years global warming is masked by a cooling effect. One discover the causes and the cooling effect is discounted in the expectations.

Imagine a world, in which a serious global warming may occur due to human intervention in the global system. Suppose furthermore that this is a world in which the egalitarian perspective dominates at the start and agents do not ignore differences between observations and measurements. In such a world, a cooling surprise would to a slowing-down of emission reduction due to greater dominance of the hierarchistic and individualistic perspectives (Figure 8a). This results in an additional increase of about 1°C by 2100. The cooling surprise does not result in a lower economic output. Although the damage costs have a severe impact, an early transition towards a fossil free society results in a reduction of economic growth. Ignoring the observations (tol = 1°C) leads to less differences between a surprise and a non-surprise scenario (Figure 8b).

Assume a fragile world in which the individualistic perspective is dominant at the start. If mismatches between observations and measurements are not ignored (tol=0°C), the dominating perspective turns towards an egalitarian one which implies a reduction in emissions of CO_2 (Figure 9a). In the event of a cooling surprise confronting the dominating individualistic agents, a switch to an egalitarian perspective occurs only after 2050, leading to a higher emission path, a higher temperature increase and a higher impact on economic growth. If we assume a certain level of ignorance (tol=1°C), the differences between surprise and non-surprise are less pronounced (Figure 9b). This is caused by the fact that due to the ignorance of mismatches between expectations and observations after 2050, the individualistic perspective remains dominant in a world which functions according to the egalitarian world view.

By analogy to the cooling surprise we can analyze the effects of a warming surprise. Assume that the temperature records in the next 50 years are masked by a warming effect which is not caused by a human-induced climate change. After 50 years the warming effect disappears or one discovers the causes and adjust the expectations.
What are the risks of a warming surprise? Lets assume a world in which a human-induced climate change will have no serious impact. Assuming a system which functions according to the individualists we start the 'battle of perspectives' for two cases of dominating perspectives (egalitarian and individualistic) and compare the projections of a warming surprise with projections without surprises.

If the dominating perspective in 1995 is an individualistic one, then whether or not the mismatches between observations and measurements are ignored, a warming surprise does not significantly influence the projections (Figure 10a,b). The rate of learning and adapting the management styles is too slow to convert to a more preventive management style before the additional warming has stopped. In fact most agents are not surprised, and therefore remain loyal to an individualist management style.

If the initial dominating perspective is an egalitarian one, the management style will rapidly change towards an individualistic one resulting in a high emission path of fossil CO_2 (Figure 11a,b). However if the observations are masked by an additional warming the egalitarian management style will dominate during the first decades. In the event of the agents with a dominating egalitarian management style ignoring the mismatch between observations and expectations, the emission reductions hold throughout the next century, which leads to a significantly lower economic growth than would have been possible.

7. Limitations and Future Developments

In this paper, a means of implementing the "Battle of Perspectives" is described. Some explorative experiments have been performed whereby we hope to have demonstrated the potential richness of the approach, but have also pointed out that a number of topics will need to be explored before the method can join the family of integrated assessment modelling approaches:

Multi-agent modelling

The present version of the method deals with only one kind of agent. Although there is a variety of opinions within the population of agents, the concept can be enriched if more kinds of agents are incorporated who have different interests, management options, costs and benefits, and abilities to influence others. In such a system, the evolution of perspective change may imply different directions for the various agents. For example, agents who are confronted by high damage costs may turn to a more egalitarian perspective compared with those agents who are confronted with relatively high mitigation costs.

The fitness of perspectives

For the purpose of this paper, we have assumed that agents are confronted by the same kind of surprises, namely mismatches between expectations and observations of temperature change, although we recognise that the various perspectives have different indicators according to which we may value the fitness of the perspectives. A next step might be to use different indices with which values surprises for a set of indicators.

Dealing with uncertainty

Every run of the model is unique thanks to the stochastic characteristics of the genetic algorithm. Dealing with this kind of uncertainty is not straightforward. A spectrum of a set of runs will probably improve the visualisation of possible outcomes, although we have to recognise that the uncertainty ranges will probably be structurally biased.

The Model

For practical reasons, the concept has been worked out on a simple climate-economy model. In the next phase the notion of the changing perspectives of active agents will be introduced within the integrated assessment model TARGETS (Tool to Assess Regional and Global Environmental and health Targets for Sustainability) which is currently under development at the RIVM (Rotmans *et al.*, 1994). Furthermore, we have assumed that there are no differences among the world-views in the structure of the model, an option which is presently adopted in implementing the utopias and dystopias for the TARGETS model.

8. Conclusions

In this paper we have presented an approach which simulates the response of similar agents to the changes in the system. Such responses are influenced by the world-views and resulting management styles of the agents. Observations of the global system may change the perspectives of the agents in the coming decades. Before presenting the conclusions, we emphasize the fact that the results are inevitably tentative. Further work will include a multi-agent version including a multi-indicator fitness function, and agent interactions will be applied to the integrated assessment model for global change TARGETS. There is no claim of realism for the model we have presented, although, we suggest that some basic aspects of the learning and adaptive behaviour presented here might well hold. The dynamic aspects of the Cultural Theory need to be more thoroughly explored than before in order to implement learning and adaptation more satisfactory. Notwithstanding these reservations, the following are the major conclusions.

The concept enables us to render the notion of surprises more explicit than earlier modelling activities in the field of integrated assessment for global climate change. Instead of projecting images of the future in terms of assumed or 'optimal' policies, our approach tries to simulate the adaptive and learning behaviour of agents. The inclusion of various perspectives among agents is used to render surprises explicit, whereby genetic algorithms are used to simulate the adaptive behaviour of agents.

The results show that in a world in which climate change was the only problem to worry about, agents would learn from observations of the system and may adapt their management styles.

Futures with high levels of fossil CO_2 emissions are associated with low temperature increases as well as low emission paths together with high temperature projections. This fact is due to the learning and adaptive behaviour of the agents: A system in which climate change caused serious impacts would drive the agents to reduce their emissions, while a system in which there was no serious climate change would not lead to restrictions in the long-run.

However, including learning and adaptation will not avoid the possibility of collapses. A dominance of an individualistic management style at the start may lead to collapses in a world which functions according to the egalitarian or hierarchist. It therefore makes a difference, especially in the long-run, which path is followed in the coming years. The results are too tentative to permit more explicit statements to be made, but they show clearly that learning will not necessarily prevent us from making irreversible mistakes.

In sum, the results of the 'battle of perspectives' demonstrate a different concept in scanning the future. Taking account of the notion of learning and adaptation may lead us to new kinds of images based on the assumptions of the global system and the decision-rules adopted by agents. We expect that this approach may prove to enhance our insights into possible images of the future.

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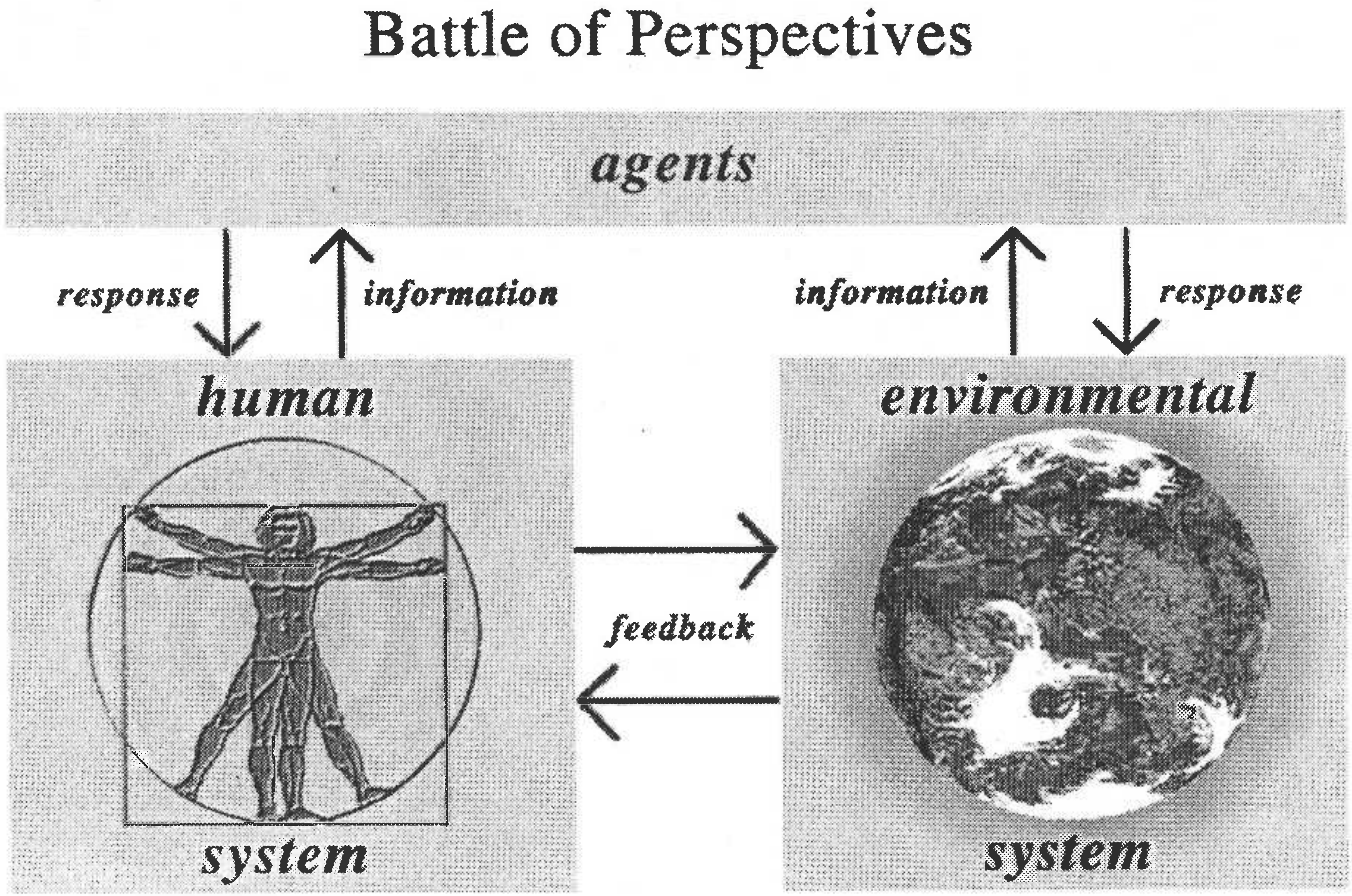

Figure 1: The Battle of Perspectives: The integration of agents with the human and environmental system.

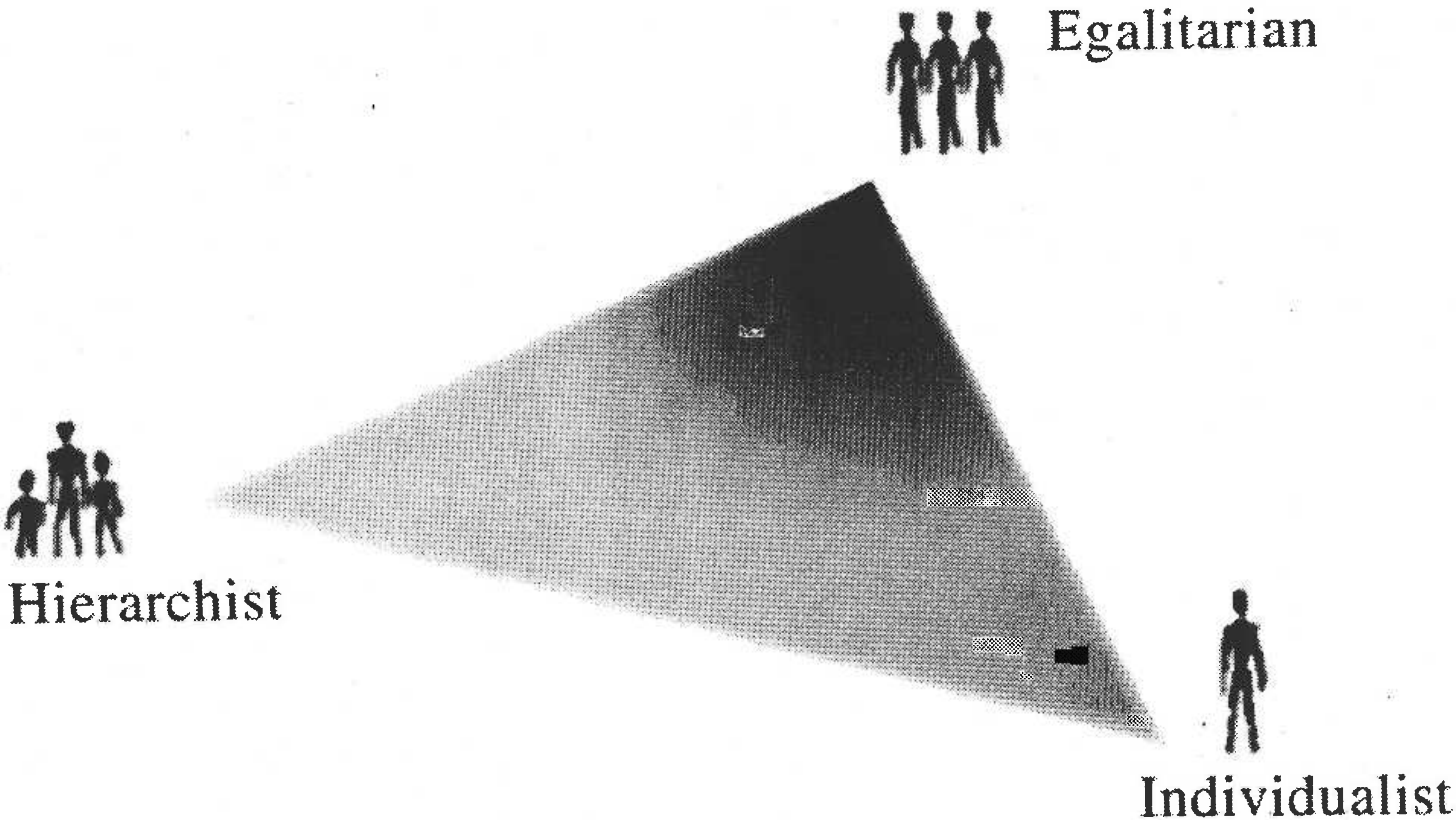

Figure 2: Spectra expanded by the active perspectives (source: Van Asselt and Rotmans, 1995).

Operators of a genetic algorithm

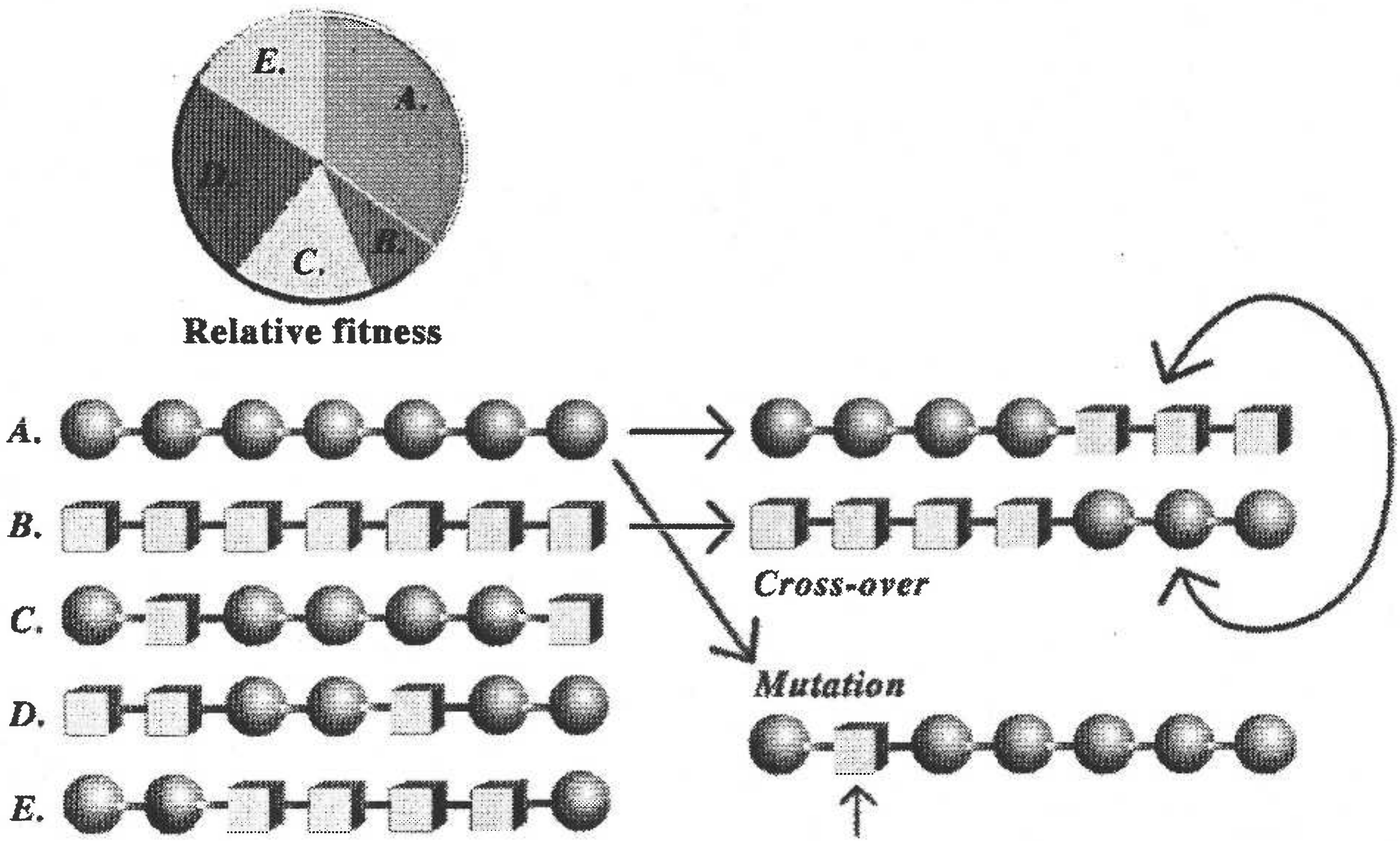

Figure 3: Schematic diagram of a genetic algorithm.

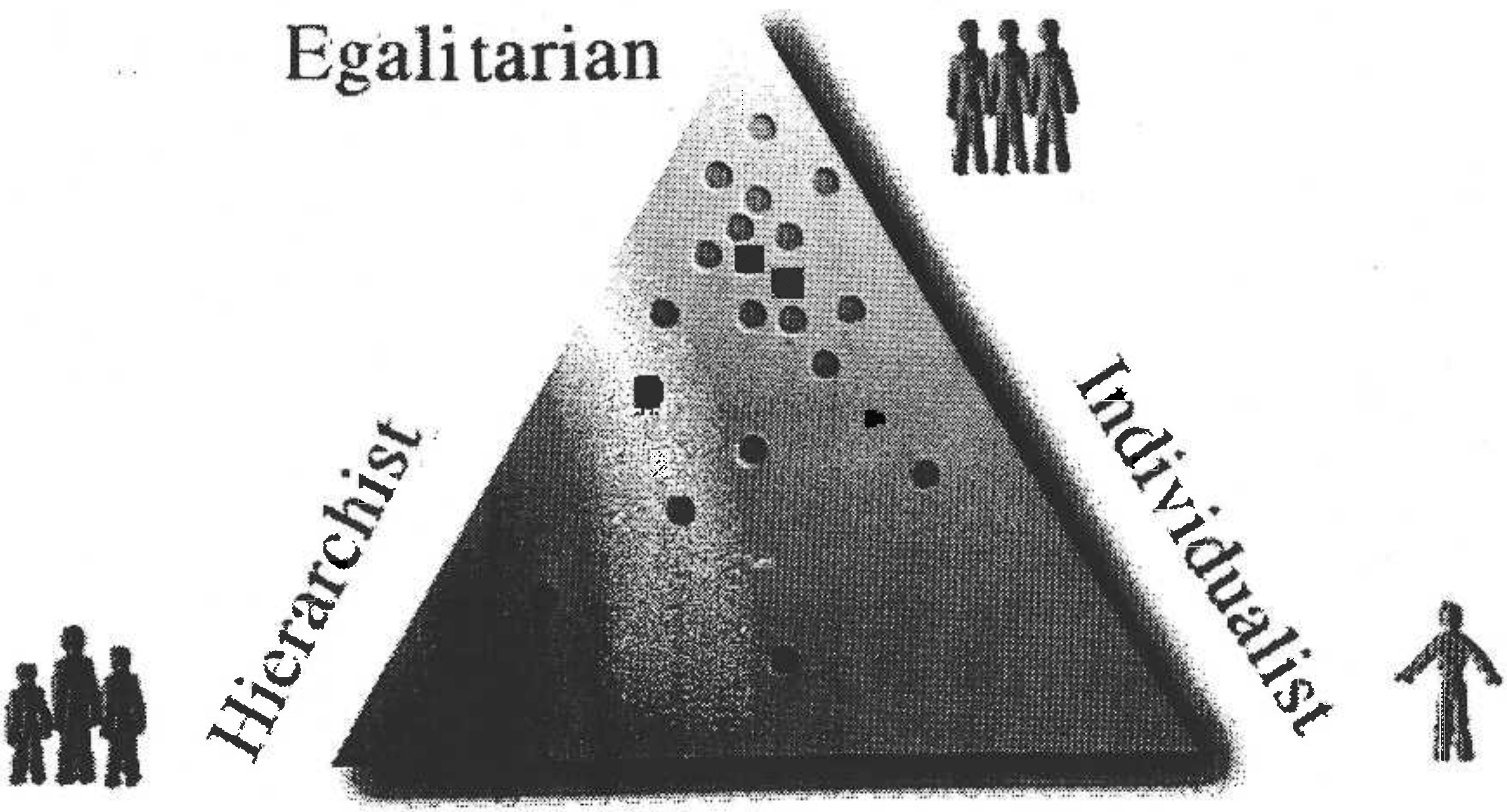

Figure 4: Agents's perspectives located within the perspective triangle.

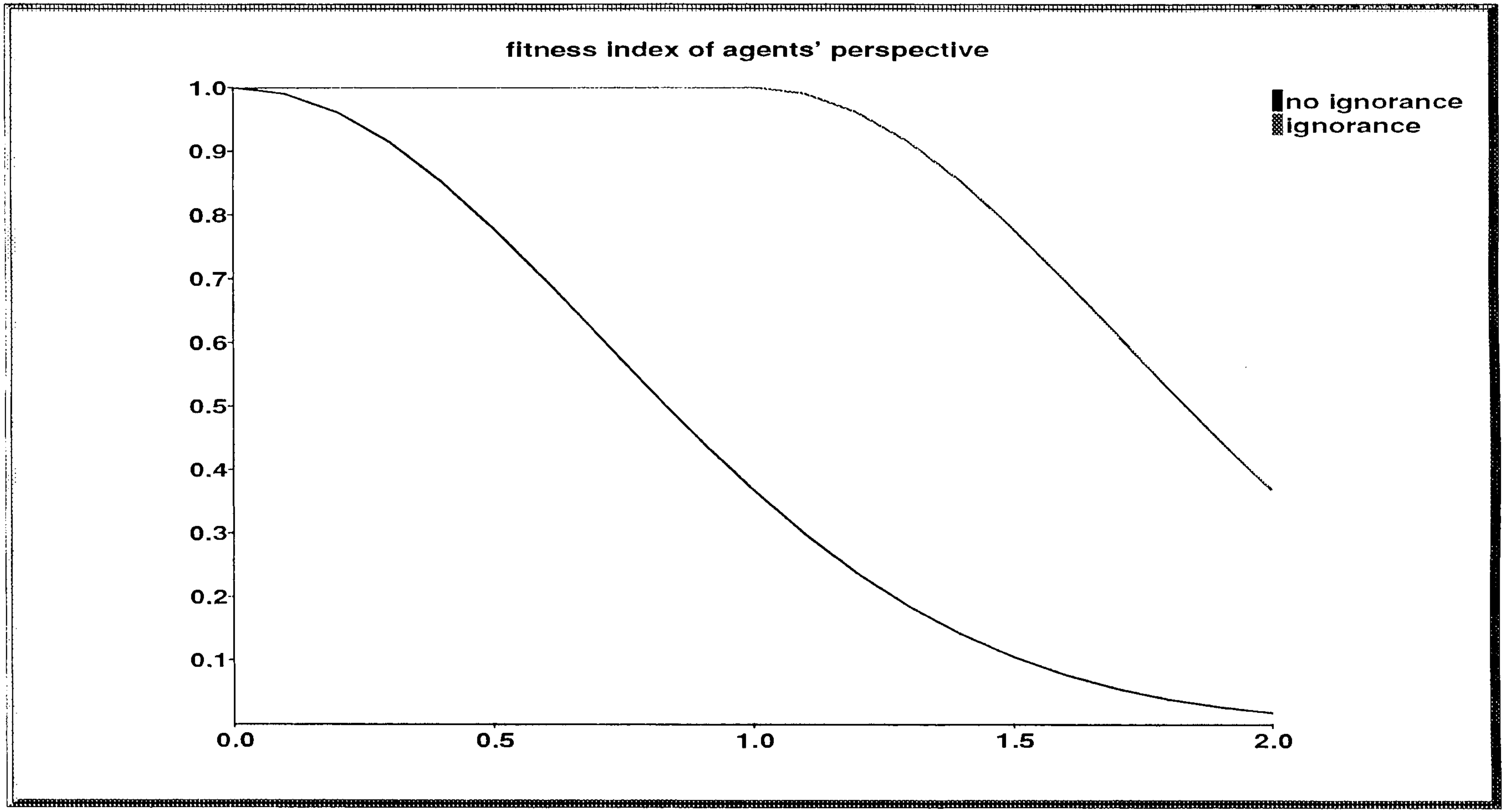

Figure 5: Fitness function of agents' perspective related to the mismatch in expectations and observations (horizontal axis; in degrees Celsius). For ignorance we used tol = 1 and for no-ignorance we used tol = 0.

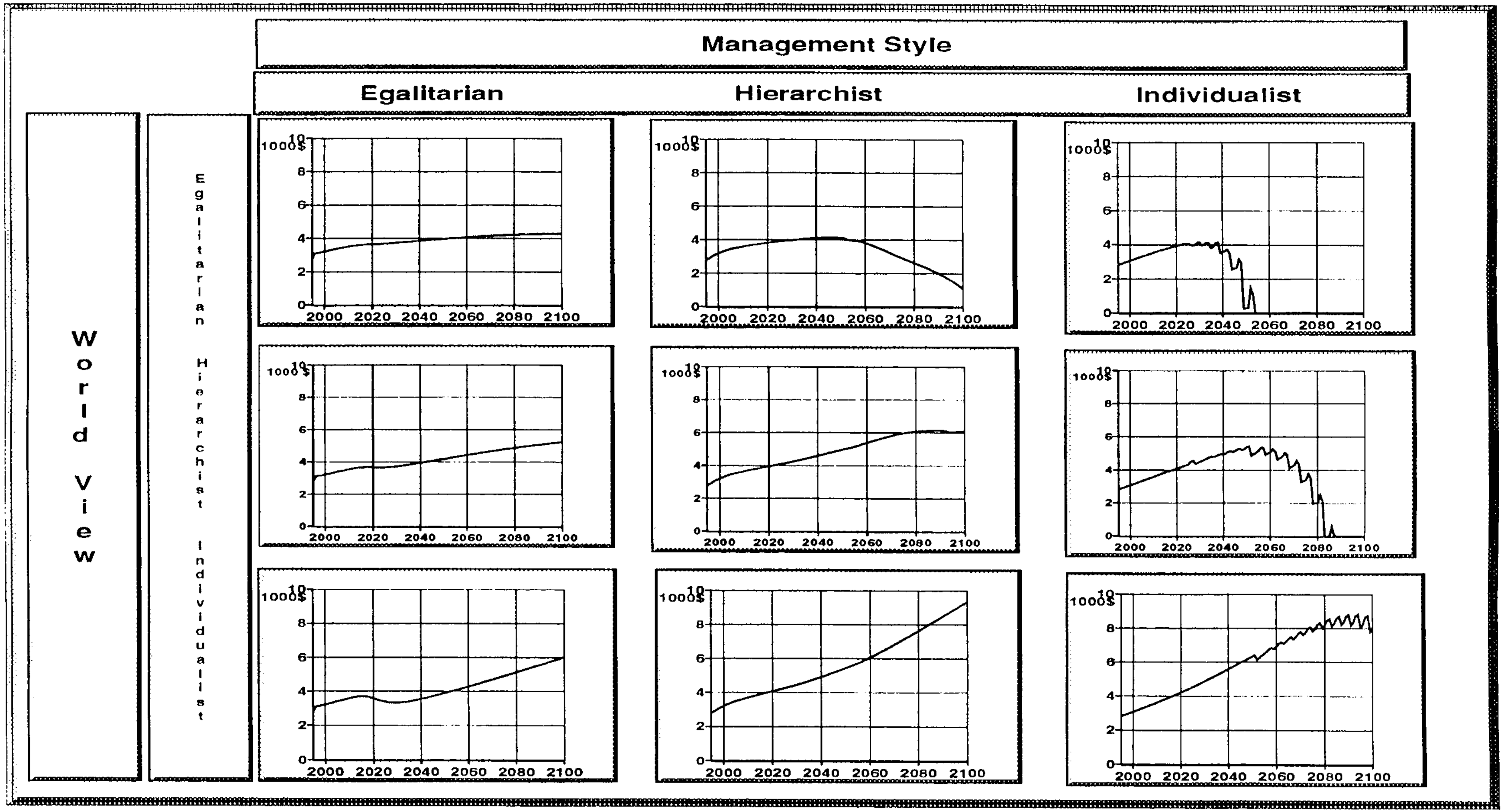

Figure 6a: Consumption per capita in utopias/dystopias.

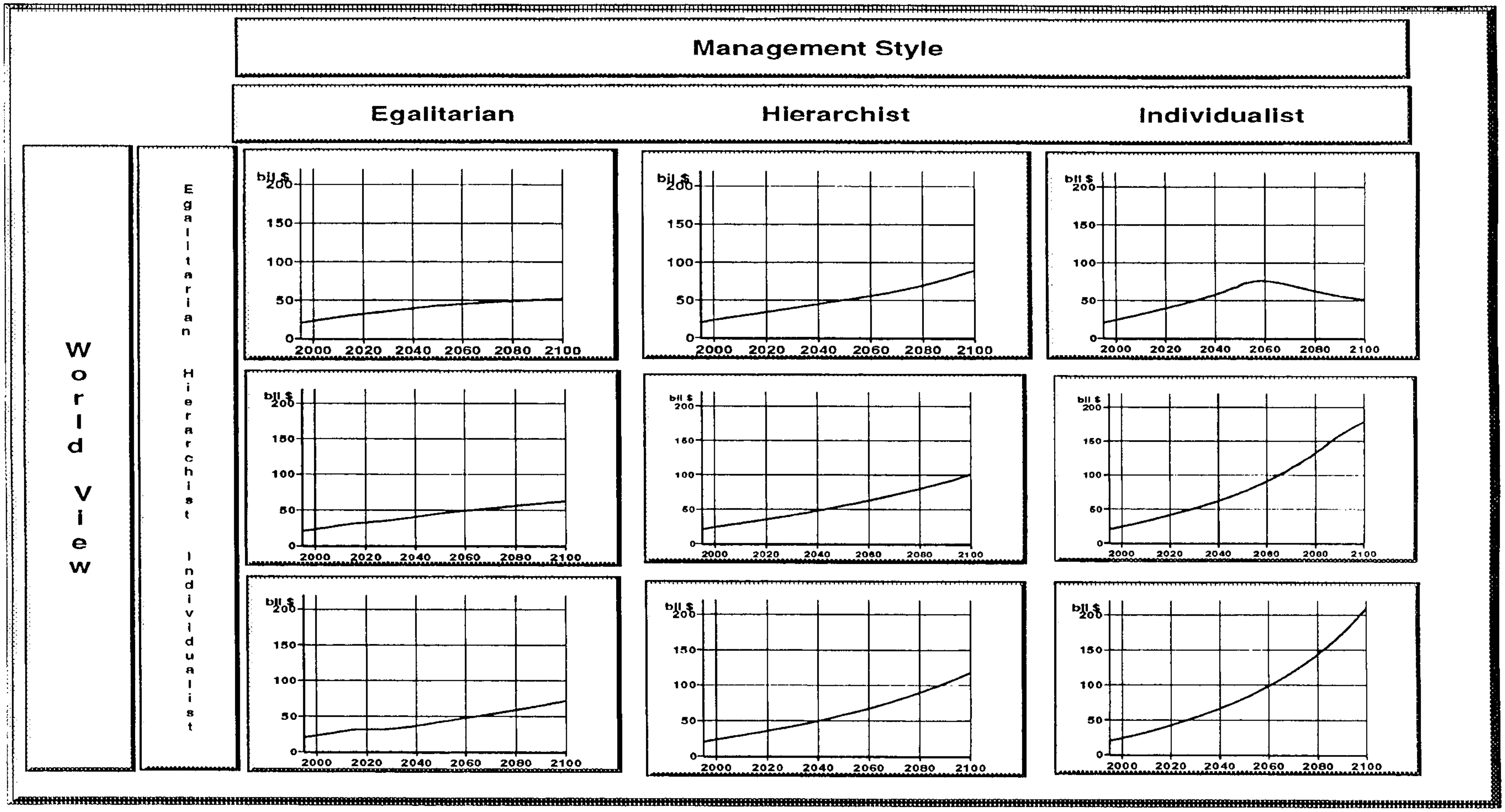

Figure 6b: Economic output in utopias/dystopias.

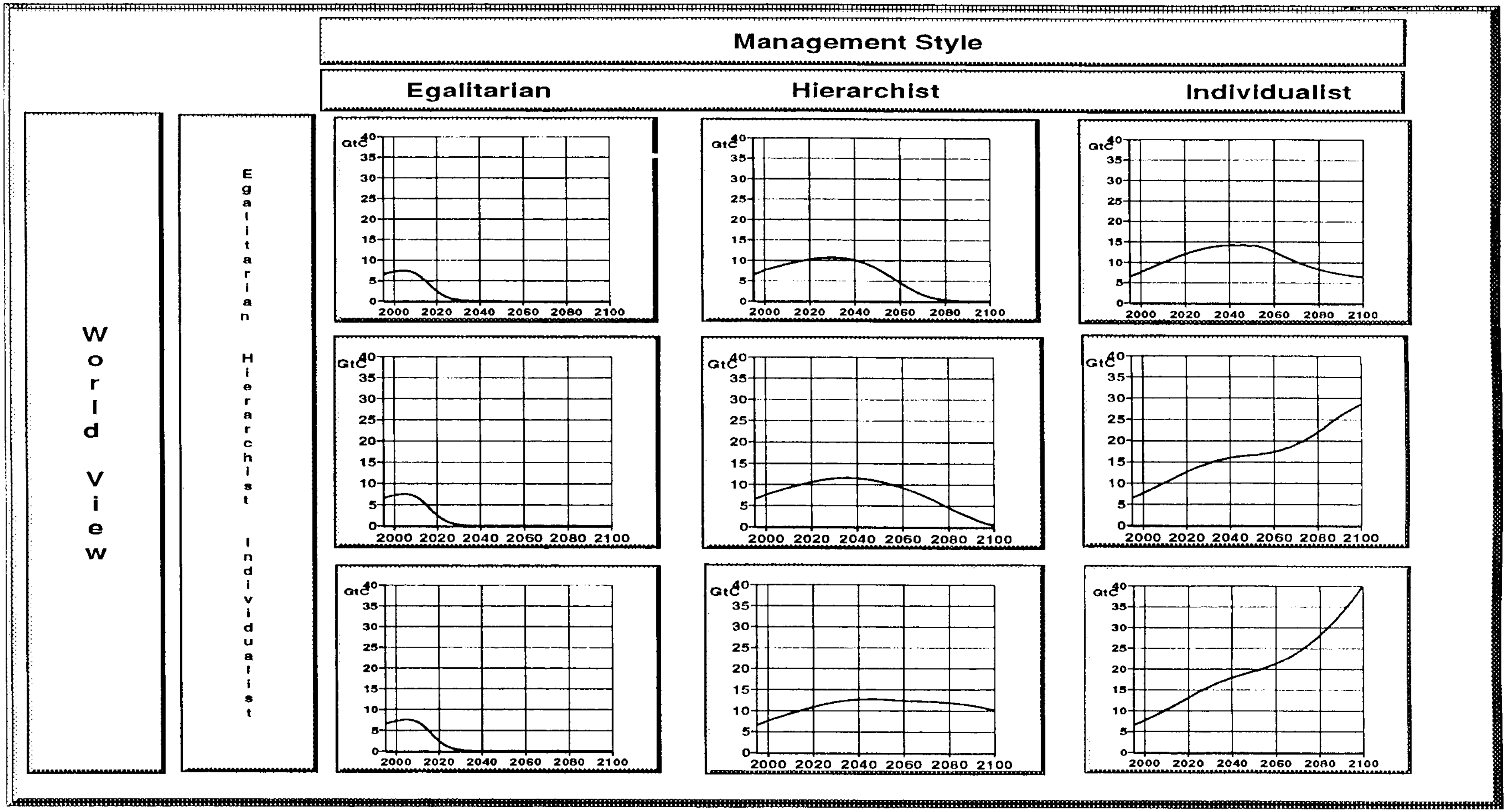

Figure 6c: Fossil CO_2 emissions in utopias/dystopias.

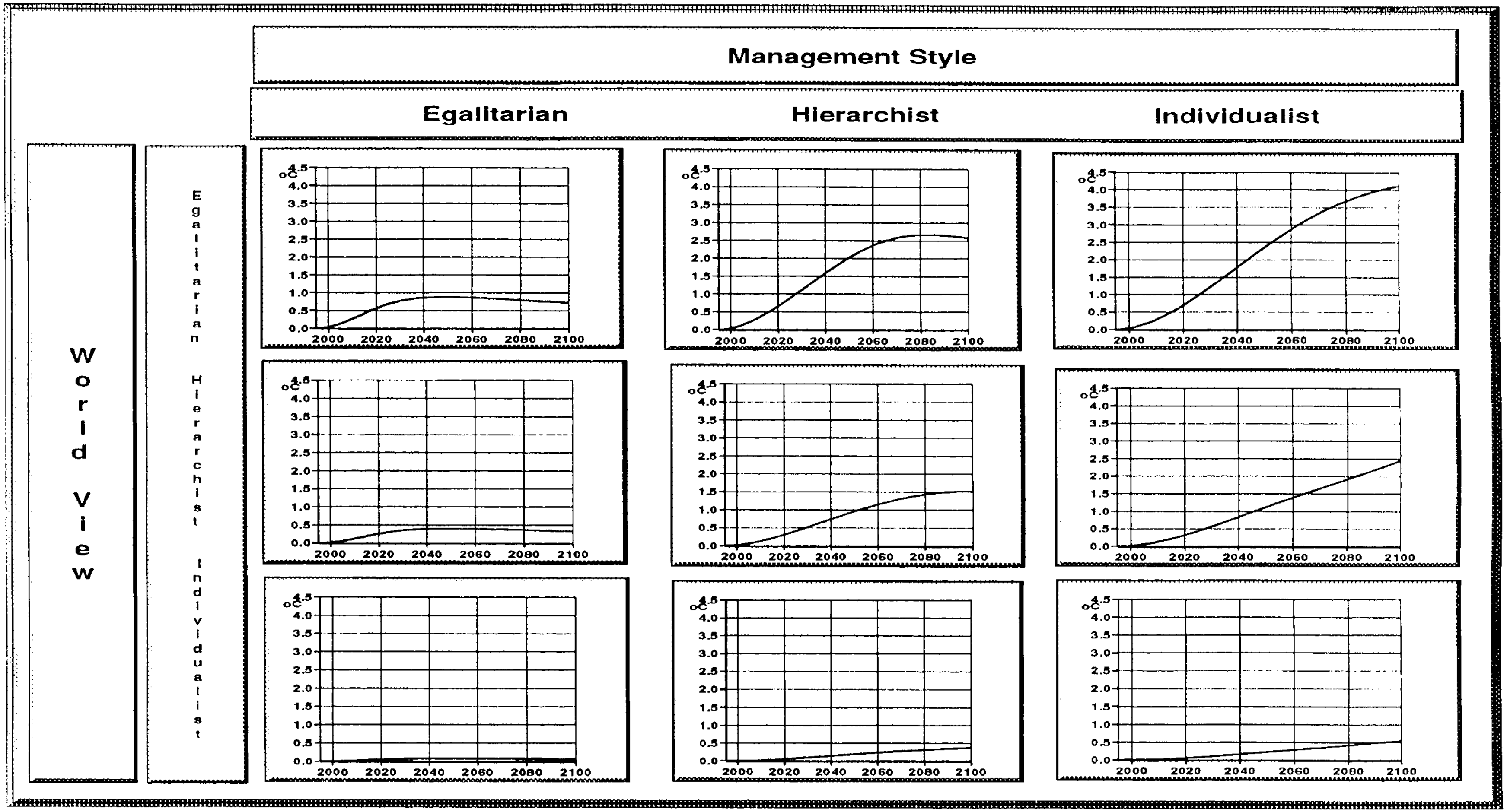

Figure 6d: Temperature change in utopias/dystopias.

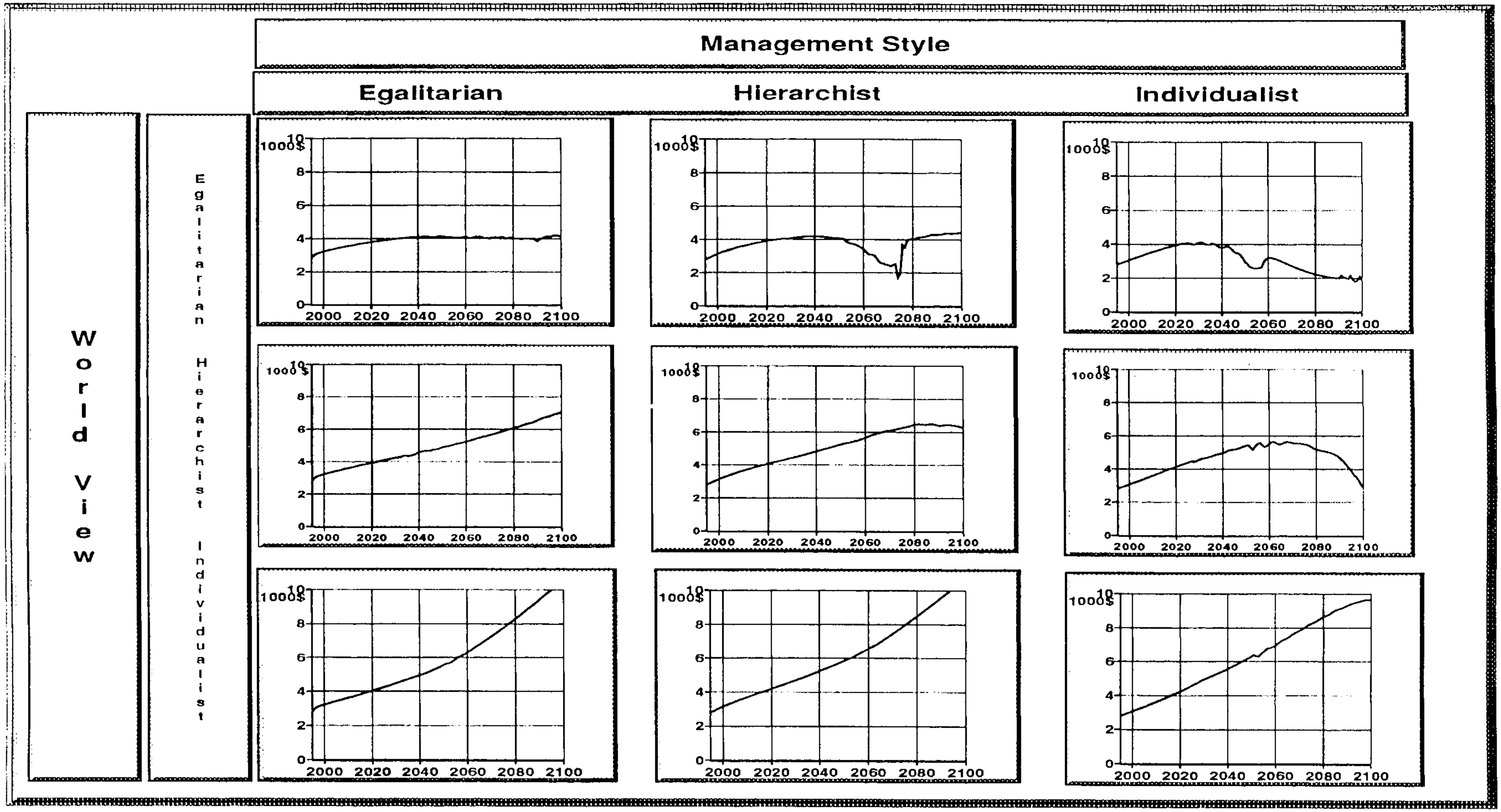

Figure 7a: Consumption per capita in the event of agents learn and adapt their management style.

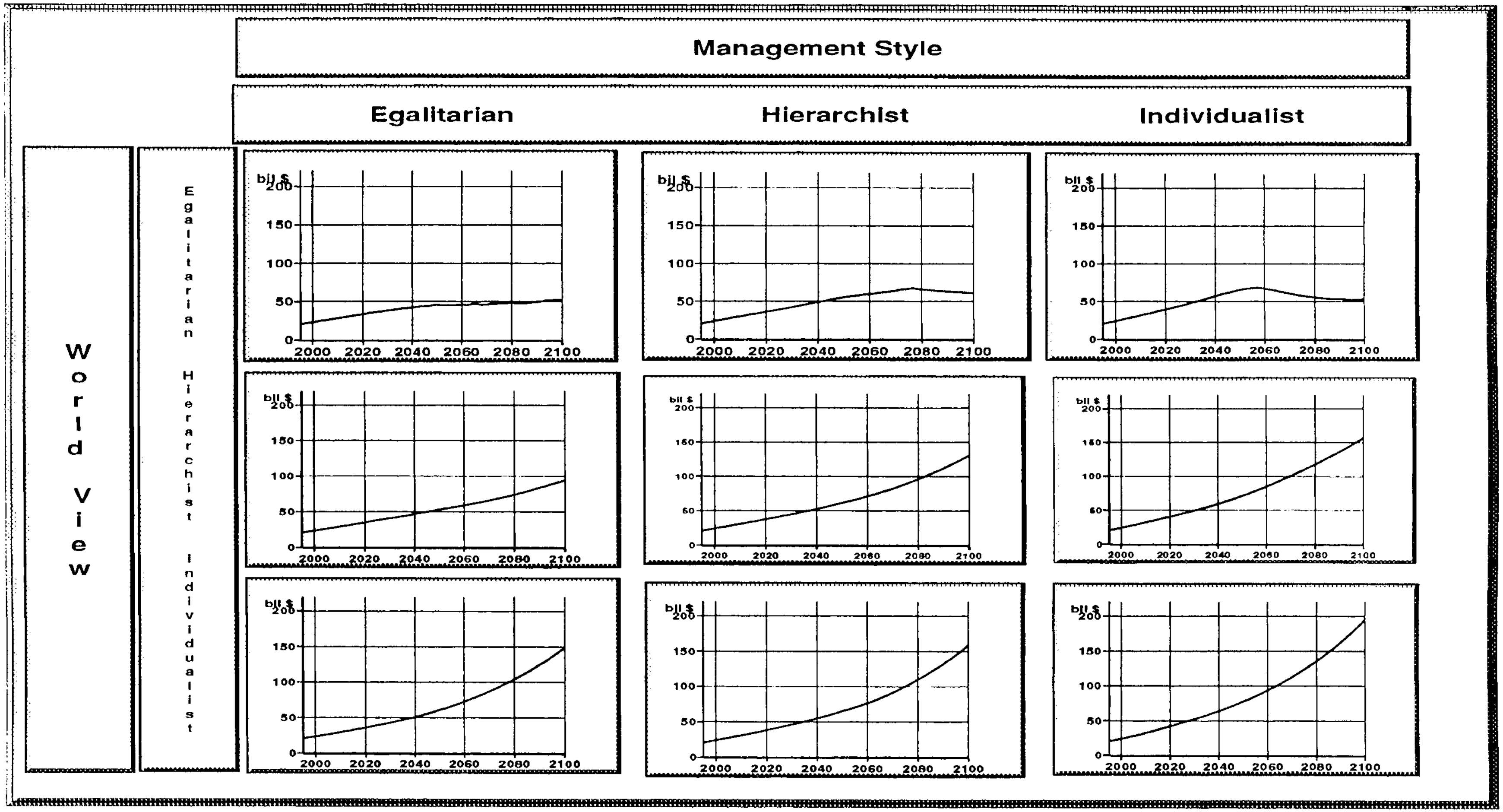

Figure 7b: Economic output in the event of agents learn and adapt their management style.

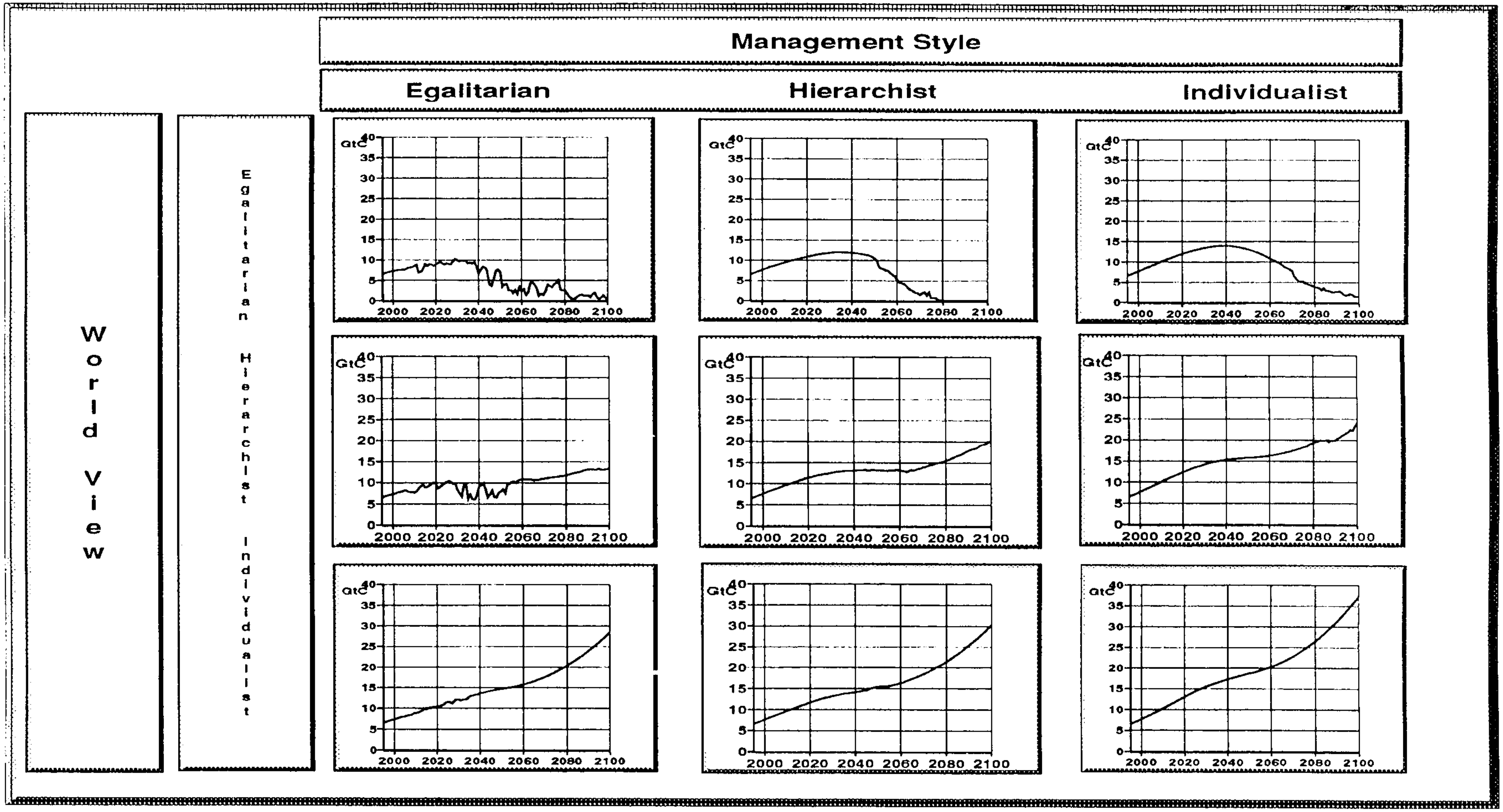

Figure 7c: Fossil CO_2 emissions in the event of agents learn and adapt their management style.

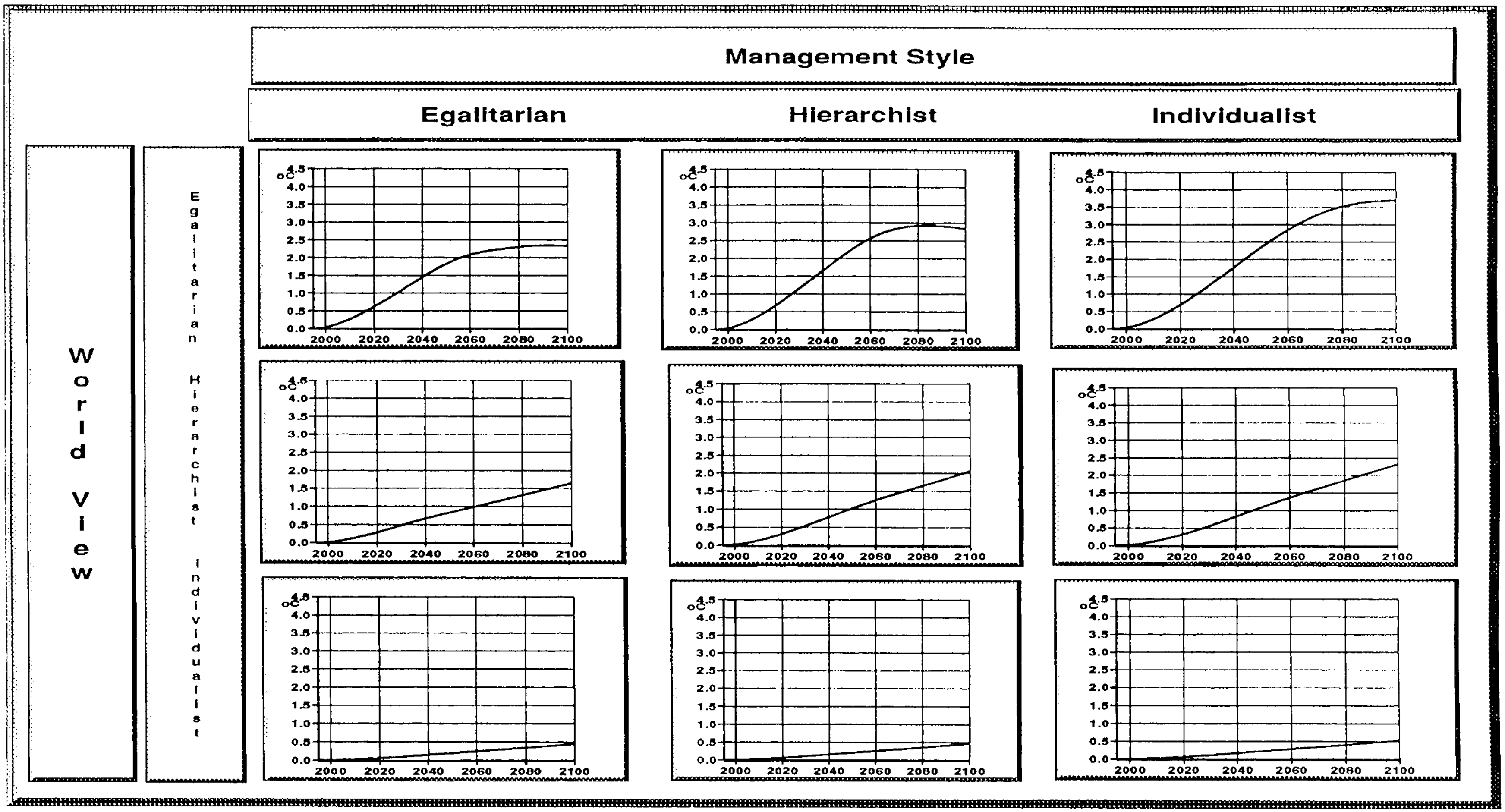

Figure 7d: Temperature change in the event of agents learn and adapt their management style.

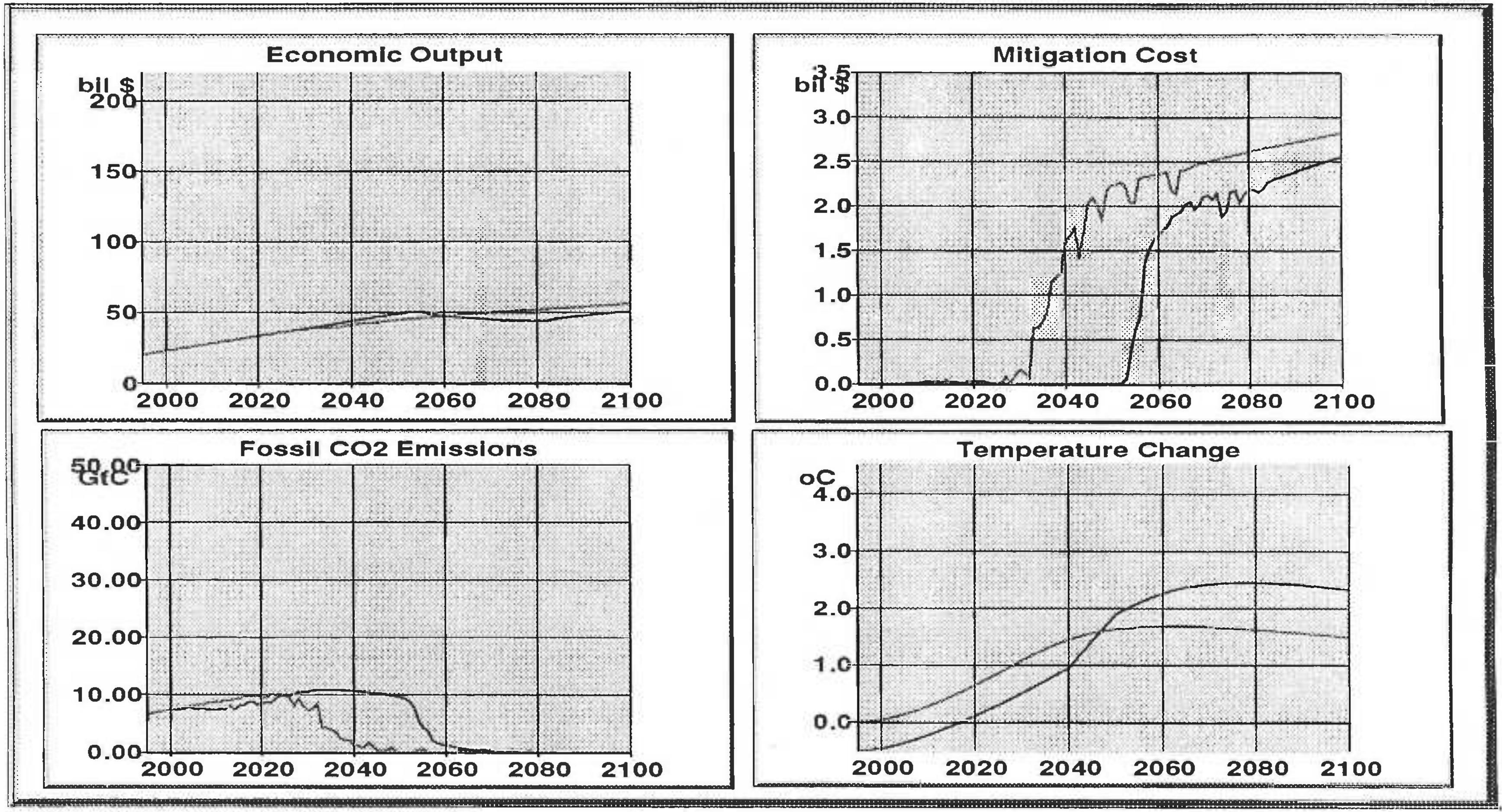

Figure 8a: A cooling surprise in a world which functions according to the world view of the egalitarian, in which the dominating perspective at the start is egalitarian and in which agents do not ignore surprises.
(____ = with surprise; .... = without surprise)

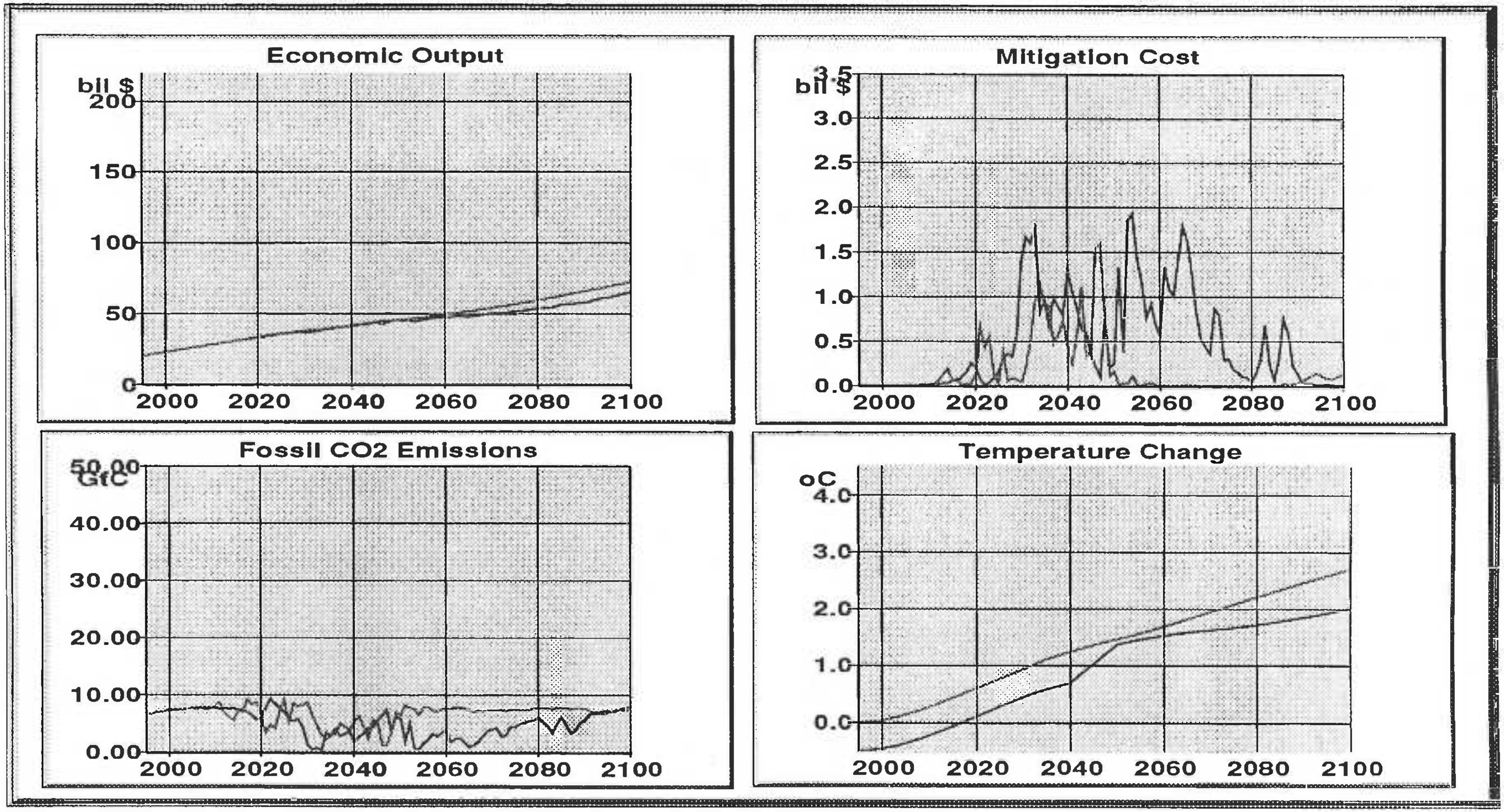

Figure 8b: A cooling surpise in a world which functions according to the world view of the egalitarian, in which the dominating perspective at the start is egalitarian and in which agents largely ignore surprises.
(__ = with surprise; .... = without surprise).

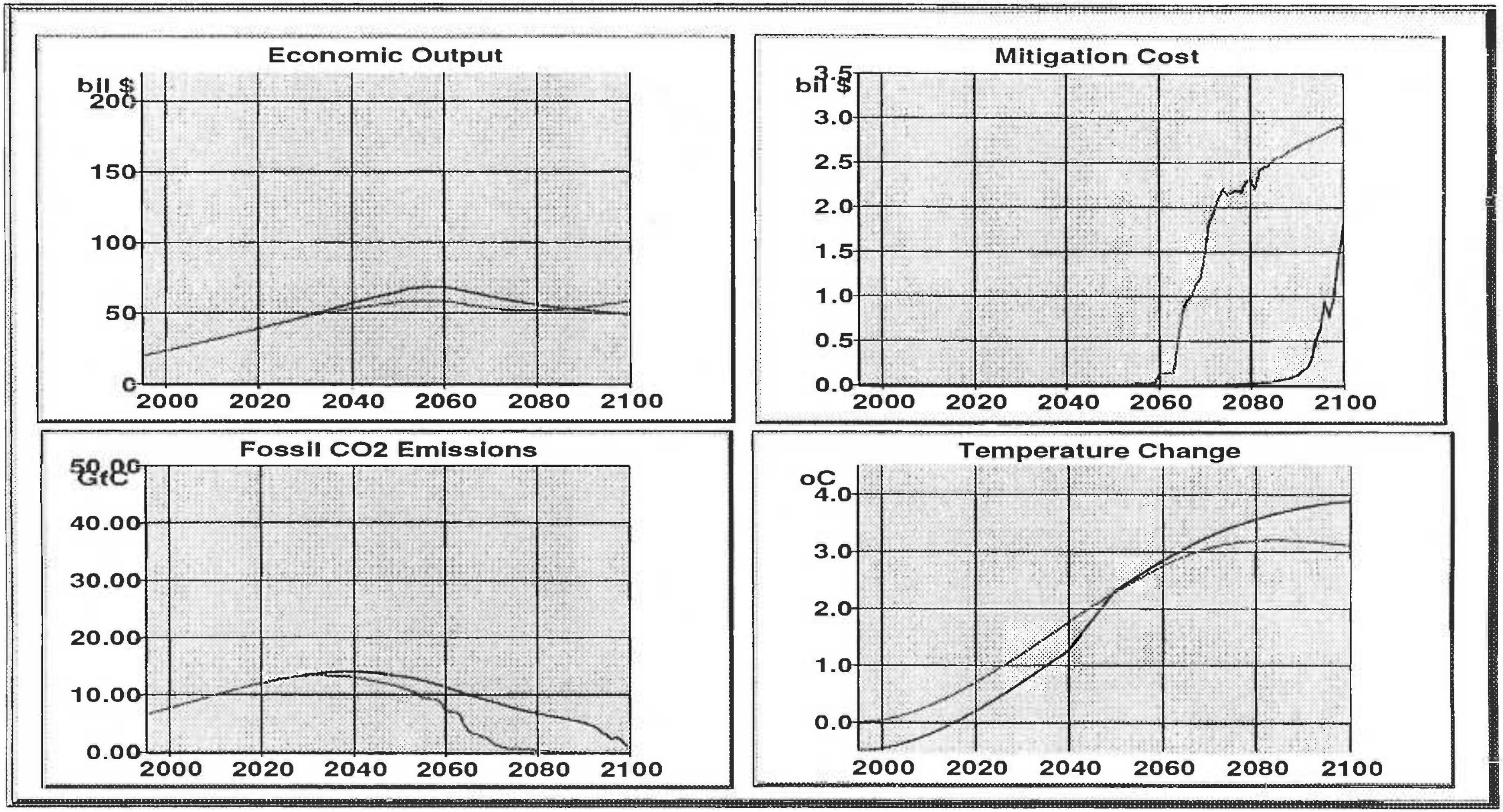

Figure 9a: A cooling surprise in a world which functions according to the world view of the egalitarian, in which the dominating perspective at the start is individualistic and in which agents do not ignore surprises.
(__ = with surprise; .... = without surprise).

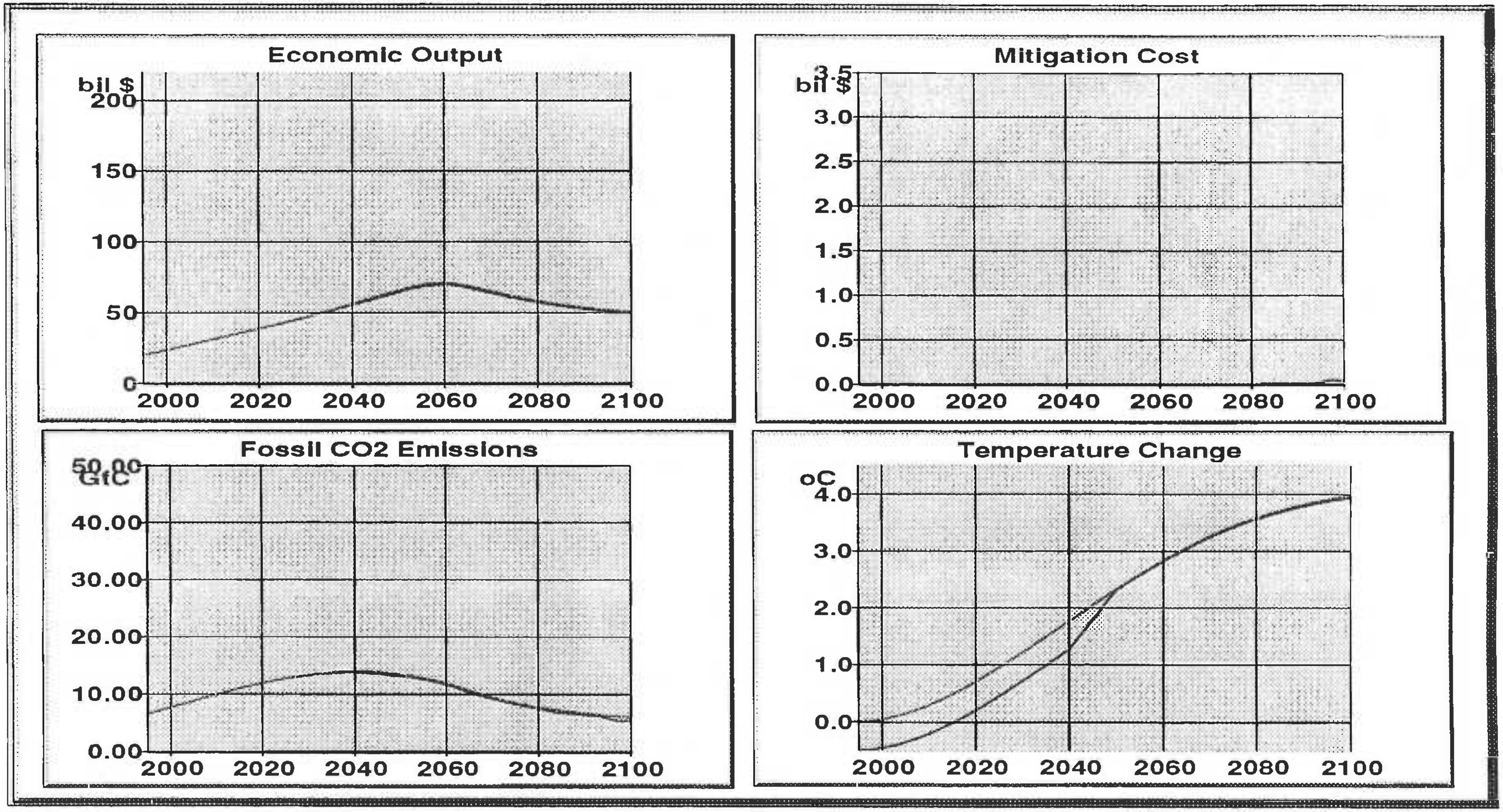

Figure 9b: A cooling surprise in a world which functions according to the world view of the egalitarian, in which the dominating perspective at the start is individualistic and where agents largely ignore surprises (__ = with surprise; .... = without surprise)..

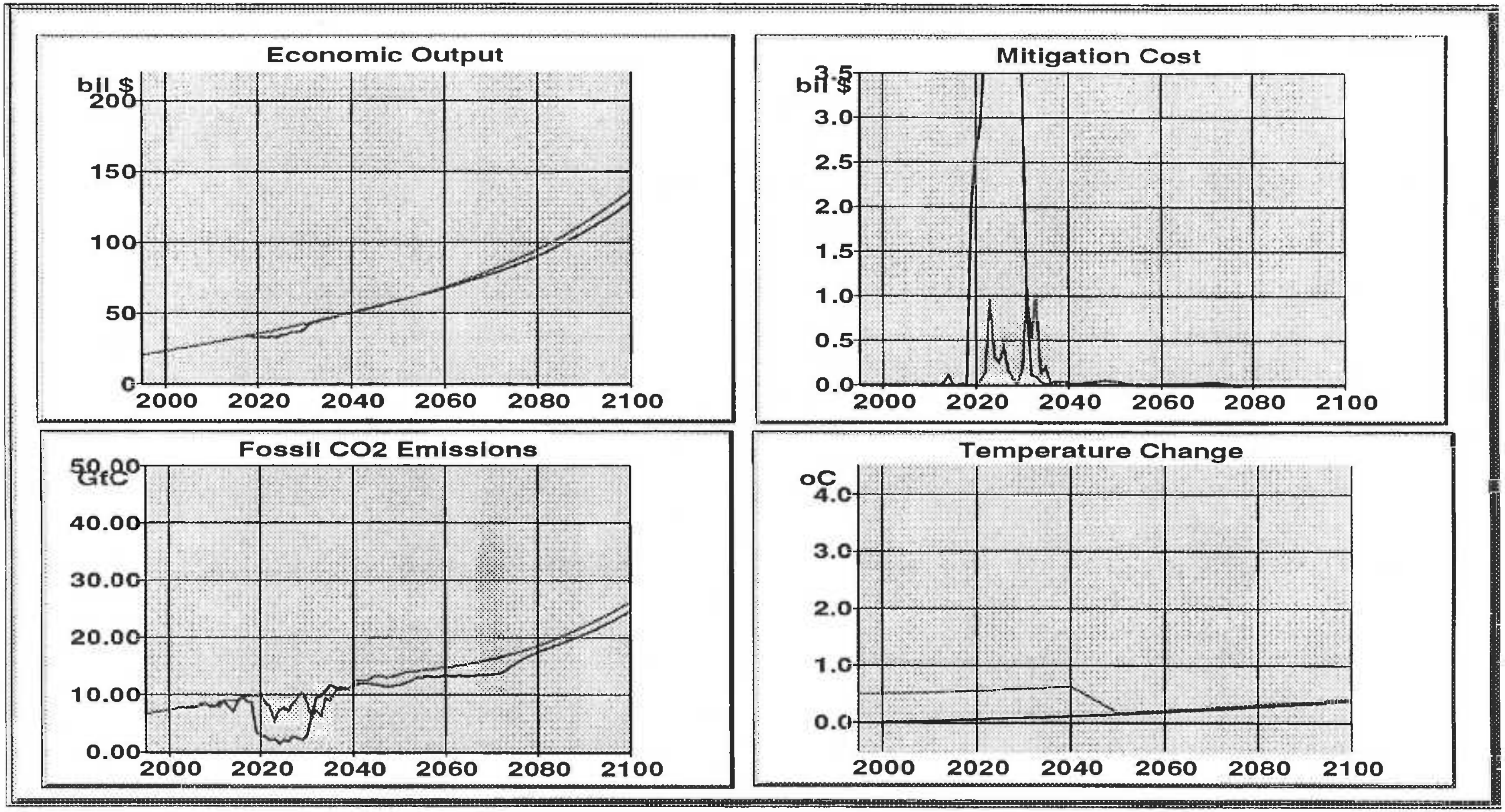

Figure 10a: A warming surprise in a world which functions according to the world view of the individualist, in which the dominating perspective at the start is egalitarian and in which agents do not ignore surprises. (__ = with surprise; .... = without surprise).

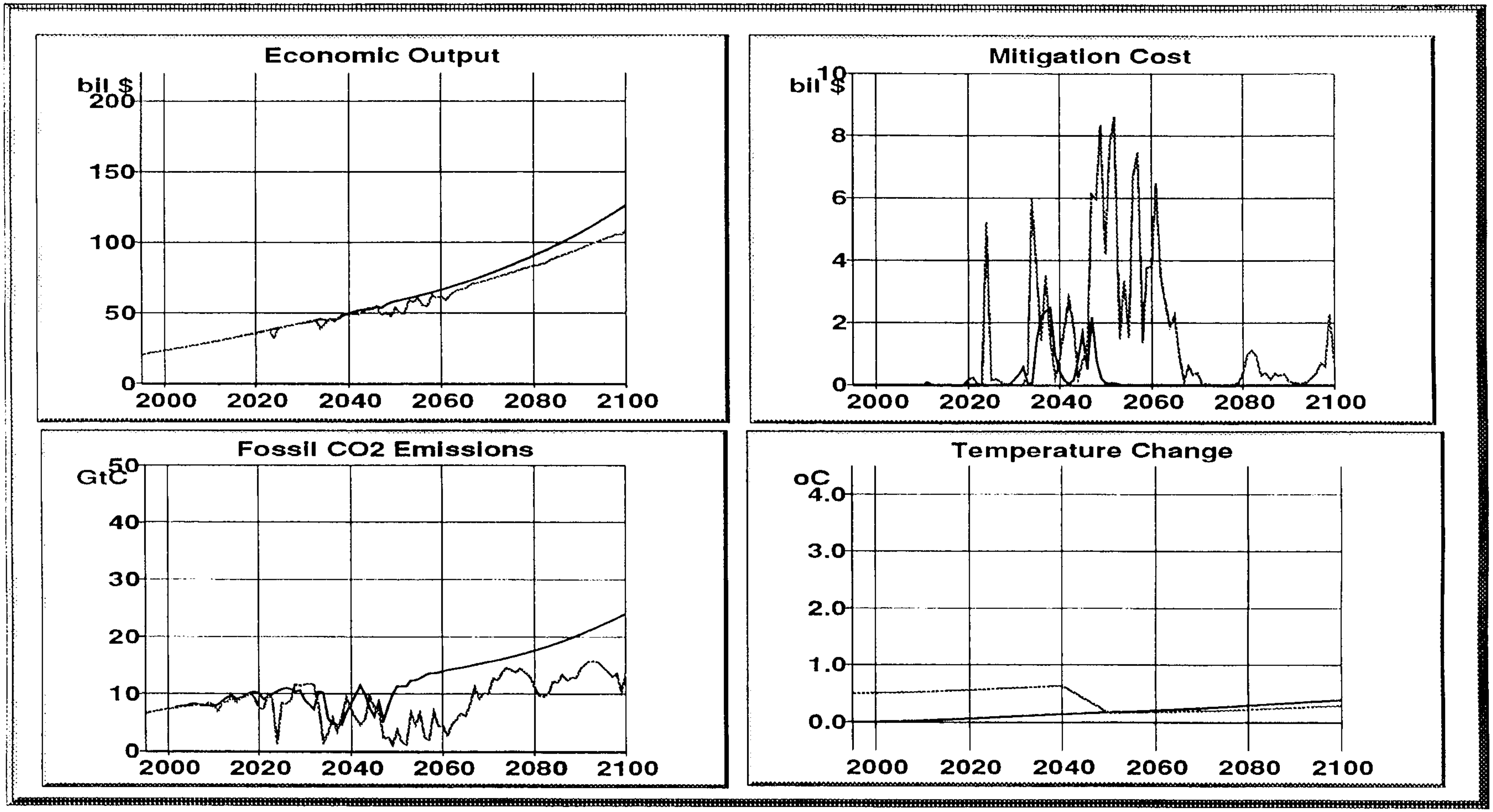

Figure 10b: A warming surprise in a world which functions according to the world view of the individualist, in which the dominating perspective at the start is egalitarian and in which agents largely ignore surprises.
(__ = with surprise; .... = without surprise).

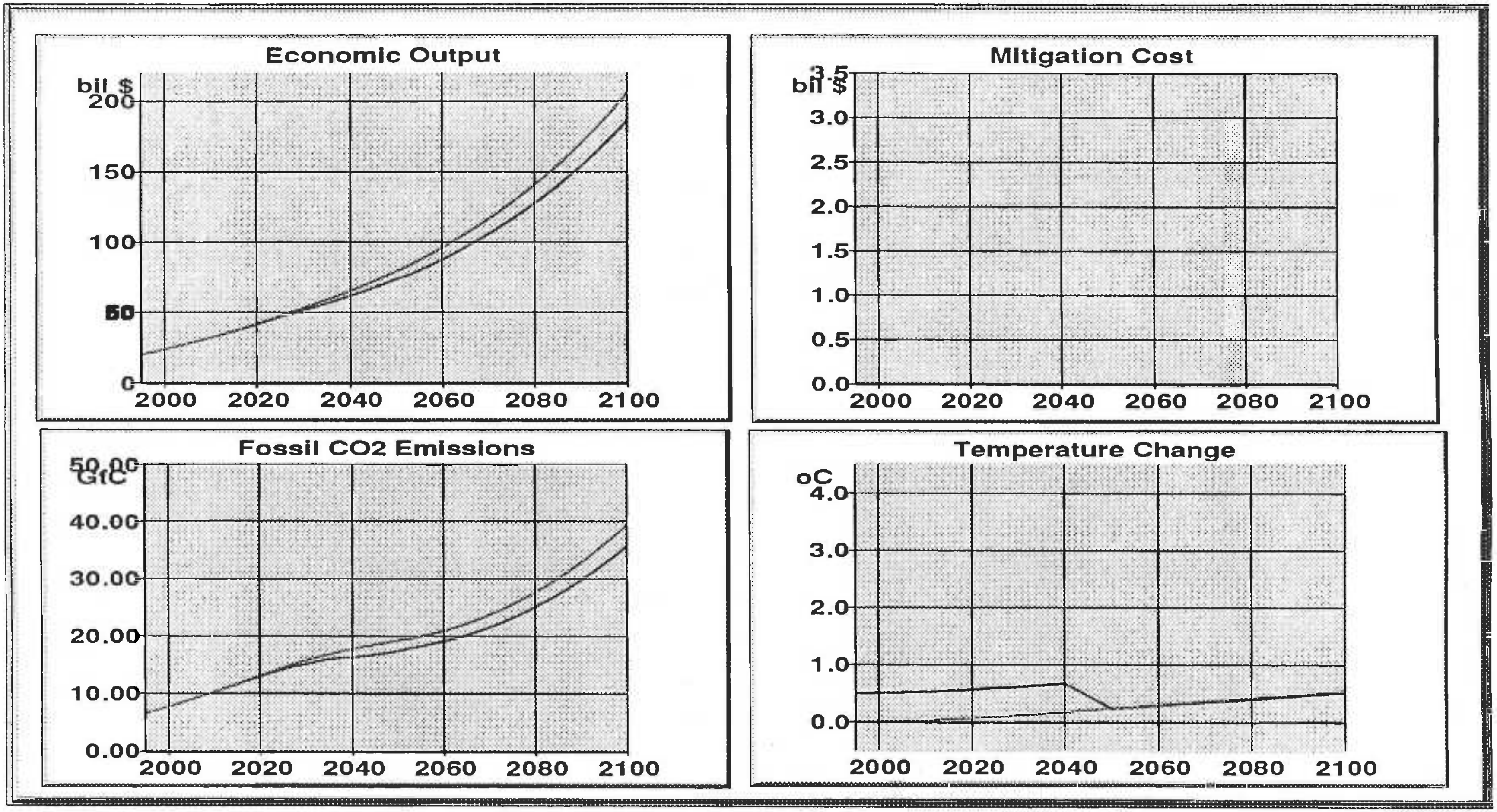

Figure 11a: A warming surprise in a world which functions according to the world view of the individualist, in which the dominating perspective at the start is individualistic and in which agents do not ignore surprises.
(__ = with surprise; .... = without surprise).

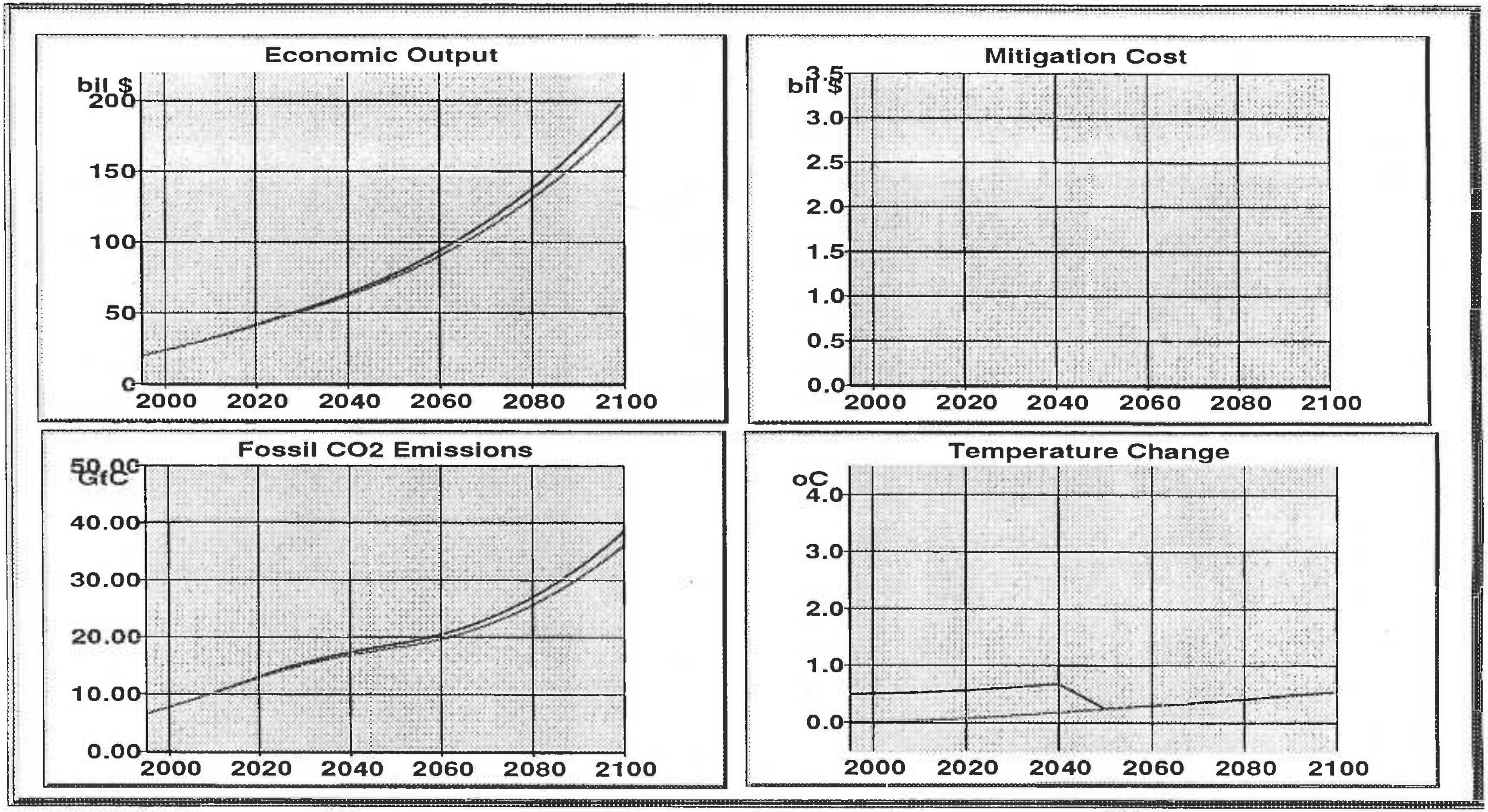

Figure 11b: A warming surpise in a world which functions according to the world view of the individualist, in which the dominating perspective at the start is individualistic and in which agents largely ignore surprises.
(__ = with surprise; .... = without surprise).