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REGULAR ARTICLE

The impact of personal beliefs on climate change: the "battle of perspectives" revisited

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Abstract The paper proposes a multi-agent climate-economic model, the "battle of perspectives 2.0". It is an updated and improved version of the original "battle of perspectives" model, described in Janssen (1996) and Janssen/de Vries (1998). The model integrates agents with differing beliefs about economic growth and the sensitivity of the climate system and places them in environments corresponding or non-corresponding to their beliefs. In a second step, different agent types are ruling the world conjointly. Using a learning procedure based on some operators known from Genetic Algorithms, the model shows how they adapt wrong beliefs over time. It is thus an evolutionary model of climate protection decisions. The paper argues that such models may help in analyzing why cost-minimizing protection paths, derived from integrated assessment models à la Nordhaus/Sztorc (2013), are not followed. Although this view is supported by numerous authors, few such models exist. With the "battle of perspectives 2.0" the paper offers a contribution to their development. Compared to the former version, more agent types are considered and more aspects have been endogenized.

Keywords Climate change · Climate-economic models · Multi-agent modelling · Agent-based modelling · Perceptions · Learning

1 Introduction

The paper contributes to the development of agent-based climate-economic models. It offers an updated and improved version of the "battle of perspectives" model, originally developed by Janssen (1996). Agent-based models are regarded as a useful complement to the predominant scenario projections and intertemporal cost-benefit

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assessments (Janssen and de Vries 1998; Moss et al. 2000; Patt and Siebenhüner 2005; Giupponi et al. 2013). They enable the inclusion of heterogeneous agents' behavior and its evolution over time through interaction and through experiences with the model world, a feature mostly missing in traditional climate-economic models à la Nordhaus (1992, 2008, Nordhaus/Sztorc 2013).

Climate change is a complex problem with a long-term horizon. Although scientist mostly agree that anthropogenic CO_2 emissions are causing it, the magnitude of temperature increase and economic consequences over several decades cannot be predicted with exactness. IPCC reports as well as other scenario calculations thus work with possible ranges and confidence levels (IPCC 2014) and the revisions of assumptions and scientific evidence over the five IPCC reports from 1990 to 2014 illustrate the level of uncertainty in their predictions (IPCC 2014).

Climate change is caused by CO_2 emissions, resulting from energy consumption. Decisions on energy consumption patterns on the individual as well as political level are its driver. These decisions depend on individual beliefs about the significance of the problem and about best responses to deal with it. Scenarios and calculations on the basis of current behavior and external assumptions about its changes are not able to capture effects of the endogenous dynamics of agents interacting with their environment and with each other. Agent-based models may help to close this gap and support the analysis of effects of bounded rationality and behavioral adaptation on the climate system and the world economy. The paper thus follows calls for more agent-based models and for the importance of acknowledging evolutionary processes in the climate change discussion (Patt and Siebenhüner 2005; Van den Bergh 2007; Balbi and Giupponi 2010; Gsottbauer and van den Bergh 2013; Miller and Morisette 2014).

Although the world community regularly meets on climate conferences, attempting to agree on a mitigation policy, no substantial international agreement had been reached until the COP21 conference in Paris 2015. However, it is already clear that the "intended nationally determined contributions" to CO_2 emission reductions agreed on in Paris will not be sufficient to keep global warming below +2° (UNFCCC 2015). Meanwhile, worldwide CO_2 emissions are continuously increasing (Statista 2015). Climate-economic models unanimously agree that it's cheaper to pay for at least a moderate level of climate protection than to bear the costs of the damages expected otherwise.[1] However, governments, business and households don't follow the cost-efficient paths derived in optimization models. There are obvious reasons related to the common good's character of climate protection, which are not the topic of the current paper. But there is also disagreement about the exact magnitude of the problem and adequate reactions. Even standard climate-economic models, using quite similar assumptions about both systems, may deviate with respect to the cost-minimizing optimal paths, as can be seen comparing Nordhaus (1992, 2008) and Stern (2007). Thus, if "optimal" behavior, as derived from climate-economic models, cannot be observed, supplementing optimization models with models to analyze the consequences of non-optimal behavior may offer new insights. The real world is populated by people taking climate change seriously and investing in its mitigation, as well as by people placing short term economic growth above mitigation necessities, and by a number of other

[1] Rotmans 1990; Nordhaus 1992, Peck/Teisberg 1992, Manne et al. 1994; Janssen 1997; Weber et al. 2005; Stern 2007; De Bruin et al. 2007; Nordhaus 2008; Hope 2009, Nordhaus/Sztorc 2013.

behavioral types. Agent-based models are a useful tool to depict such heterogeneous agents and their interaction.

While there is an ongoing discussion about the need for such models (Moss et al. 2000; Patt and Siebenhüner 2005; Giupponi et al. 2013) and the impact of bounded rationality on climate policy (Gsottbauer and van den Bergh 2013) only a few agent-based climate-economic models exist. Among those, most cover local issues or deal with climate related specific issues, such as land use or water management (Balbi and Giupponi 2010). Others concentrate on particular aspects of bounded rationality, such as the fact that peoples' accordance with climate policy depends on their relative welfare compared to immediate neighbors in their social network (Nannen and van den Bergh 2010). Such detailed models are relevant for the analysis of specific questions or local case studies. A global climate-economic model, comparable to the Nordhaus models, however, has to depict behavior on a more general scale. Up to now, the "battle of perspectives" model by Janssen (Janssen 1996; Janssen and de Vries 1998) still seems to be the only one explicitly implementing a more generally valid behavioral agent-based component in a global climate-economic system (Balbi and Giupponi 2010). The structure of the model is comparable to state-of-the-art macro climate-economic models (Nordhaus and Sztorc 2013), and it is based on similar equations for economic development and the climate system. The general assumptions about agent types are based on cultural theory (Douglas and Wildavski 1982), which is relevant up to the present (Wildavski and Sweditorlow 2005; Adger et al. 2013). Therefore, this model has been chosen as a basis for the revised "battle of perspectives 2.0".

Being 20 years old, the original model is outdated and has some limitations, which are addressed. (1) The data input is revised with respect to economic development and climate scientific evidence, as well as regarding the assumptions about agents' beliefs. (2) Mistakes are corrected. (3) More aspects are endogenized and are now linked to effects of the agent's decisions. In order to do so, the model has first been re-implemented on the basis of published equations by Janssen (1996) and Janssen and de Vries (1998). This approach follows the "Model to Model" concept, proposed to check the validity of published models (Edmonds and Hales 2003; Rouchier et al. 2008). By doing so, the accuracy of the model and its robustness against data changes could be checked. Divergences in the model behavior are mainly observed in the magnitude of time paths, the latter due mostly to higher starting values as well as enhanced endogenous influences for scenarios with the most optimistic word view.

The paper is organized as follows: Part 2 reviews the literature on agent-based climate-economic modelling and discusses existing models. Part 3 gives an outline of "the battle of perspectives 2.0". Part 4 discusses its results and part 5 concludes, indicating possible future research for multi-agent climate-economic modelling.

2 Climate economic modelling and the role of uncertainty and evolutionary processes

Climate-economics is dominated by integrated assessment models deriving cost-minimal protection paths (Rotmans 1990; Nordhaus 1992, 2008; Peck and Teisberg 1992; Manne et al. 1994; Janssen 1997; Weber et al. 2005; De Bruin et al. 2007; Hope 2009; Nordhaus and Sztorc 2013). Results vary between them, partly because of different rates for intertemporal discounting, such as in the Nordhaus (1992, 2008) and Stern (2007) reviews (Weitzman 2007) and partly because of differences in assumptions on the climate as well as the economic dynamics. Part of the latter differences relates to an uncertainty about costs and benefits of future technologies or prevention measures (Weyant 2008). Consequently, there is a literature discussing uncertainty in climate predictions and cost assessments (Schelling 2007; Watson 2008; Finus and Pintassilgo 2009; Ackermann et al. 2009). As such uncertainties exist, their influence on decision making, attitudes to deal with the related risk, bounded rationality and the need for learning is discussed as well (O'Brien et al. 2007; Etkin and Ho 2007; