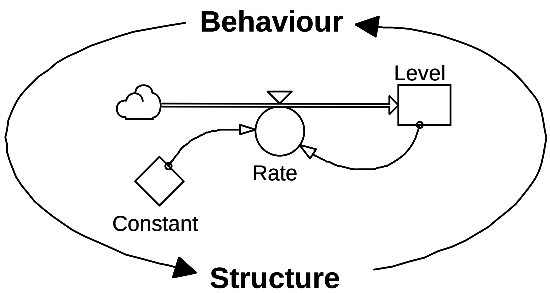
WORKING PAPERS IN SYSTEM DYNAMICS

WPSD 1/05 **ISSN 1503-4860**

The World Model Controversy

by

Magne Myrtveit



The System Dynamics Group

Department of Geography
University of Bergen
P.O. Box 7800, N-5020 Bergen, Norway

The World Model Controversy

in partial fulfilment of Ph.D. requirements
Faculty of Social Sciences, University of Bergen

by

Magne Myrtveit
magne@myrtveit.com

Table of contents

Abstract

In 1971 Jay Forrester published his book *World Dynamics*, where he presented a high-level simulation model of the socio-economic-environmental world system. The main purpose of the model and the accompanying book was to encourage an open debate about the long-term future on our planet. The World Model was created in a time where pollution and other negative effects of industrialization and economic growth started to become recognized. Forrester made the assumption that life on earth is bounded within certain limits, such as available space and resources. Based on this he concluded that exponential economic growth cannot continue forever; sooner or later one or more limits will be reached. The question, then, is how mankind can manage its own future in ways that can avoid an unpleasant encounter with the limits to growth. The Club of Rome, a non-profit research organization, appointed Dennis Meadows, Donella Meadows and others to elaborate on the work initiated by Forrester. The resulting report, *Limits to Growth*, became a bestseller almost over night. Large parts of the established economic community reacted with massive criticism towards the limits to growth ideas, and characterized the work as dooms day prophecies with no basis in observed data and established theories. In this essay I describe system dynamics and econometrics; the scientific home bases of the two sides in the controversy. Based on a theoretical framework developed by Ernan McMullin, I try to categorize the issues that were discussed in the context of the World Model. My findings are that the World Model debate is a *mixed controversy*, involving different views on *facts, theories, principles* and *values*. The controversy has evolved over three decades, and has not ended. The main questions are still relevant and subject to discussion among scientists, politicians, environmentalists, and ordinary people.

1 Introduction

Over the last 20 years I have worked with computer-based modelling as a way to improve decision making processes. In particular, I have worked with simulation technology in connection to complex, dynamic business problems. In the 1980s I started a company that develops system dynamics software, and offers consulting services based on this technology.

Over the years, my customers have taught me that there are many different analytical tools available, and that they can be used alone or together when addressing a given problem. In several of the largest projects I have been involved in, we combined system dynamics and spreadsheet technology in our solutions. From a pragmatic point of view, the marriage between system dynamics software and spreadsheet software has proven to be a fruitful one, in the sense that we managed to deliver working solutions on this platform.

However, system dynamics software and spreadsheet software belong to quite different schools of thought. On one hand we have the field of system dynamics, and on the other hand the field of econometrics[1]. In the early 1970s a deep disagreement started between scientists belonging to the two camps. In connection with sales presentations or discussions over lunch I have experienced that the term "system dynamics" still can make some people quite upset, and others quite sceptical.

The roots of such reactions can be traced back to the World Model[2] created by system dynamics scientists in the early 1970s. In 1971 Prof. Jay W. Forrester published his book *World Dynamics* (Forrester 1973, 2nd ed.). Here he presented a holistic simulation model of the socio-economic-environmental world system, showing the modes of behaviour that can arise from the interactions between the sectors of such a system (Forrester 1974, p.169). As a follow up to Forrester's work, Donella Meadows and others published *Limits to Growth* later the same year (Meadows et al. 1971). *Limits to Growth* was written as a scientific report, initiated by the Club of Rome[3].

Since I am a practitioner in the field of system dynamics, I want to find out more about the critics against system dynamics in general, and the World Model in particular. The questions I address in this essay relate to the controversy between advocates of the system dynamics methodology and advocates of econometrics. What is the controversy actually about? To what extent is it a disagreement about one particular model – the World Model – and to what extent is it a disagreement on a more general level? Is it a *scientific* controversy, or is it just a quarrel among strong personalities? Is the controversy terminated, or does it still exist?

The remainder of this essay is organized along the following lines.

> First, I choose a framework for describing and categorizing the controversy about the World Model.
>
> Methodological questions represent an important source of scientific controversy. The second and third sections are devoted to the system dynamics methodology and the econometric methodology.
>
> In the fourth section I describe the World Model that created the controversy in the 1970s.

---

[1] *Econometrics* literally means 'economic measurement'. (Source: wordiQ.com)

[2] There are actually a number of different versions of the World Model. As the versions do not differ very much, I see no need to separate between them in this essay.

[3] More information about the Club of Rome can be found using the following URL: http://www.clubofrome.org.

The following section contains arguments from the debate. Here I try to link the arguments to the criteria defined in the first section. I will also try to find out whether the controversy is ended.

At the end I have included some final remarks to wrap things up.

2 Scientific Controversy

In his essay, *Scientific controversy and its termination* (McMullin 1987), Ernan McMullin describes the nature of scientific controversy, as opposed to other controversies, such as controversies in ethics and in law. The scientific controversy, says McMullin, concerns itself with disagreement about *facts, theories, principles*, or a combination of these. Controversies in ethics are about *values*, and controversies in law are about *rights*, says McMullin.

McMullin (p. 51-54) gives several necessary criteria for a controversy to be said to be a scientific controversy. The criteria are summarized in Table 1, below.

continuing	The controversy must consist of a *continuing exchange* of argument and counterargument,
open	The controversy must be *open to the public* so others are able to take part,
significant	The controversy must be deemed by the scientific community to be *worth taking seriously*.

Table 1: Criteria of a scientific controversy

This means that a dispute between two scientists is not a scientific controversy until it reaches the public, so the scientific community can assess the arguments and participate in the discussion. The outcome of a scientific controversy does not only depend on the arguments and counterarguments going back and forth between the protagonists, it also depends on the responses in the scientific community, acting more or less as judges in the debate. The third criterion serves to disqualify controversies as scientific, unless the scientific community thinks the controversy is significant and should not be ignored. As an example, if the community believes that a controversy is rooted in incompetence rather than facts, theories or principles, the controversy will not qualify as a scientific controversy.

McMullin describes several kinds of influences on the course of a scientific controversy, summarized in Table 2, below:

	epistemic factors	non-epistemic factors
standard factors	observation reports hypothesis interpretations assumptions criticism responses	
non-standard factors	philosophy world view meta physics theology	personality traits institutional pressure political influences hostility between scientists from different countries “chance” events guesswork

Table 2: Factors determining the course of a scientific controversy

The epistemic[4] factors have to do with the scientific arguments that are used by the protagonists to support their own views or to criticize the view of the opponent.

Standard factors relate to some kind of accepted scientific standard, such as reproducibility of scientific experiments. Hence, all standard factors must be epistemic. (The category standard, non-epistemic factors is therefore empty).

The group of non-epistemic, non-standard factors contains factors that cannot be used as arguments in a scientific controversy. All the same, the course of a controversy can be influenced by such "non-scientific" factors as personal pride, lack of research funding, death, illness, personal relationships, etc.

The non-epistemic, non-standard factors cannot be justified by argument. This is in contrast to the epistemic, non-standard factors, which can indeed be subject to argument and judgement. In general, agreement is more difficult to reach when the factors are non-standard.

The actual disagreement can, again according to McMullin, be grouped in three categories, as described in Table 3.

facts	Disagreement about claims that are made based on observations.
theories[5]	Disagreement about how a problem can be understood or explained.
principles	Disagreement relating to methodology[6] or ontology[7].
mixed	Disagreement involving scientific factors as well as other factors, such as moral or political principles.

Table 3: Categories of scientific controversies

McMullin points out that controversy relating to *facts* are less common in modern science, due to the requirement that observations should be possible to reproduce by independent scientists.

Controversies over *theories* are more common. There is no universal formula for how competing theories should be assessed, other than in cases where enough evidence is accumulated to conclude that one theory stands out as a better explanation of a problem or phenomenon than the competing theory or theories. Until a resolution is possible on the grounds of evidence, McMullin points out that non-standard factors can play a major role in the course of the controversy (Table 2).

Controversies that stem from differences in ontological perspective are very difficult to resolve. McMullin gives as an example the cosmological debate in the 1950s, where the disagreement was based on very different "notion of time, of beginning, and of conservation". He also puts important elements of the controversy over the quantum theory in this category, as the disagreement was to a large extent anchored on opinions relating a deterministic versus stochastic universe.

McMullin claims that methodological controversies are not very common in science. When they do occur, however, they are quite intractable. There is now higher order methodology in science that can be used to arbitrate between conflicting methodologies. Non-epistemic factors are therefore quite likely to get into play in situations like this. The resolution of

---

[4] *Epistemology* is the branch of philosophy that deals with the nature, origin and scope of *knowledge*. (Source: worldiQ.com)

[5] In sciences, a *theory* is a model or framework for understanding. (Source: wordiQ.com)

[6] *Methodology* is sometimes used synonymously with *method,* particularly a complex method or body of methods, rules, and postulates employed by a discipline. (Source: wordiQ.com)

[7] In philosophy, *ontology*, is the most fundamental branch of metaphysics. It is the study of being or existence as well as the basic categories thereof. It has strong implications for the conceptions of reality. (Source: wordiQ.com)

controversies in principle, says McMullin, "is slow, and oblique, and practice oriented" (p. 75). Over the course of time the application of one principle will be likely to take dominance over the competing principle.

The last category in McMullin's list contains mixed controversies. These controversies usually involve the application of science to some human *purpose*. When science is used to create technological solutions to human problems political or ethical issues may surface. As an example, the use of nuclear physics to produce electricity has caused a mixed controversy. Here scientists disagree on the wisdom of a particular *action* and the *relative value* of different human goods, says McMullin. In the case of nuclear power production, there is a trade-off between access to electrical power and preservation of an environment free of dangerous radiation. In particular, possible long-term effects of the use of technology can be an important contribution to mixed controversy. It should not come as a surprise that non-epistemic factors play an important role in mixed controversies.

A scientific controversy exists in time; the controversy begins, lasts for a while, and then it ends. Table 4 summarizes McMullin's description (p. 77f.) of how scientific controversies can end.

resolution	The participants themselves reach agreement.
closure	Authority is used to end the discussion.
abandonment	The participants stop arguing (but they have not agreed on the matter).

Table 4: Ways that scientific controversy can end

The factors involved in *resolution* of a controversy must be of the *standard epistemic* kind (Table 2), at least they must be perceived so by the parties involved in the agreement. There is always a chance of inadequate resolution, says McMullin, if the factors should turn out to be non-standard after all. Resolution does not mean that ultimate knowledge is reached; only that the contesting views at the particular point in time have been sorted out in the favour of one or the other, or that agreement is reached on some middle ground.

According to McMullin, *closure* of a scientific controversy means "the employment of external authority to declare a controversy ended" (p.78). Closure implies that the controversy is ended on the basis of *non-epistemic, non-standard* grounds. The controversy is not resolved; it is brought to an end through the use of power in some form. In this respect closure of scientific controversy bears similarities with the termination of controversy of law. In the case of law, a court or judge has the *power to decide* in favour of one side or the other, closing the controversy. There is no scientific procedure for epistemic *closure* of scientific controversy, however. In cases where some factors are hidden from the public a controversy that ends by closure, may seem to the community to have ended in resolution. Especially in the case of minor controversies closure can play an important role; "a department head, a dissertation director, a funding agency, and a journal editor all have certain limited powers of closure", says McMullin. When closure plays an important factor in the termination of a controversy, resolution is typically not achieved, and the controversy can resurface in some form or another at a later point in time.

The third, and last, way scientific controversies can end is through *abandonment*, says McMullin. The controversy is not resolved, and it is not brought to and end through closure. This happens for example when the community looses interest in a controversy or when the main protagonists no longer fight (they too may loose interest, grow old, or die). The controversy is no longer considered to be *significant* (see Table 1), and it stops being a scientific controversy.

3 System dynamics

System dynamics thought leaders define their field as a paradigm[8] or world view (Meadows 1980, p.24). System dynamics is also a methodology, and it comes with its own technology: system dynamics software.

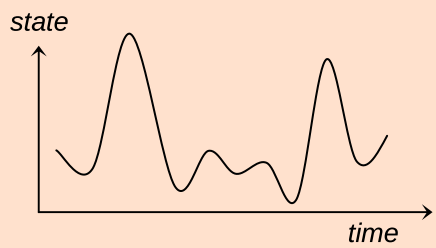
The main purpose of system dynamics is to improve our *general understanding* of a problem, and to identify *working policies* for improving the performance of *systems*.

System Dynamic is *problem oriented* in that researchers in the field study the *reasons* for and possible *solutions* to problems that manifest themselves in systems.

As system dynamics builds on general, mathematical principles, the researcher is quite free to choose which kind of problem to study. System dynamics is mainly used on managed systems, where the role of decision rules (or policies) plays an important role in the performance of the system. Some examples of system dynamics applications are given below:

Supply chain management
Product development
Market dynamics
Design and control of production systems
Fight against the spread of viruses such as HIV.
Drug, alcohol or tobacco addiction
Welfare
Fight against community crime
International conflicts
Protection of the environment

System dynamics can only deal with problems that develop over time. The researcher represents the problem situation in a computer model, consisting of variables. The system state at any time is captured by a set of state variables, called *stocks*[9]. The problem definition is normally stated qualitatively, as the pattern of behaviour displayed when the values of certain key variables (stocks) are plotted against time (see Figure 1). The identification of a working solution is observed in the same way; i.e., as a *more desirable* pattern of behaviour.



The figure to the left illustrates a possible pattern of behaviour for a given stock. The y-axis shows the value of the stock variable, and the x-axis represents point in time. A point on the graph represents the value of the stock at a given point in time.

The problem statement can in this example be related to the high peaks in the stock level. As an example, think of the vertical axis as waiting time in a supply chain. Long waiting times can lead to lost orders, angry customers, stopped production, etc.

Figure 1: A stock's behaviour over time

The state variables (stocks) of a system dynamics model can only change through accumulation or draining processes. Such processes take time in order to have an effect, and this is why system dynamics cannot be applied to static (non-changing) systems. Accumulation is represented as a flow into a stock, whereas drainage is represented as a flow out of a stock. Mathematically, we are dealing with integration processes. But there is a

---

[8] In his book *The Structure of Scientific Revolutions* (Kuhn 1970) the philosopher Thomas Kuhn defines a scientific paradigm as: *What* is to be observed and scrutinized. The kind of *questions* that are supposed to be asked and probed for answers in relation to this subject. *How* these questions are to be put. *How* the results of scientific investigations should be interpreted. (Source: wordiQ.com)

[9] State variables have many names: stocks, levels, accumulators, reservoirs.

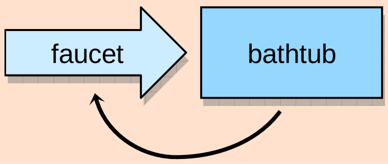
simple metaphor that can be used to explain what is going on in a much more intuitive way; system dynamics looks upon everything as a collection of interconnected bathtubs!

You can think about a system dynamics state variable (stock) as a bath tub. The current level of water represents the value of the stock. When the faucet is open, water pours into the bathtub, and the water level rises. This process represents accumulation, and it is caused by an inflow (through the open faucet).

In the bottom of the bathtub there is a plug. When the plug is open, water escapes out, and the water level decreases. This process represents drainage, and it is caused by an outflow from the stock variable.

Figure 2: The bathtub as a metaphor for stocks and flows in a system dynamics model

The dynamic behaviour (over time) of a system dynamics model is fully determined[10] by the initial states of the stocks and the values of the flows into and out of stocks during simulation of the model on a computer. The process of increasing or decreasing the openings of flows is in general a function of the system stocks. This introduces the concept of feedback into the system, i.e., a change in a variable can in time have an impact upon the variable itself. It is quite easy to illustrate this using our bathtub metaphor.



The figure to the left illustrates the feedback process that takes place when someone fills up a bathtub. The process starts with an empty bathtub and a closed faucet (and the plug installed in the bottom of the bathtub). Then the following phases take place:

1. Person opens faucet.
2. Bathtub fills up (over time) due to positive inflow
3. Person observes water level and closes faucet when desired level is reached. Bathtub stops filling up.

The flow through the faucet influences the state of the bathtub. At the same time information about the state of the bathtub is used to determine the setting of the faucet (open or closed). This illustrates the circular feedback relationship between stock and flow.

Figure 3: Illustration of the circular feedback relationship between stocks and flows

A similar relationship exists between the bathtub and the outflow from the bathtub when the plug is removed. Starting with a bathtub containing water, a person opens the plug. The bathtub starts emptying. After some time there is no more water left, and the outflow stops. (In this case the person does not need to do anything to the outflow in order to make it stop. The draining process stops due to physical laws when the bathtub gets empty. Otherwise, the level in the bathtub would go negative!). It is the responsibility of the modeller to formulate mathematical expressions that mimic the functioning of the real-world counterparts to each flow in the model. The notion of stock and flow is also related to the conservation of mass; it is not permitted in a system dynamics model to let mass appear or disappear other than through explicit flows.

According to system dynamics principles, the stocks and the flows of a system dynamics model should have concrete counterparts in the real-world system that is portrayed. This is important since a major purpose of system dynamics models is to contribute to greater understanding. A model element that does not have a meaningful interpretation in the real system, cannot be used to explain *causes* or identify *solutions* that can be carried over from the abstract modelling world to the concrete real-world system which is studied.

[10] It is possible to include stochastic functions in a System dynamics model. Models can also be influenced by varying external inputs. In these cases the course of a simulation may not be deterministic, or it may not be fully determined by the model equations.

System dynamics focuses on *causes and effects* in models, expressed in terms of interconnected stock and flow structures. As mentioned before, the dynamic behaviour of a model is a function of the initial state of the system and the system structure (the variables and the relationships between the variables).

It is a major point in system dynamics that models should form *closed systems*, as opposed to open systems. The behaviour of a closed system depends on factors that are internal to the system. This is in great contrast to open systems, which rely heavily on choice of values for external factors. In order to be able to reproduce the key characteristics of the behaviour of the system which is studied, the researcher must be open to take a broad perspective on the problem at hand. This puts pressure on the model boundaries, leading in the direction of *holistic perspectives* to problems, and focus of the origins or roots of problems

An entirely closed system has no independent[11] variables. In practice, system dynamics models typically have a relatively small number of independent variables that can be used to study model behaviour under varying conditions, assumptions and alternative decision policies. The time path of exogenous variables are set before starting a simulation "experiment", and are not changed during the simulation. For example, the results of a simulation with different independent inputs can be compared to identify a robust set of decision parameters.

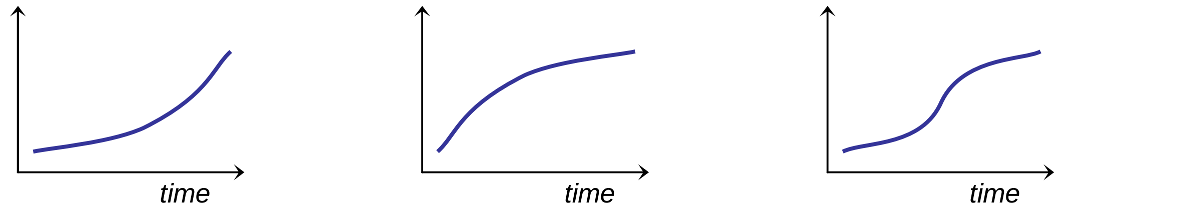
Since system dynamics is mainly about generating overall understanding and identifying causes of and solutions to problems, it is important to manage the complexity of the models that are used in the study. A large and complex model cannot be easily understood, and therefore it will have reduced potential for creating understanding. This implies that a "good" system dynamics model must be small. In order to achieve this objective, researchers are advised to study problems on a high level of aggregation, and to model averages instead of individual elements. As explained above, system dynamics treats change as a continuous process represented using flows. This too leads away from a detailed view on systems. At the lowest level processes may operate on individual objects, but in a system dynamics model objects will be grouped together into "masses" or quantities that can be treated together

A major implication of the averaging and aggregation that is done in most system dynamics models is that the results become less accurate and less detailed. This is not such a big problem to the system dynamics researcher, as the objective of the work is mainly *process oriented*, as opposed to product oriented. This means that the purpose of the modelling exercise is to generate more knowledge. Learning is stimulated through a systematic process where questions are asked, beliefs are challenged, information is collected and shared, hypothesis formulated (as models) and tested iteratively. When the work is complete, there is no need for the model any longer; *learning is the end result*, - not the model.

Although system dynamics can be used to study physical processes and historic patterns of events, its main application has a focus into the future. The perspective is normally long-term, so the researcher can study the development of the problem over time. The methodology stresses the importance of delays and possible side effects of policies, and recommends that problems are studied both in a short-term and a long-term view. System dynamics models often contain elements relating to human behaviour, purpose or activity. This, together with the relatively long time horizon, makes it *impossible to make meaningful predictions*; independent of methodology. Again, accurate predictions and precise results are not part of the purpose behind the model, and therefore not of great concern to the modeller.

[11] In a simplified context like this essay, we can treat the term *exogenous* variable as a synonym for *independent* variable. The antonym *endogenous* variable is used for a *dependent* variable.

How, then, can a system dynamics model represent the qualitative behaviour of a system correctly? The answer given by the practitioners in the field is related to feedback theory. There are essentially two kinds of feedback, reinforcing and balancing. Both kinds of feedback are exponential in nature. An implication of this is that the strongest feedback loop will tend to dominate the mode of system behaviour at any point in time. Dominance can shift from one loop to another during the course of a simulation. A model that captures the dominant feedback loops of a system will be able to reproduce the system's qualitative pattern of behaviour. Figure 4 shows three qualitative behaviour patterns that are common in models (and in reality).



Positive feedback leads to exponential growth, which is a diverging behaviour. The pattern of behaviour is (proportional) to the exponential function e^{+kt}, which doubles[12] its value in time (ln 2)/k.	Negative feedback leads to exponential convergence, which is a "goal-seeking" behaviour. The pattern of behaviour is (proportional) to the exponential function e^{-kt}, which halves its value in time -(ln 2)/k.	When dominance shifts from a positive to a negative loop during the period of study, S-shaped behaviour is created.

Figure 4: Examples of behaviour patterns.

In his book *Business dynamics: systems thinking and modeling for a complex world* (Sterman 2000) John D. Sterman gives a thorough presentation of the underlying theory and methodology, and he also includes many examples of how real-world problems can be cast into system dynamics models. The title of Sterman's book points at a closely related field called Systems Thinking. The bestseller *The Fifth Discipline: the Art and Practice of the Learning Organization* (Senge 1990) by Peter M. Senge describes the use of system archetypes as thinking tools for identifying causes and possible solutions to typical problems. Senge does not use simulation in his book, and he presents no numerical figures. I mention this here, in order to reiterate the important fact that practitioners in the fields of system dynamics and Systems Thinking, do not focus on producing exact results or predictions with their models, but that the main objectives are learning and policy formulation.

In this chapter I have lined out the characteristics of system dynamics, including the kinds of questions (problems) addressed, the methodology which is applied, and the interpretation of the results. The table below contains a summary.

[12] The doubling time d of the exponential function with growth rate k can be computed by solving the equation $e^{k*(t+d)}) / e^{k*t} = 2$. The equation can be expanded to $e^{k*t + kd} / e^{k*t} = 2$, which is the same as: $(e^{k*t} * e^{kd}) / e^{k*t} = 2$. This is the same as $e^{kd} = 2$. We use the natural logarithm on both sides: kd = ln 2. Dividing both sides by k gives us the result: d = (ln 2) / k.

purpose	Generate understanding of causes and effects creating a problem. Identify solutions, in the form of policies, to problems.
scope	Holistic perspective; include all factors that have significant impact on how the problem develops over time. Long-term (relatively speaking); study both short- and long-term consequences. Closed system view (few or no exogenous variables); both source of problem and solution are found within the modelled system itself. Aggregated system view; details are removed through averaging, and sequences of events are grouped into continuous flows.
assumptions	Behaviour can be reproduced from initial state and system structure, without the need for exogenous input. The qualitative behaviour of a system is generated by a relatively low number of feedback loops constructed from interconnected stocks and flows. Conservation of mass.
results	Qualitative (as opposed to quantitative); patterns of behaviour rather than predictions, forecasts or prognosis. Focus is on the process (learning) rather than on the product (model/results).

Table 5: Characteristics of system dynamics

4 Econometrics

Some of the main critics of the World Model come from econometricians. Therefore, knowledge about the nature of econometrics can be useful when trying to understand the controversy that is the topic for this essay. As I am not an econometrician myself, my description below must be considered as a lay-man's attempt to extract relevant information from the field by using readily available sources, such as the Internet. The main purpose of this chapter is to look for characteristics of econometrics that can be used in sorting out the nature of the controversy about the World Model.

According to wordiQ.com, the "two main purposes of econometrics are to give empirical content to economic theory and also to empirically verify economic theory". Econometrics—"economic measurement"—is a *quantitative* methodology, seeking numerical answers to questions. The methodology is mainly *product oriented*, as opposed to process oriented, as the numerical end result is the main outcome of an econometric analysis.

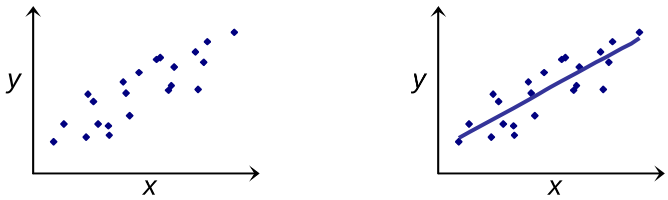
Econometricians base their work on statistical analysis of data. Any given statistical analysis is performed on the basis of a priori assumptions about the kinds of relationships that are assumed to exist within the data. Data in itself cannot be used to determine causality. Therefore the focus of the econometrician is on correlation (as opposed to causality)[13]. (A more modern view on econometrics includes causality within the scope of the discipline). Linear regression is one of the main statistical tools used by econometricians, and serves as an appropriate example here in spite of its simplicity. The underlying assumption of linear regression is that a dependent variable y can be described as a *linear*[14] function of another variable x, which is said to be independent, i.e: $y = a \cdot x + b$, where a and b are constant. The kind of relationship between independent and dependent variables is taken from economic theory. Economic theory typically does not deal with quantification of such relationships; this

[13] In his *Elemements of Econometrics* (Kmenta 1986, p.653), Kmenta writes: "Econometricians as a rule avoid the concept of causality altogether and determine the classification of variables by consideration based on economic theory or on common sense". (I am grateful to Liv Osland for pointing me to this source).

[14] Non-linear regression techniques can be used to investigate non-linear relationships between variables.

is left as an exercise for quantitative methods such as econometrics. This relationship is illustrated in Figure 5:

$$y = a \cdot x + b$$



Step 1: Economic theory is used to derive or postulate the kind of relationship between two variables, x and y. In this example, the relationship is assumed to be linear with slope a and offset b.	Step 2: Data for x an y are collected. Attempts are made to collects pairs of x and y values where the effect of other variables that can influence y is kept to a minimum.	Step 3. Regression analysis is used to determine the slope of the curve (a) and offset (b) and to test H0: a=0 and/or b=0.

Figure 5: Typical steps of an econometrical analysis.

A simple example[15] of a simple, linear model in economic theory is the following

'personal spending' = 'inclination to spend' · 'personal income' + 'error term'

The above model says that a person spends a fraction of his or her personal income. The fraction can be estimated by collecting data about spending and income in a population. Based on this, it can be possible to compare spending ratios across population groups and countries, for example.

If two variables A and B are correlated, this can have several reasons:

1. A causes B
2. B causes A
3. A and B are independent, with a common cause C
4. A and B are interdependent

The three first cases describe one-way causality. In the third case there is no causal relationship between A and B, either way; the reason for the correlation is linked to the fact that both variables depend on a third variable, C. The fourth case represents a structure where both A and B are part of the same (feedback) loop. In econometrics such relationships are modelled using simultaneous equations that compute the *equilibrium* state.

