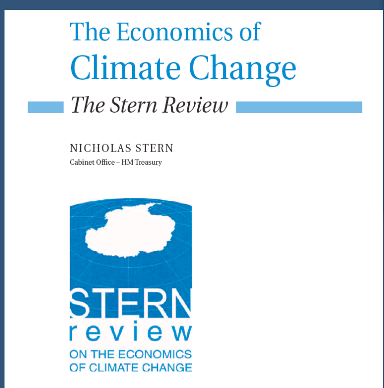
Climate Change Policy

Positive or Negative Economic Impact? Why?

Roland Kupers | Diana Mangalagiu



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European Climate Forum e.V.
P.O. Box 600648
D-14406 Potsdam
Germany

info@european-climate-forum.net
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Climate Change Policy

Positive or Negative Economic Impact? Why?

Roland Kupers[1] | Diana Mangalagiu[2]

1 Visiting Fellow, Institute for Science, Innovation and Society, Oxford University & Senior Lecturer University of Nijenrode.

2 Visiting Fellow, Institute for Science, Innovation and Society, Oxford University & Professor, Reims Management School.

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ABSTRACT

The UK and German governments have both commissioned thorough analyses of the economic impact of climate change policies, summarized, respectively, in the Stern Review and the Jochem, Jaeger *et al* report[3]. While Stern covers the global perspective, Jochem, Jaeger *et al* is limited to Germany.

According to the Stern review, the average expected cost of preventive actions to be taken now in order to stabilize global greenhouse gas (GHG) emissions at 500-550 CO2e will amount to a cost of 1% of annual global GDP by 2050 (~$1trillion).

In sharp contrast, the Jochem, Jaeger *et al* report concludes that the German policy target of 40% reduction over the 1990 emissions level by 2020 will create at least 500,000 jobs and add at least +2-3% (€70bn) to the German GDP by 2020.

These diverging conclusions on the average expected GDP growth reflect the specific aspects of various economies, but also a different way of viewing the dynamics of the economic system itself. Understanding these differences matters as other countries follow suit in analyzing or setting their own policies. The difference between a net benefit and a net cost is highly relevant in obtaining political support for climate policy measures. Different ways of modeling the economic system and assumptions in both reports reflect a fundamentally different understanding of the equilibrium nature of the economy. From these follow then the opposite predictions on the cost of mitigation.

Keywords: Climate Change
Complexity
Systems Dynamics
Stern Review
Meseberg Program

3 The study was performed by a consortium formed by Potsdam Institute for Climate Impact Research (PIK), Fraunhofer Institute for Systems and Innovation Research (ISI), European Climate Forum (ECF), Munich Re Group and Swisscanto and led by PIK.

THE FOUNDATIONS OF ECONOMIC THEORY AND MODELS

The 2008 financial crisis put the spotlight on some fundamental aspects regarding the foundations of economics. While economists had in the past drawn attention to these issues, the debate was limited to a relatively low intensity background discussion amongst scientists. The crisis and the failure of academic economics both to provide early warning, as well as to be able to deliver a comprehensive explanation after the fact, have now highlighted these shortcomings (Colander, 2009). Our concern here is with the impact of these fundamental issues on scoping and quantifying economic policies to address climate change. In other words, if fundamental assumptions hidden under economic theory and modeling materially impact the choices we make in addressing climate change, these assumptions should be made explicit, so that they might be properly considered together with the recommendations. The climate change impact debate is held in terms of impact on GDP, and indeed this is the scope of this paper. We note however that GDP itself is increasingly coming under pressure as a reasonable proxy for welfare optimization (Stiglitz, 2005). In the absence of other consensus metrics, we continue to frame our contribution in terms of GDP impact of climate change mitigation.

Physicists talk about their "standard" model a lot—economists seldom do, although it exists. The standard model in economics is known as the competitive general equilibrium market model (GE) and although economics literature contains many critical deviations from that standard, the GE remains the backbone of the discipline. At its heart, economics assumes that markets are in equilibrium, so that supply and demand balance through the combined action of economic agents, who use all information available in the marketplace to make rational decisions. In other words, the GE assumes that prices reflect all known information and provide the best possible estimate of value. We emphasize that this is not simply a modeling issue, but is a fundamental assumption on the dynamics of economic systems, which then makes its way into the chosen models and the subsequent interpretation of their results. The great advantage of this assumption is that it lends itself readily to modeling through mathematical formulations that have well defined analytical or numerically soluble solutions. Yet we pay a price for this mathematical elegance, namely that we have to assume that the full breadth of human behavior can be captured within these mathematical constraints, and that economic agents behave in a homogeneous way (Arthur, 2005). Underlying General Equilibrium is a conception of linear causality, that is, that small causes have small effects and big causes have big effects. So, the implication is that a big event such as the recent credit crunch must have had a big cause. This is typical of uniformly stable systems in equilibrium.

The underlying assumption of economics agents as homogeneous and rational is not supported by empirical evidence (Colander, 2008). In fact, it is quite possible to design models that mimic a set of human behaviors that more closely resemble those that occur in reality. The ensuing difficulty for scientists is that these agents learn and adapt, and as a consequence the overall system is never in equilibrium for a long time (Arthur, 1991).

Systems can fail to reach a stable equilibrium, through feedbacks between classes of agents that are otherwise independent. The system is described in terms of a finite set of system level properties. This is comparable to a set of coupled oscillators, which you can imagine as a number of balls connected with springs. The same dynamic behavior arises in economic systems consisting of stocks (corresponding to the balls) and flows (corresponding to the spring forces), which introduce delays in reactions. The coupling between the different economic sub-system components, in contrast to the springs-and balls-analogy, is moreover typically nonlinear. The mathematics of such models can then not be solved analytically, but only through numerical simulations using computers, – a discipline of system dynamics introduced into economics in the 1960's (Forrester, 1961). Including these system level interactions is an important modification to equilibrium models, as even simple nonlinear models often exhibit counter-intuitive behaviors.

An important further complication occurs when the interactions are not longer limited to classes of agents, and the behavior of the individual agents depends on properties of the overall systems, involving interactions at multiple scales. One can imagine a case where the choice of a consumer of a product depends on how many of his friends already own that particular product. Thus the probability of purchasing the product continually evolves over time. This class of problems can also not be solved analytically, but can nevertheless be modeled numerically using approaches such as Agent Based Models (Farmer, 2009a). While the tools to study complex systems are relatively new (Holland, 1991; Arthur, 1991; Tesfatsion, 2003), the realization that the equilibrium assumption in economics is artificial and limiting is much older and part of the roots of classical economics (Smith, 1776). Notwithstanding this realization, it has become increasingly unchallenged that the associated reduction is an accurate description of the economic system.

As a foundation for the discussion in the sections on the Stern and Jochem, Jaeger *et al* reports below, the following table summarizes some of the characteristics that can be considered when comparing classes of models (for a systematic comparison, see (Borshchev, 2004)).

	General Equilibrium Models	System Dynamics Models	Agent Based Models
Characteristics	Representative agent (underlying homogeneous behavior assumption) Optimization algorithms	Classes of representative agents System level feedback (differential equations) “Top Down” simulation	Heterogeneous agents Multi scale feedback (micro-level interaction rules) “Bottom-up” simulation
Possible states	Single optimal equilibrium	Single equilibrium Multiple equilibria Periodic attractors Chaotic state	Emergent order Instability

To understand the impact of the assumptions at the foundation of economics on climate change policies, we need to consider the consequences of the reductions implied in the different representations of the economic dynamics (Hasselmann, 2008). Addressing climate change necessarily implies large-scale changes to systems, such as the energy and transportation systems, that have evolved over time. Equilibrium models assume an optimal state, for which there will always be a net cost to move away from. This is not a trivial matter, but a self-fulfilling prediction of the assumptions we have made in the first place. Under non-equilibrium assumptions, multiple stable states can potentially exist, and indeed the system can evolve from one equilibrium to the next. This principle is well accepted in the natural sciences, where new emergent phenomena can occur at a macro level, without obvious direct link to the micro-level of individual agent interaction (Anderson, 1972). In order, for economists, to assess the impact of both the heterogeneity of agents and the consequential existence of emergent multiple equilibria, they must necessarily move away from general equilibrium models and investigate alternatives in the form of systems dynamics and agent based models.

We conclude that the assumptions underlying the foundations of economics can have a determinant effect on the assessment of the cost of climate change mitigation. Hence it is highly important to make those assumptions explicit and understand their impact.

CLIMATE CHANGE

The very nature of the climate system as a complex system may in fact be a cause of the difficulty in focusing the debate. Climate change is a phenomenon that takes place on many scales, from the atmosphere as a whole to local micro-climates and the ecosystems and socioeconomic systems they support. A wide range of emergent effects must be taken into account (Quiggin, 2007). Many of the climate skeptics have chosen to attack the causal relationships between the observed data and the conclusions. Yet in a complex system far from equilibrium, the very nature of those relations is different from the causality that is expected in public policy debates.

The problem of human induced climate change couldn't be more important, given the primordial role of the climate system in supporting life on earth. It has long been pointed out that the steady increase in carbon emissions from burning fossil fuels, as well as the release of other greenhouse gases, since the 19th century has an influence on the climate. The Swedish scientist Svante Arrhenius is credited with first calculation of the effect on the climate in 1896, although given the rate of emissions at the time, he thought the problem would not occur for many centuries (Arrhenius, 1896). This marked the beginning of a long tradition of research, empirical and theoretical, culminating in the establishment of the International Panel on Climate Change (IPCC) in 1988 as the leading body for the assessment of climate change.

The IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. It was given its mandate by the UN General Assembly to prepare a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change, the social and economic impact of climate change, the possible response strategies, and elements for inclusion in a possible future international convention on climate. Given the perceived importance of climate change, the IPCC was devised as an instrument to establish on a formal authoritative basis the scientific consensus and policy options.

This approach has had limited success in establishing the definite source of authority on climate change. In the first and second IPCC reports, the human-induced climate signal could not yet be clearly identified in the data above the natural climate variability noise. This provided fuel to the climate skeptics, who for various reasons opposed climate action. However, in the last two IPCC reports, enough data on global warming and more sophisticated signal processing methods had been devised to clearly demonstrate the existence of a climate change signal.

The fourth assessment report in 2007 concludes both that "*Warming of the climate system is unequivocal*" and that "C*ontinued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century*" (IPCC, 2007). Today, no government disputes the reality of human-induced climate change. Nevertheless, the unavoidable levels of scientific uncertainty in the predicted climate change variables (as well as human errors in the details of the scientific assessment), in the impacts of climate change on society, and in the implications for climate policy, continue to be hotly debated.

For the purpose of this paper of understanding the impact of assumptions of economics on policies to address climate change, we note the continuing debate and occasional skepticism, but base ourselves on the IPCC conclusions.

THE STERN REVIEW

The Stern Review (Stern, 2006a) was commissioned by the UK government, but with a global perspective on climate change. The Review has focused on the feasibility and costs of stabilization of GHG concentrations in the atmosphere in the range of 450-550 CO2e (i.e. the concentration range which is expected to contain the temperature rise within 2°C).

The Review, based on salient points observed in a broad subject-by-subject review of international scientific literature, considers **(1)** the economic costs of the damage of climate change and **(2)** the costs and benefits of action to reduce the emissions of GHG that cause it. In this article, we are focusing on **(2).**

(1) The estimated economic costs of climate-change damage in the business-as-usual case are based on the PAGE2002 economic model (Hope, 2003), an existing general equilibrium models of the monetary cost of climate change, with eight regions and two impact sectors. On this basis, the Review estimates that for a central climate change scenario and the cost of inaction is, on average, 10 percent now and forever.

One of the critical assumptions in this analysis is the discount rate that is applied, and this choice has lead to heated debates. The Stern Review choice of a Social Discount Rate of 1.4% to estimate the cost of inaction, rather than a more usual finance discount rate several times higher, is based on the view that environmental and social goods do not depreciate as economic goods generally do. The level of discount rate has been the subject of considerable debate (Hasselmann, 1999; Nordhaus, 2006; Neumayer, 2007). It is worth noting here that the very assumption of a constant discount rate is highly questionable. This is derived from a long-standing convention in the financial industry, whereby money is lent at a constant interest rate. This is largely a convention of convenience, but has led to the adoption of a constant discount rate for non-financial matters such as natural capital, hence the debate on the appropriate level. Stern (2008) provides a thorough description of the confusion between Private Discount Rates and Social Discount Rates. In addition, there are strong empirical indications that the behavior of both humans and animals agents is better described with hyperbolic discounting. This has important implications for economics, as it implies a much larger weight for the future than traditional exponential discounting rates (Farmer, 2009b). It is beyond the scope of this paper to assess the exact impact of hyperbolic discount rates on the models used in the Stern Review, but it lends support to an even lower net discount rate than the review assumes, hence further reducing the implied cost of climate change mitigation.

(2) The costs incurred for a world shifting from a high-carbon to a low-carbon trajectory, whilst taking into account the new business opportunities that arise as the markets for low-carbon, high-efficiency goods and services expand (our focus in this article) are estimated in two different ways:

(i) The resource costs of mitigation measures, including the introduction of low-carbon technologies and changes in land use, are compared with the costs of the business-as-usual alternative. This provides an upper bound on costs, as it does not take account of the opportunities mentioned above.

(ii) Alternatively, the results (a) from a wide range of economic models such as EMF (Weyant, 2004), IEA (2006) and surveys of modeling results such as IPCC (2001) that estimate the economic impacts of climate change and (b) meta-analyses, such as Fisher and Morgenstern (2005) and Barker et al (2006), are combined to explore the system-wide costs and effects of the transition to low-carbon energy systems for the economy as a whole. In this way, the dynamic interactions of different factors, including the response of economies to changes in prices, are tracked over time. The Review acknowledges the complexity of these estimates and the fact that their results are affected by a whole range of assumptions.

In **(i)**, the costs are estimated by looking at costs of individual emission-saving technologies and measures: abating non-fossil-fuel emissions, particularly in land use, agriculture and fugitive emissions; reducing the demand for emission-intensive goods and services; improving energy efficiency, by obtaining the same outputs from fewer inputs; and switching to technologies which produce fewer emissions and lower the carbon intensity of production (Stern, 2006a, 214). The cost estimates are based on a large scientific literature and on studies carried out specifically for the Stern review such as Grieg-Gran (2006) and Anderson (2006). The global cost is estimated at around $1 trillion in 2050 or 1% of GDP in that year, with a range of –1.0% to 3.5% depending on the assumptions made. The models used are general equilibrium models: for example, the extra resources for emissions reductions represent a tightening of the general equilibrium constraint and shadow prices are opportunity costs which can be determined by correcting market prices for market imperfections. For a formal definition, see Drèze and Stern (1990).

In **(ii)**, results from more detailed consumer and producer behavioral equilibrium modeling, as well as from the cost and choice of low-GHG technologies assumptions, are drawn from a comparative analysis of international modeling studies tailored to tackle a range of different questions in estimating the total global costs of moving to a low-GHG economy. Although most of the model estimates for 2050 are clustered in the –2 to 5% of GDP loss in the final-year cost range, on average around 1% of annual global GDP by 2050. These costs depend on a range of assumptions, such as technological change, flexibility between sectors, flexibility between technologies, flexibility between gases, changes in consumer and producer behavior through time, potential co-benefits, design and application of policy, whether or not governments send the right signals to markets and get the most efficient mix of investment. Barker et al (2006), in their meta-analysis, switch on or off the factors identified as being statistically and economically significant in cutting costs. For example, the 'worst case' assumption assumes that all the identified cost-cutting factors are switched off (costs total 3.4% of GDP). At the other extreme, the 'best case' projection assumes all the identified cost-cutting factors are active, in which case mitigation yields net benefits to the world economy of 3.9% of GDP.

On the basis of the two approaches described above, the Review's central estimate is that stabilization of GHG at levels of 500-550ppm CO2e will cost, on average, around 1% of annual global GDP by 2050. "This is significant, but is fully consistent with continued growth and development, in contrast with unabated climate change, which will eventually pose significant threats to growth." (Stern, 2006b, 13).

However our main concern here is the assumptions underlying the modeling of the economic system, as an equilibrium versus non-equilibrium system. PAGE2002 is based on a General Equilibrium Model with eight world regions and two damage sectors (economic and non-economic). The regional damages are estimated as a percentage of gross domestic product lost per doubling of CO_2. The fact that climate mitigation is a net cost to the economy is an input parameter: the minimum and maximum values for the regional factors are based on "a large amount of judgment to encompass the different studies cited by the IPCC". The equilibrium model then simply allocates the cost to various regions and sectors, depending on how the model parameters are set.

Although there is much evidence that innovation leads to economic growth by developing new industries and creating new employment (Audretsch, 1995; Foley, 1999), the model employed by the Stern Review cannot take this into consideration due to its very nature as an equilibrium model.

We conclude that the fact that mitigation of climate change in the Stern Review is a net cost to the economy, is a consequence of the assumptions on the nature of the economy and the input data, rather than a result of the modeling itself.

THE JOCHEM, JAEGER ET AL. REPORT

The German climate change target of a 40% reduction over 1990 levels by 2020 is ambitious, although facilitated by the extensive modernization of the infrastructure of Eastern Germany, precipitated by unification. German policy was articulated in 2007 in a report known as the "Meseberg Program" (Meseberg, 2007). Nicholas Stern (Stern, 2009) reports that "Germany is a clear example of how government policy can support a transition to a close-to-zero-emissions electricity generation", pointing in particular to the rapid growth of wind to 7% of power generation in 2007 and an important new German export industry with €6bn in 2007.

The Jochem, Jaeger *et al* report (Jochem, Jaeger *et al*, 2008a), commissioned by the German government to translate its emissions reduction target into economic impact, concludes that this target is achievable and adds at least 500,000 jobs and €70bn to the German GDP, while requiring additional net investments of €30bn p.a. The investment is spread across many sectors, with the largest amounts allocated for buildings and renewable energy. A notable challenge is that this requires the reversal of the present trend of falling net investments from 10-15% in the post-war period to 5% today, well below other European countries, bringing investments back to 8%. Note that this critically differentiates Germany from other countries such as notably China.

The macroeconomic analysis of the impacts of the German climate policy on economic growth, consumption and employment was carried out with the ASTRA economic model, designed for the European transport sector. The ASTRA Model is a systems dynamics model. ASTRA's objective was the development of a tool that analyses the long-term effect of the EU Common Transport Policy not only for the transport system but also for the most important connected systems (ASTRA2000). ASTRA models the interaction of several system level properties (e.g. GDP, investment…) between a discrete set of sectors (e.g. transport, energy…).

The Meseberg program spells out 31 interventions through regulation, ranging from energy efficiency standards to changes in the taxation system. In the Jochem, Jaeger *et al* study, the cost/benefit of each of these interventions is estimated and fed into the ASTRA model as investment options. The economic effect of the investments in climate change technology is crucial – this can either be negative, if they crowd out more productive investments, or positive, if they are similarly value creating. Another essential effect is whether these investments are net additions or whether they displace existing investments. In the Jochem, Jaeger *et al* analysis, these assumptions are fed into the ASTRA model, which has a direct effect – but in addition the model endogenously predicts extra growth from the macroeconomic interactions (Jochem, Jaeger *et al*, 2008b).

The Jochem, Jaeger *et al* report also considers the effect of first-mover advantage, using the findings of a Roland Berger analysis (Roland Berger, 2007): the world market for environmental technologies is expected to grow to about €2.2trillion, of which about €1.7trillion would be in the area of climate protection (including transport technologies) in 2020. For Germany, this is predicted using conservative assumptions to lead to €17bn additional export demand by 2020 – which is set as an input parameter for the ASTRA model. The motivation for this adjustment is that - since the model does not include the markets outside Europe -, this demand is exogenous to the model. Germany, as the second largest exporter in the world, has consistently demonstrated that its industries can capture and hold export markets sustainably, and it is undeniably an early mover in climate mitigation technologies, so the assumption is reasonable. In any case, we note that excluding this effect would not materially change the contrast of the conclusions of the Jochem, Jaeger *et al* study with the Stern Review.

With these inputs, the ASTRA model computes the macro-economic effect of the entire Meseberg program. The investment levels and priorities between different interventions may change, as the model looks at competing investments over time. Also macro-economic benefits from effects such as reducing energy imports from more efficient consumption are computed.

The conclusion of the Jochem, Jaeger *et al* report that there is indeed a path from the current energy and transportation system to a much less carbon rich one, yielding a net benefit, is not a foregone conclusion, but a relevant result from both the inputs and the simulations themselves. This also implies that these conclusions do not necessarily apply to other economic systems than Germany's, and need to be studied and considered in each case. In particular, the reversal of the net investment rate in the German economy is a specific circumstance that has a large influence and may not be present elsewhere.

There is a follow-up project to build an agent based model (Mandel, 2009) to look more deeply at the dynamics of the economy, simulating interactions between individual agents and at multiple scales. This will remove further reductions from the modeling assumptions, and it is hoped that it will allow a more realistic study of the impact of mitigation investment strategies. The importance of the inclusion of effects at diverse scales is further underscored by Ostrom (2009), who describes how local benefits in the form of increased social capital and local reputation for individuals, combined with communication and reward systems, can be a powerful source of emergent global change.

Finally, it is worth noting that the Jochem, Jaeger *et al* report assumes discount rates for ranking investments between 4 and 10% depending on the type of investment. The issue of hyperbolic or other discounting options mentioned above is still relevant, and should be considered in future studies.

COMPARISON AND RECOMMENDATIONS FOR INDIVIDUAL COUNTRY APPROACH

The following table provides a summary of the characteristic differences in the underlying assumptions between the Stern and the Jochem, Jaeger *et al* approaches:

	Stern Review	Jochem, Jaeger *et al* Report
Economic dynamic	General equilibrium	System level property feedback
Modeling	General Equilibrium (PAGE)	Systems Dynamics (ASTRA)
Role of innovation	Negative correlation between investment in climate mitigation and GDP included directly as growth correlation	ROI from 31 mitigation measures input to model – then subject to economic dynamics

At their core, both studies start for similar facts, such as the return on investment of such concrete measures as building insulation or renewable energy generation. We note that the average expected GDP growth rate forecast by Jochem, Jaeger *et al* falls within range quoted in the Stern Review (-2% to +5%), although significantly away from the average (-1%). As such, the Jochem, Jaeger *et al* approach can be considered to build on the work of the Stern Review, yet - by going beyond a General Equilibrium view of the economy - reach a divergent conclusion in terms of whether climate mitigation is a net cost or benefit to the economies they each consider.

We conclude that future studies of the impact of climate change should go beyond general equilibrium models and include the complex dynamics in the economy without which the associated change to the economy cannot be realistically modeled and understood. The Jochem, Jaeger *et al* report on the German economy captures some of these dynamics, and although the results cannot be directly generalized to other economies due to the particular state of Germany, its method is a relevant example. Future studies should consider including multi-scale effects by using Agent Based Modeling and assessing the impact of non-constant discounting.

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P.O. Box 600648 • D-14406 Potsdam • Germany
info@european-climate-forum.net • www.european-climate-forum.net