An econometric analysis is performed in the context of economic theory, and it may involve implicit or explicit *a priori assumptions about cause-and-effect* relationships that can explain correlations in the observed data. The statistical analyses applied as part of the econometrician's toolbox are not suited for *determining* causality, however. Therefore, an econometrician does not explain *why* something happens, only *that* it happens, and under what *circumstances*. The question if the reason for a correlation between A and B is 1, 2, 3 or 4 in the above list is therefore not really addressed in econometrics. The *researcher* may have opinions about the direction of causality, and economic *theory* may involve causality, but econometrical *data* analysis cannot uncover causality.

As already mentioned, a researcher in the field of econometrics does not aim at identifying the causal structures which are at work when a correlation is measured. It is important, however, to define the circumstances under which the correlation takes place. In econometric research it is important to keep control over external factors that can influence the results. In an ideal situation the researcher changes one variable and observes the effect on another variable while

[15] The example is adopted from www.wordiq.com/definition/econometrics.

holding all other variables constant. This is called the *ceretis paribus*[16] clause. In economic theory the laws of supply and demand can be used in formulating predictions, under the assumption that all other factors that might influence the market situation, are inactive. As an example, if the price of cars goes down, more cars will be sold, *assuming all other factors that can influence car sales stay the same*. This assumption is necessary in order to make the prediction about increased sales; one must rule out effects that could cause a different result. Examples of such effects can be increased prices on gasoline or car insurances, increase in unemployment, restrictions on the use of cars, age of existing cares (such as during the oil crisis in 1973), etc.

The use of statistical methods to establish correlations relies heavily on the availability and quality of data. Without data, econometrics would be impossible. In econometric research it is typically not possible to conduct controlled experiments, as the variables involved are beyond the control of the researcher. To compensate for this difficulty, econometrics has stimulated to systematic collection of all kinds of data relating to the social and economic development of countries. These sources of data are invaluable resources that can be used by many different kinds of socio-economic modelling disciplines, including system dynamics.

In the system dynamics paradigm, there is a requirement that the *structure* of the problem stays the same in order for the qualitative "prediction" to hold. This is a much weaker assumption than the ceretis paribus assumption in economics.

Economists are aware that economic data only tell something about the period in time the data were collected from, and that projections based on historical data can generally not be carried far into the future.[17]

Econometrics has a reductionist[18] perspective when compared to the holistic[19] approach that system dynamics uses. I base this claim on the fact that econometric theory deals with the effect that (one or) a few number of independent variables has on (one or) a few dependent variables, under the assumption that all other independent variables that can have an influence on the dependent variables remain unchanged.

The same argument leads to the conclusion that econometric models are *open models* in the sense that only a small part of the problem is captured by the models themselves, and that all other aspects are kept outside the model in the form of exogenous (independent) variables.

Econometric models based on regression analysis cannot take into account issues like *conservation of mass*, overflow or underflow in reservoirs. This is not a problem if a system is studied in states that are at safe distance from extreme values, and if predictions are made only for relatively short distances into the future. Over a long time horizon, however, conservation of mass can be a critical factor in understanding the behaviour of the system. As an example, a model that does not account properly for the accumulation of industrial waste will not be able to expose the hazards relating to increased levels of pollution.[20]

---

[16] Ceteris paribus is a Latin phrase, literally translated as "other things the same," and usually rendered in English as "all other things being equal." (Source: wordiQ.com)

[17] In the book *Causality in Economics* (Hicks 1979, p.38) John R. Hicks writes: "All economic data are dated, so that inductive evidence can never do more than establish a relation which appears to hold within the period to which the data refer". (Again, I want to thank Liv Osland for making me aware of this source).

[18] Methodological *reductionism* is the idea that explanations of things, such as scientific explanations, ought to be continually reduced to the very simplest entities possible. (Source: wordiQ.com)

[19] The denial of reductionist ideas is *holism*; the idea that things can have properties as a whole that are not explainable from the properties of their parts. (Source: wordiQ.com)

[20] In *Cloudy Skies: Assessing Public Understanding of Global Warming* (Sterman and Sweeney 2002) the authors point out that "in his widely cited DICE model, Nordhaus (1992a, 1992b) violates the law of

The influence of econometrics on the development of econometric theory is in the direction of *simplified economic models* (theories). The danger here is that theories get simplified to an extent where they only capture small fragments of the real-world problems they address. The focus on *correlation and prognosis* within econometrics can also influence economic theory development to focus on *measuring* behaviour at the expense of work on *explaining* behaviour.

The buzzword of our time is "globalization". It implies that continents, countries and people get more and more interconnected and interdependent. Today, more than 30 years after the first World Model debate, there is probably a greater need for holistic world models than ever before. In his book *Globalization and its discontents* (Stiglitz 2002) Joseph Stieglitz, winner of the Nobel Prize for economics in 2001, stresses the need for better models for understanding and planning world development.

> "Assessing how a particular policy is likely to affect the general interest requires a model, a view of how the entire system works." (p. 217)

In his book Stieglitz gives many examples of failed economic policies, based on over simplified economic models.

The table below contains a summary of the characteristics of econometrics, discussed above:

purpose	To give empirical content to economic theory. To empirically verify economic theory.
scope	Reductionist perspective; focus on a small number of variables and keep the remaining variables constant. Short-term perspective in forecasting. Often disconnected from time (in the case of equilibrium models) Open system view (many exogenous variables). High level of aggregation.
assumptions	Builds on economic theory about the nature (e.g., linear) of given economic relationships. Results are based on correlations identified within data.
results	Quantitative prediction. Determination of the equilibrium state. Main focus is on the product (i.e. estimates and hypotheses tests).

Table 6: Characteristics of econometrics

5 The World Model

In this chapter I will describe the World Model that is at the heart of the controversy discussed in this essay. Jay W. Forrester presented the first version of the World Model in his book *World Dynamics* (Forrester 1973, 2nd ed.), and the year after the best-selling[21] *The Limits to Growth* (Meadows et al. 1971) was published. A number of versions of the World Model have been created, and researchers still refine the models based on recent developments and new understanding. See for example (Saeed 1998).

It is beyond the scope of this essay to go much detail regarding the World Model. Instead, I will focus on the purpose, assumptions, and conclusions presented by the authors of the model. In the following chapter I will cover some of the controversy around the model.

conservation of mass by assuming a significant fraction of carbon emissions simply disappear (Nordhaus assumed these emissions flow into a limitless sink outside the model boundary)".

[21] *The Limits to Growth* sold 12 million copies in 37 languages (source: Keith Suter)

In the foreword to his book (Forrester 1973, p.ix) Forrester points out that most research is focused on "separate facets of the world system". The purpose of the world model is to show "how the behavior of the world system results from mutual interplay between its demographic, industrial, and agricultural subsystems". An important motivation for the work is stated like this:

> "many persons are coming to believe that the interactions within the whole are more important than the sum of the separate parts".

The figure below shows the sub-systems that are considered in the World Model. The arrows indicate how "everything is connected to everything"[22].

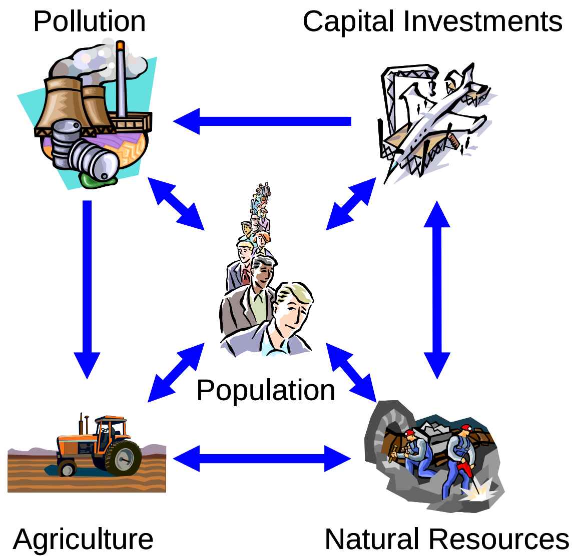


Figure 6: Sectors of the World Model

In the preface of his book Forrester states the purpose of the model:

> "The model … was devised … as a basis for discussion ... It must be considered a preliminary effort. But all models will be tentative, for new insights will continue to appear." (Forrester 1973, p.x)

Forrester reiterates his purpose of creating a better understanding through the modelling exercise:

> "By proposal and counter proposition our understanding of social systems can advance".

Therefore, Forrester encourages others to present a better model of the world system.

When Forrester talks about the scope of the model, his focus is on "broad aspects of the world system" (p.xi) and not on "implementing the changes that will be necessary" to alter the present course of events. Many details are left out, says Forrester, for example:

> "Many important variables are omitted."
>
> "Aggregation is at such a high level that the distinctions between developed and underdeveloped countries do not appear explicitly."

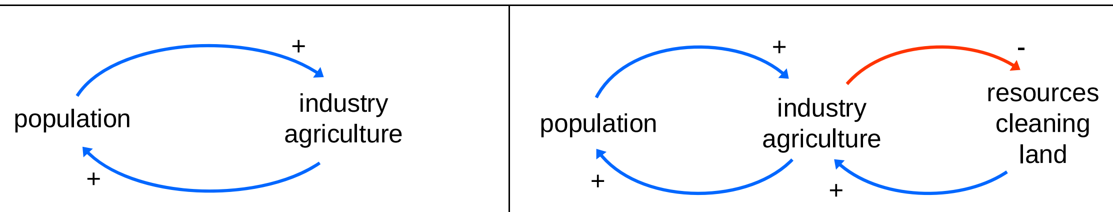
[22]This expression is borrowed from Barry Commoner, who in his book *The Closing Circle: Nature, Man and Technology* (Commoner 1971) writes: "There are Four Laws of Ecology… Everything Is Connected To Everything Else, Everything Must Go Somewhere, Nature Knows Best and There Is No Such Thing as a Free Lunch." Norway's Prime Minister, Gro Harlem Bruntland, used the same expression when she was leader of *United Nations Commission on Environment and Development* in 1987.

Forrester expects that new knowledge and understanding (including learning from the World Model) can alter the decision making of mankind, leading to a different course of events than those described by the World Model. Such consequences are not included in the model.

> "Therefore the book does not incorporate the possible changes in human aspirations and values that might come from widespread recognition of the predicament facing mankind". (Forrester 1973, p.ix)

The main assumption in the model is that exponential growth cannot continue forever. Exponential growth implies a constant doubling time. In all real systems, there will be limits, and when a system state approaches its limit, stress takes place in the system. These stress forces may not be very noticeable until the system gets near its limits. But ultimately system behaviour will be forced to depart from its exponential growth curve.

The short version of the scenario that is created in the World Model is that population growth takes part in a reinforcing feedback loop, and that exponentially growing population, industry and agriculture puts more and more stress on remaining land, remaining natural resources, and the environment (remaining clean air, water, and soil).



<u>Growth</u>: Population, industrialization, and agriculture form a positive feedback loop, creating exponential growth. (Plus means positive influence. Minus means negative influence. A loop with an even number of minuses stimulates growth. A loop with an odd number of minuses limits growth.)	<u>Stress</u>: Population, industry and agriculture generate pollution. As the cleaning capacity of the earth is limited, the pollution density will increase at some point, reducing further population growth. Population, industry and agriculture use limited land and resources, which in the long run will prevent further growth.
Note: The above causal-loop-diagrams are simplifications made by the author on the basis of the stock-and-flow structures of the World Model. Consult the referenced sources for complete diagrams and models.	

Figure 7: Two phases of the World Model: Growth and Stress

The World Model tries to represent the important limits of the world system, and how exponential growth eventually will push up against one or more of the limits. The model opens up for several alternatives when it comes to identifying the first limit that will stop net growth in the population. It can be any one of the following:

resource	comment
resources	Insufficient natural resources or energy.
environment	Insufficient cleaning of industrial, agricultural and residential waste (related to limited area of land and limited volume of water and air).
space	Insufficient space for industry, agriculture, roads, homes, recreation, etc.
food	Food production is limited by reduced available land for agriculture, and can be further degraded due to pollution.
other	"some other equally powerful force"

Table 7: Physical Limits that world growth can run up against

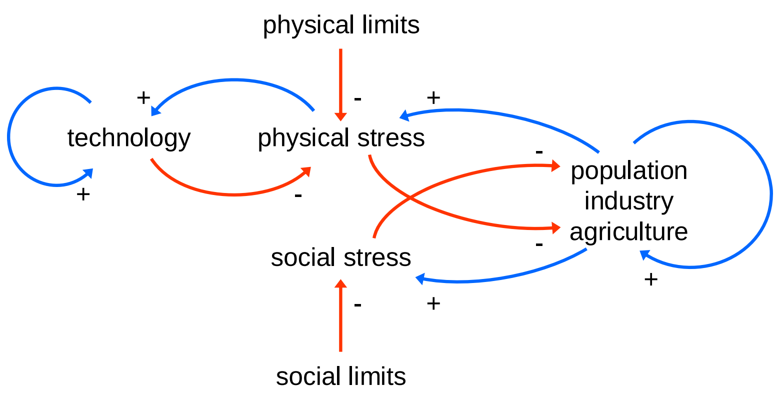
The last item in the above list is quite interesting, as it shows that the authors of the World Model are open to many different kinds of limits, and that some of the limits may not even be present in the then current version of the model. Forrester is open for scenarios where growth does not reach any of the limits, but this will then have to do with factors such as "persuasion and psychological factors" (Forrester 1973, p.ix) such as "self restraint" (Forrester 1973, p.130).

In the second edition of World Dynamics, Forrester adds a chapter about physical versus social limits. Technology serves as a means of increasing the physical limits, but the limits cannot be removed, says Forrester, and social stress continues to increase as the population grows. Below is a summary of social stress symptoms mentioned by Forrester.

symptom	comment
(risk of) atomic war	Risk increases when countries are brought to the breaking point.
aircraft highjackings	
political kidnappings	
riots	
political frustration	
intergroup conflicts	
political control	

Table 8: Some symptoms of stress related to social limits

The figure below is a simplified causal-loop-version of Forrester's model fragment showing the role that technology can have in reducing physical stress, thus allowing for more growth, which in turn can shift the stress over to social factors.



Society is limited by physical and social limits. Technology can lead to better utilization of physical resources, and therefore reduce physical stress for a given state of the world system.

However, when the physical stress is relieved, more growth is stimulated. This increases social stress, which can then become the limiting factor for growth.

An alternative to running up against the limits is to apply self-restraining policies that switch the development from growth to equilibrium. (This part is not show in the simplified figure above).

Figure 8: Two phases of the World Model: Growth and Stress

Forrester claims that the traditional ways to deal with physical and social stress (Table 9) are insufficient in the long run.

traditional solution	comment
migration	There are fewer and fewer areas available to migrate into.
expansion	Same as above.
economic growth	Can reduce physical stress, but arguably creates social stress.
technology	Can move limits, but not remove them. See also social limits.

Table 9: Traditional ways to release growth related stress in the world system

The main message of the World Model, and of the books describing the model, is that the world economy should be managed towards a state of sustainable equilibrium. It is also claimed that quality of life near the physical or social limits, is far from comfortable (see

Table 7 and Table 8). Therefore, efforts should be made to level off the growth before the limits push the growth back forcefully.

There are many paths towards this state, some more favourable than others. Part of the message is that the present (i.e., 1970s) actions, attitudes, and policies do not represent a smooth transition from growth towards equilibrium.

The simulation results of the World Model are based on "statements, observations, and assumptions" about the world system. All assumptions in the model are described in detail in (Forrester 1973, ch.3, p.31ff). This is an important element of Forrester's purpose to invite others to criticize the model and suggest improvements. A computer model makes the theory unambiguous and the assumptions visible.

> "The assumptions can then be criticised. They can be compared with the assumptions in alternative proposed theories. Data and observations can be used to improve the assumptions." (Forrester 1973, p.31)

The World Model can show a variety of different developments, depending on the *policies* that are chosen for the future (Forrester 1973, p.ix). Another determining factor is the future development in *science*. Science may find ways (i.e., technology) to use more plentiful metals (substitution) and to increase our sources of energy, so that shortage of resources does not occur (Forrester 1973, p.ix). This may seem like good news, but according to Forrester, there are other limits waiting around the corner, such as pollution of social stress.

6 The World Model controversy

I will now return to the subject of scientific controversy, and make an attempt to link the various aspects of the World Model controversy to the criteria, factors, and categories described in the chapter Scientific Controversy (starting on page 3). The first question I will address is the following;

> *Is the World Model controversy a scientific controversy?*

McMullin's criteria for scientific controversy are summarized in Table 1, p. 3. The first criterion is that a scientific controversy must consist of *continuing* exchange of argument and counterargument. It is quite easy to find historical records showing that such an exchange took place in the 1970s. The discussion did not end in the 1970s, as new books and reports were published in the debate many years to follow. One thread of discussion is the following:

year	publication
1971	World Dynamics (Forrester 1971) Limits to Growth (Meadows et al. 1971)
1972	On Criticisms on World Dynamics (Forrester 1972)
1973	World Dynamics, 2nd edition (Forrester 1973)
1973	World Dynamics: Measurement Without Data (Nordhaus 1973)
1974	The Debate on World Dynamics: A Response to Nordhaus (Forrester 1974)
1992	Beyond the limits: confronting global collapse, envisioning a sustainable future (Meadows, Meadows, and Randers 1992)
1992	Lethal Model 2: The Limits to Growth Revisited (Nordhaus 1992)
1998	Towards Sustainable Development: Essays on System Analysis of National Policy (Saeed 1998)
2003	Prophecy de Novo: The Nearly Self-Fulfilling Doomsday Forecast (Marxsen 2003)

Table 10: Some of the books and reports published in the World Model debate

Based on this, we can safely conclude that "our" controversy satisfies the first criterion of continuity.

In his *Lethal Model 2* paper (Nordhaus 1992, p.50ff.) Nordhaus has gathered support from "the community" in that Martin L. Weizman is invited to fill the last 10 pages of the paper with his support. Weizman starts out as a good supporter should: "This is an outstanding paper…" Our controversy clearly satisfies McMullin's second criterion, which states that the discussion must be open to the public.

The third and final criterion has to do with the reaction of the community; is the matter considered to be an important one? The World Model created massive interest. A large number of copies were sold, especially of *Limits to Growth*. Journalists as well as scientists within different fields jumped to their typewriters to report, argue and counter argue on the model itself, the approaches taken by the authors of the model, and most of all: the implications, policy recommendation, and future scenarios that were painted. It is therefore clear that also the third criterion in McMullin's list is satisfied.

Hence, the controversy over the World Model is a scientific controversy.

I will now turn to the contents of the controversy. It is not my intention to evaluate the arguments or judge between the different views. Instead, I will apply McMullin's categorization (see Table 3, p. 4) on the arguments, and try to find out if the controversy is about *facts, theories, principles, values* or a combination of these.

I have limited my study to a few sources in order to keep the discussion within a manageable number of pages. There is a danger that I have missed some important arguments by doing this. In this essay I am merely interested in the *kinds of arguments* that are used. Therefore, there is really no need to investigate all the different instances of arguments that have been used by different people at different stages of the debate.

The World Model discussion is a discussion about the future on this planet. This is obviously a topic loaded with many of the *non-standard* factors described by McMullin (see Table 2, p. 3). In these areas scientific argument cannot be used, and the proponents and opponents fall back on rhetoric[23] writing. As an example, Forrester seems to anticipate that opponents will attempt to criticize his work by associating the Wold Model with the work of Malthus (Malthus 1798). Therefore, Forrester points out that he is aware of Malthus, and he explains Malthus' view that food supply represents "one ultimate barrier to unending population expansion … is not erroneous; it is merely incomplete". Sure enough, in (Nordhaus 1973) Nordhaus starts his first sentence by referring to Malthus. Malthus did not predict the effect of the industrial revolution on food production and the effects of higher standards of living on the number of children per family, says Nordhaus. According to Nordhaus, the World Model is "in the spirit of Malthus" (p.1157).

The World Model is formulated as a formal model (theory) that can be simulated on a computer. Researchers in the field of system dynamics advocate many benefits from this approach, and Nordhaus too sees some benefits.

[23] *Rhetoric* (from Greek ρητωρ, rhêtôr, "orator") […] Rhetoric can describe a persuasive way in which one relates a theme or idea in an effort to convince. (Source: www.wordiQ.com)

Meadow's list of benefits of a simulation models versus a mental model (Meadows 1980, p.27)	Nordhaus' also mentions some benefits of a simulation models (Nordhaus 1973, p.1157)
It is precise and rigorous instead of ambiguous and unquantified.	It has greater speed and precision (than that of the human mind).
It is explicit and can be examined by critics for inconsistency or error.	If assumptions about functional forms and the data are accurate, simulations will lead to accurate predictions.
It can contain much more information than any single mental model.	
It can proceed from assumptions to conclusions in a logical, error-free manner.	
It can easily be altered to represent different assumptions or alternate policies.	

Table 11: Both sides see some benefits of simulation models

The World Model looks into the far future, and it takes a holistic perspective on the world system, connecting sub-sectors in an interdependent network. On page 12 we saw that econometricians point out that "data are dated", i.e., data about economic and social systems cannot be used to describe relationships or make predictions far into the future.

In the case of the world system, there were (1970) probably large gaps in historical and present data about relationships within and between sub-sectors of the world system. And even to the extent that such data existed, econometricians would warn that such data cannot be used safely for long-term projections into the future. Economic theory typically produces qualitative results in the form of mathematical relationships between variables at a very high level of aggregation. When it comes to concrete values, econometrics steps in. But as we have seen, econometricians point out that quality data is needed to measure, and the relationships found in the data are reliable only for relatively short periods of time.

It seems to be a fact, acknowledged by econometricians, that current econometric methodology is unable to say anything reliable about the long-term development of the world system. Econometricians obviously have their views on these matters, as we all have, but we are then talking of *non-standard* factors belonging to personal or scientific *world view*.

System Dynamicists, on the other hand, do think they can say something valid about the future, even when little data is available. They base this on the fundamental belief that characteristic behaviour stems from the structure of the system, and that the behaviour of even large systems, is controlled by a small number of dominant structures (feedback loops). The opinions about purpose of simulation models and the usefulness of the results also differ much between the system dynamics group and the econometricians:

Meadows' perspective (Meadows 1980)	Nordhaus' perspective (Nordhaus 1973)
Quantitative precision is unnecessary and probably unattainable (in relation to models that can contribute to general understanding of the long-term behaviour of complex systems) The primary assumption on the system dynamics paradigm is that the persistent dynamic tendencies of any complex system arise from its causal structure.	Simulation models based on purely hypothetical functional relationships and contrived data which have not been subjected to empirical validation are *void of meaning* … such a model contributes nothing to the understanding of the system being simulated.
System Dynamicists are generally unconcerned with precise numerical values of system variables in specific years. They are much more interested in general dynamic tendencies.	Without an accurate model there is no assurance that systems dynamics is better than mental models; the main result is spurious and misleading precision.

Table 12: Different views on purpose and validity of simulation models

The statements above point out two fundamental disagreements, which are independent of any particular model (such as the World Model). The first disagreement has to do with purpose (generate understanding versus make predictions). The second disagreement has to do with model validation (validation based on structure (prior data) versus validation based on data).

This kind of disagreement belongs to McMullin's category of principles. Again, we are dealing with *non-standard* factors. Such factors are difficult to resolve since they have to do with choice of problem and competing methodologies/paradigms.

Nordhaus (p. 1158) also makes a point out of criticising the terminology that Forrester uses in his book. "I will use standard economic terminology rather than Forrester's vague and often confusing appellations". As an example, Nordhaus mentions that economists uses the term "Stock of pollution" where Forrester just says "Pollution". This may seem like a minor point, but I use it to illustrate two things. First, it illustrates how language can be used to hint that the other part in the controversy is incompetent; he or she does not even know the right names for things. The other, and more important point, is that researchers from different fields can have great difficulties in communicating because of different (implicit) assumptions about terminology. In the case of "Pollution", a system dynamicists like Forrester uses a separate graphical symbol for stocks. The stock shape of a variable immediately makes it clear that one deals with a stock variable, and it is therefore not necessary (useful) to add "Stock of " as a prefix to the name. Economy uses a non-graphical modelling language (mathematical equations), where the distinction between stock and non-stock must be made explicit in the text (or in the variable name). So, when Nordhaus criticizes Forrester for his "non standard" terminology, he is actually criticizing him for being in the wrong field.

In addition to the factors relating to principle, there is also a discussion around the actual assumptions, relationships and results of the World Model. Below is a short summary of the critique raised by Nordhaus and the response to these from Forrester.

6.1 The population sector

Nordhaus' first point is about the population sector. His claim is that the World Model displays a behaviour that is counter to cross-sectional data and time series data:

> "[Forrester's] assumptions imply that affluent countries grow fast and poor countries decline, while exactly the opposite is seen in the data".

Using McMullin's terminology, the above claim is an epistemic, standard factor relating to the hypothesis and assumptions in the World Model. The disagreement is not about facts (data), but the theory (equations and parameters) of the World Model and the relationship between the observed world and the results of the simulation.

On page 4 scientific disagreements were grouped into disagreements about *facts*, *theories*, or *principles*, in addition to *mixed* controversies, which cover different views relating to values, ethics, politics, etc. The disagreement about the population sector of the World Model belongs to the *theory category* of scientific controversy.

Forrester's response is that cross-sectional and time series population data from the real world are the result of many factors that influence population growth, such as standard of living, crowding, food, pollution, etc. In his analysis of the population sector in the World Model Nordhaus did not use the entire model. Instead he disconnected a few variables from the model, translated it to econometric form and computed the behaviour under the *ceteris paribus* assumption, i.e., that all other variables stay constant. This assumption is not true in the real world, and it is not the case in the World Model.

Therefore, Nordhaus did not test the World Model; he tested a disconnected piece of the model in a static environment. Forrester continues by running Nordhaus' analysis on the entire World Model, and shows results that are in line with the data Nordhaus refers to.

> "In fact, the data Nordhaus provides lend support to the model and, …, should increase confidence in the model.", concludes Forrester (Forrester 1974, p.177)

Figure 9 on page 22 shows Nordhaus' model and analysis (left) compared with Forrester's model and analysis (right).

It is interesting to see how the same data and the same model can lead to so widely different conclusions. When Nordhaus presents his data together with his own, simplified version of Forrester's model, there is a big discrepancy between observation (data) and theory (isolated model sub sector), as displayed at the bottom, left corner of Figure 9. When Forrester adjusts the assumptions of his World Model from world averages to US conditions, and uses the full model to simulate the results, a good match is found between data and theory (World Model).

Nordhaus follows his econometric paradigm, and studies an isolated part of the system under ceteris paribus conditions, and observes great discrepancies with the reality. Forrester follows his holistic system dynamics paradigm, and studies the whole system, achieving a close match between model and reality. Forrester takes this as a strong evidence of the power of his methodology, pointing out that no structural changes were necessary in order to change the "World Model" into a "US Model" (only parameter changes, such as population, had to be changed).

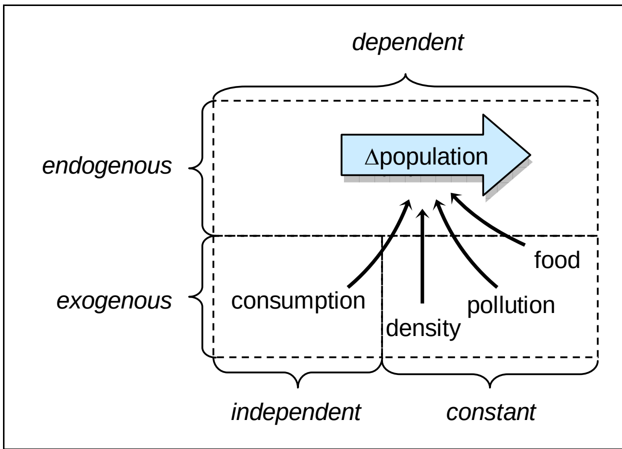
So, why is Nordhaus using his own version of Forrester's model instead of analyzing the full World Model[24]? There is no reason to believe that Nordhaus willingly misrepresents Forrester's model. It is more likely that econometric tools are not suited for analyzing holistic, dynamic models like the World Model. When our tools are not fit for the problem, it is only natural that we try to adopt the problem to the tools. (If you can't bring the mountain to Mohammed then, bring Mohammed to the mountain.)

The way Nordhaus addresses the testing and analysis of the World Model, points at two important limitations with econometrics in dealing with dynamic systems:

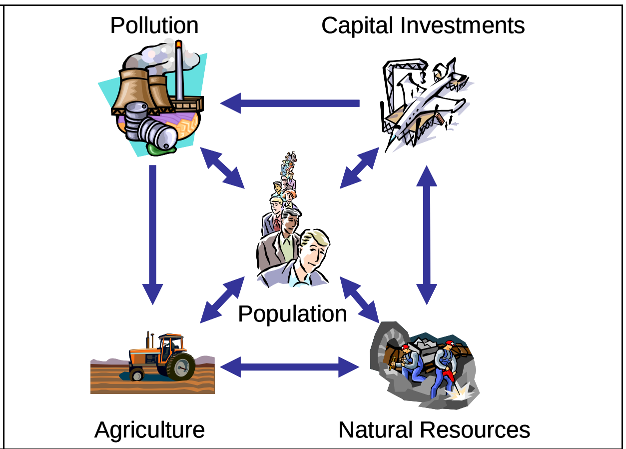
---

[24] In (Nordhaus 1973) Nordhaus devotes a chapter to sensitivity analysis. But he does not perform the analysis on Forrester's model. Instead, Nordhaus creates a new (simplified) model, where many of the feedback loops are removed. This model is unable to reproduce history as well as Forrester's model, and it is much more sensitive to changes in the assumptions.

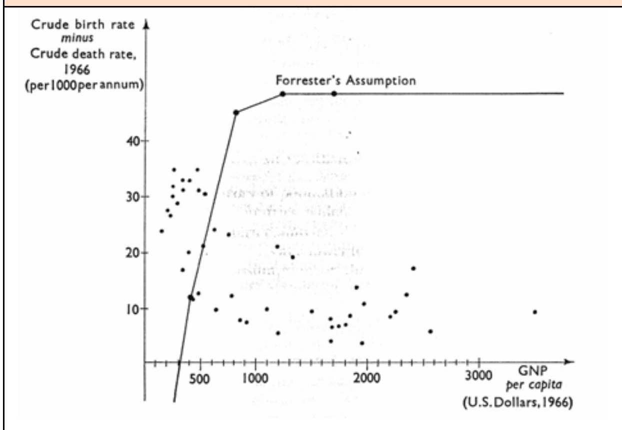
1. The World Model *could not be analyzed* using traditional econometric tools. Therefore Nordhaus transformed the model into another (simplified) form.
2. The World Model *could not be translated* into traditional econometric form. Therefore Nordhaus' analysis of the transformed model produced dramatically different results than Forrester's analysis of the full World Model.



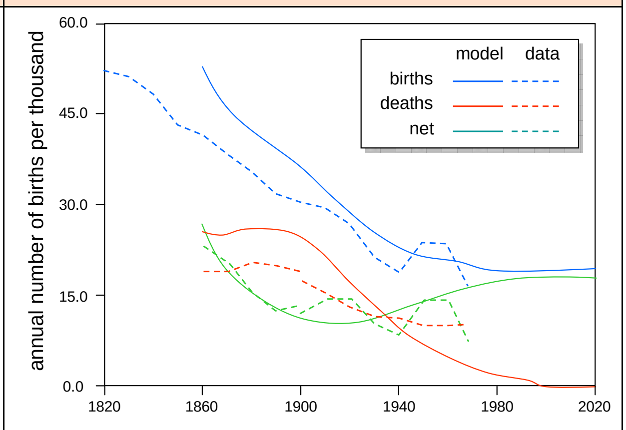
The model fragment that Nordhaus detached from the World Model in order to investigate the effect of the independent variable consumption on the dependent variable population growth rate. Note that all variables, except one are made independent, and that the remaining variables are kept constant.



In the World Model population growth, consumption, density, pollution and food are endogenous, non-constant variables that depend on, and contribute to, the behaviour of the entire system.



The above graph shows the comparison Nordhaus makes between data (dots) and the behaviour of his manipulated version of the World Model.



The above graph is created by overlying the historical data presented by Nordhaus with the simulation presented by Forrester for US birth and death rates.

Figure 9: Different ways to compare models to data

Without taking a position in the debate, we see that part of the discussion relates to facts (data), theories (models) and principles (analysis); i.e., *epistemic* factors of *standard* (facts and theories) and *non-standard* (analysis) form.

6.2 The role of technology

Nordhaus has issues with parts of the World Model that deal with capital and resources, and in particular the effects of improved technology. The debate on these issues is to a large extent centred on level of *aggregation* and *formulation* of relationships. The World Model treats all resources as one stock variable, and capital (including technology) as another stock. This prevents many details, such as the substitution of one resource for another, and explicit representation of technology as opposed to other kinds of intellectual or physical capital.

The discussion between Forrester and Nordhaus on these matters requires too much detailed understanding of the model and economy to be described here. But it is quite clear from the exchange that we have to do with similar *epistemic* factors as in the previous discussion about population.

6.3 The role of prices

According to Nordhaus, "prices are one of the obvious adaptive mechanisms by which economic man does adjust to changes in *relative* scarcities…" Forrester's response is that shortages in the World Model are *absolute*—not relative. Without going into more detail, the discussion on prices is in part a discussion about level of *aggregation*, and in part a discussion about *formulation*.

Both aggregation and formulation are related to *epistemic*, *standard* factors in McMullin's categorization. It is also worth noting that the argument is not related to observable *facts*, but to *theories* and *approaches* on how to analyze the system portraying the facts.

6.4 Non-epistemic factors

McMullin points out that non-epistemic factors can contribute to the course of a scientific controversy. In the case of the World Model, there seems to be plenty of epistemic factors that can outweigh any non-epistemic effects, such as personality traits or use of institutional power. When Forrester wrote his Response to Nordhaus (Forrester 1974), the *Economic Journal* (where Nordhaus' critique was published) refused to accept the article.[25] Arguably, this was non-epistemic use of power from the side of the editor.

One of the criteria of a scientific controversy is that the views are worth taking seriously. In numerous places I have found the use non-scientific (rhetoric) language in addition to scientific argument[26]. Through language, the proponents do their best to make the other side seem incompetent.

6.5 To grow or not to grow, that is the question

The controversy about the World Model is a controversy about growth. If we cut away all the rhetoric, and the lengthy arguments about data, theories (models), and methodologies one question remains:

> Can economic[27] growth continue for the foreseeable future, or can it not?

It is more than 30 years since the first version of the World Model was published. This period of time has provided researchers with lots of data in the form of time series and cross-sections. We have had the opportunity to observe dramatic advances in technology and increasingly efficient use of resources. Measures have been taken to fight pollution. In many places the environment is less poisonous now than 30 years ago. At the same time we see signs of social stress in the society.

> Have the physical limits been moved so far that growth brings society up against other limits; the social limits?

There are still no definite answers to these questions. Some people will point at history, and claim that technology and markets have solved the problems so far, and will continue to do so in the future. In his article *Prophecy de Novo: The Nearly Self-Fulfilling Doomsday Forecast*

---

[25] I base this on personal communication with Dr. Michael Radzicki.

[26] Nordhaus repeatedly connects Forrester's work to Malthus. The specification of the World Model is characterized as "non-standard", "vague", "confusing", "careless" and "primitive", and the results are "absurd", says Nordhaus.

[27] Growth is in this context limited to economic growth, and does not include culture, religion, etc.

(Marxsen 2003) Craig S. Marxsen tries to convince his readers to put their trust in technology and markets. Marxsen's article documents that the limits to growth discussion is far from over. He points at the environmentalist movement and high-rank politicians such as Al Gore as representatives of what he calls "environmental extremism".

In one of the quotes on page 15 Forrester anticipates that knowledge derived from the World Model can lead to a different future than that projected by the model. Marxsen claims that the limits to growth "movement" has indeed influenced the course of events. Some people will say in a positive direction, referring to the focus that has been put on environmental issues since the 1970s. Marxsen perceives the influence as a negative one. The impact that the World Model and related works have on political thinking, legislation and regulation has increased costs and reduced economic growth, claims Marxsen. His point is that the limits to growth ideas have *created* limits that did not exist before. This explains why he talks about a "self-fulfilling forecast" in the title of his paper.

The implications of the World Model have been difficult to deal with for many economists. Growth seems to be their only viable answer to creating and maintaining high *consumption rates per capita*. When these factors are taken into account, we see that our controversy is definitely a *mixed* one (see Table 3, p. 4). We have to do with research that has implication on human *decisions* and trade-offs between different *values* or alternatives. The scientists disagree on the *wisdom* of different actions (such as environmental taxes) and on the relative value of protecting the environment versus stimulation to more economic growth. The trade-off between *short-term* and *long-term* quality of life is another example of the mixed nature of our controversy. Ethical questions relating to what kind of world we leave for our children and grandchildren is also an issue. As an example, some people say that it is only fair that we use more of the (premium) resources than the next generation, since in return each generation provides the next with a higher level of technology. The definition of "quality of life" is itself a non-standard factor with different meanings to different people. Is it proportional to consumption rate, or are there other factors that are more important when the basic, physical needs are more than fulfilled? The Norwegian poet, Arne Garborg, expresses the difference between real values and substitute values that money can buy:

Um pengar

Av Arne Garborg

Pengar hev ikkje noko verd i seg sjølv. Du kann ikkje eta dei, ikkje drikka dei, ikkje klæda deg med dei. Du kunde hava lumma full av pengar, og svelta, tyrsta, frjosa i hel - um der ikkje var mat og drikka og klæde å få.

Pengar er langt ifrå det største gode, ikkje det næst største heller. Men dei er eit stort gode for den som brukar dei vitugt.

For pengar kann ein få alt, heiter det. - Nei, ein kann ikkje det.

Ein kann kjøpa seg
mat, men ikkje mathug,
dropar, men ikkje helsa,
mjuke senger, men ikkje svevn,
lærdom, men ikkje vit,
stas, men ikkje venleik,
glans, men ikkje hygge,
moro, men ikkje gleda,
kameratar, men ikkje venskap,
tenarar, men ikkje truskap,
gråe hår, men ikkje æra,
rolege dagar, men ikkje fred.

Skalet av alle ting kann ein få for pengar.
Men ikkje kjernen; den er ikkje for pengar fal.

English translation:

About money

It is said that for money you can have everything, but you cannot.

You can buy
food, but not appetite;
medicine, but not health;
knowledge but not wisdom;
glitter, but not beauty;
fun, but not joy;
acquaintances, but not friends;
servants, but not faithfulness;
leisure, but not peace.

You can have the husk of everything for money, but not the kernel.

6.6 Resolution?

The critics of the World Model, and the many revisions and improvements to it, have focused on imperfection in the World Model, without putting forward an alternative model that is a better representation of the world system.

Part of the discussion is related to what a particular formulation in the World Model does or does not do[28]. The controversy on these points is of a nature that it would be possible to settle once and for all using *standard* scientific methods.

The majority of the controversial topics covered above are not related to interpretation of facts. Instead, the disagreement is about purpose (which questions to ask), methodology (how to address the questions), results (how to interpret the results), and implications (actions to be made on the basis of the analysis). As the text and the references suggest, the debate is still going on, and even in a much broader context than in the beginning. Politicians, scientists, environmentalists and "ordinary people" like me are occupied by future questions. A search for "limits to growth" gives more than 41 000 hits, and if you search for "future studies", you get 8 million hits on Google. The debate is far from resolution.

Based on the above, we can easily agree that the debate initiated by the World Model is not *abandoned*. We can also safely assume that there is no power that can bring this debate to a *closure*.

7 Concluding remarks

I think it is safe to say that the World Model controversy is a *mixed controversy*, bearing in it elements from all groups of determining *factors* (Table 2) and all *categories* of controversial topics (Table 3). The controversy is also not ended, neither through resolution, closure or abandonment. Being a mixed controversy, the likelihood of resolution is small.

The difficulties the parties have in understanding the language of the other side in this dispute surprised me, and made me think of my wife's uncle, Guttorm, who attended a Visual Basic course many years ago. He never learned how to program Visual Basic. One time he told me his secret recipe for debugging very large VB models: He would go to the first line that the VB compiler marked in error, and delete the line. He repeated this until the compiler found no more errors. Obviously, this approach does not work for VB models, and it does not work for system dynamics models either. When Nordhaus decided to cast Forrester's model into different (non-equivalent) forms by removing feedback loops and replacing dynamic variables with exogenous constants, he ended up with a set of models that he could analyze. But what he analyzed, was not Forrester's model, it was only fragments of the model. When Nordhaus identified behaviour that deviated from observed reality, this is in full accordance with Forrester's claims that the whole is more than the sum of its pieces.

Many of the main questions in business, politics and at the personal level must be answered without much use of data. In situations where data are missing or fragmented, we still create models to back our decisions; we create mental models that try to capture the picture of our situation and the future development. All of our models, mental or formal, are incomplete. To make use of technology that can help us make our models explicit and open for inspection and analysis, is an example of technology improvement—one of the cornerstones of the "growth movement". But technology and models do not remove the curtain we are looking into when facing future. Future is hidden, and it is full of surprises. In his article *All Models are Wrong: Reflections on Becoming a Systems Scientist* (Sterman 2002), Sterman puts it this way: "… systems thinking requires understanding that all models are wrong and humility about the

[28] As an example, Nordhaus claims that the natural resource stock in the World Model can be replenished, while Forrester claims that it cannot (since the resource stock has only one flow, which is a non-negative outflow).

limitations of our knowledge". It is my impression that many of the leading system dynamicists display this kind of humility in relation to their research and their writings. As an example, Forrester writes the following in this *World Dynamics*:

> "These preliminary interpretations need to be examined more deeply and confirmed by more thorough research into the assumptions about structure and detail of the world system… Further work may well alter the present implications and emphasis and is sure to develop new insight and clarifications." (Forrester 1973, p.ix)

When it comes to the critics of the World Model, I have difficulties finding corresponding attitude and expression of possible limitations in their own theories and views.

Must there be a big gap between system dynamics and econometrics? I guess the answer depends on the personalities and backgrounds of the people involved. Some people like to pick the tool first, and then the problem. Others do the opposite. In the latter case, I believe there is a lot to learn and a lot to gain by combining the strengths of econometrics with those of system dynamics. When available, time series, cross section data and statistical relationships can be used both in the model construction phase and in the validation phase. Such approaches rely on our ability and willingness to learn. I opt to believe that there is enough people who see limitations in any single-minded approach, and therefore appreciate that there is a multitude of methods and tools that can complement each other and improve our decision making.

I therefore intend to continue my work on "multi-paradigm" technology and include tools that have proven to be useful when used stand-alone or in combination on different kinds of problems, or different parts of a larger problem. Two of the obvious candidates for inclusion in such a technology are statistical analysis (for example regression) and system dynamics simulation. The table below contains a summary that indicates how the two methodologies can complement each other.

System dynamics	Econometrics
holistic (system)	detailed (sub-system)
closed (few exogenous variables)	open (few endogenous variables)
focus on structure	focus on data
looks for cause-and-effect in structure	looks for correlation in data
ensures conservation of mass	ignores conversion of mass, unless explicitly accounted for
long-term perspective	short term perspective
robust also under extreme conditions	operates near equilibrium
generates transients behaviour over time	generates single-mode behaviour or equilibrium
process oriented (learning)	product oriented (results)
qualitative	quantitative
general understanding	prediction and estimation

Table 13: Complementing nature of system dynamics and Econometrics

8 References

Commoner, Barry. 1971. *The Closing Circle: Nature, Man and Technology*. New York: Alfred A. Knopf Inc.

Forrester, Jay W. 1971. *World Dynamics*. Tokyo: Nippon Keiei Shuppankei.

———. 1972. On Criticisms on World Dynamics. Massachusetts: Massachusetts Institute of Technology.

———. 1973. *World Dynamics*. 2nd ed. Cambridge: Wright-Allen Press, Inc.

———. 1974. The Debate on World Dynamics: A Response to Nordhaus. *Policy Sciences* 5:169-190.

Hicks, John R. 1979. *Causality in Economics*. Oxford: Basic Blackwell.

Kmenta, Jan. 1986. *Elements of Econometrics*. 2nd ed. New York: Macmillan.

Kuhn, Thomas S. 1970. *The Structure of Scientific Revolutions*. 2nd ed. Chicago: University of Chigago press.

Malthus, Thomas Robert. 1798. *An Essay on the Principle of Population as It Affects the Future Improvement of Society, with Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers*. London: J. Johnson.

Marxsen, Craig S. 2003. Prophecy de Novo: The Nearly Self-Fulfilling Doomsday Forecast. *The Independent Review* VII (3):325–342.

McMullin, Ernan. 1987. Scientific controversy and its termination. In *Scientific Controversy*. Cambridge: Cambridge University Press.

Meadows, Donella H. 1980. The Unavoidable A Priori. In *Elements of the System Dynamics Method*, edited by J. Randers. Cambridge MA: Productivity Press.

Meadows, Donella H., Dennis L. Meadows, and Jørgen Randers. 1992. *Beyond the limits: confronting global collapse, envisioning a sustainable future*. Post Mills, Vt.: Chelsea Green Publ. Co.

Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, and William W. Behrens, III. 1971. *The Limits to Growth*. London: Pan Books, Ltd.

Nordhaus, William D. 1973. World Dynamics: Measurement Without Data. *The Economic Journal* 83 (332):1145-1183.

———. 1992. Lethal Model 2: The Limits to Growth Revisited. New York: Cowles Foundation.

Saeed, Khalid. 1998. Policy Space Considerations for System Dynamics Modeling of Environmental Agenda: An Illustration Revisiting the "Limits to Growth" Study. Paper read at Symposium on Environment, Energy, Economy: A sustainable Future, at Rome.

———. 1998. *Towards Sustainable Development: Essays on System Analysis of National Policy*. Aldershot: Ashgate Publishing Company.

Senge, Peter M. 1990. *The Fifth Discipline: the Art and Practice of the Learning Organization*. New York: Doubleday/Currency.

Sterman, John D. 2000. *Business dynamics: systems thinking and modeling for a complex world*. Boston: Irwin McGraw Hill.

Sterman, John D. 2002. All Models are Wrong : Reflections on Becoming a Systems Scientist. *System Dynamics Review* 18 (4):501-531.

Sterman, John D., and Linda Booth Sweeney. 2002. Cloudy Skies: Assessing Public Understanding of Global Warming. *System Dynamics Review* 18 (2):207-240.

Stiglitz, Joseph E. 2002. *Globalization and its discontents*. London: Penguin Books.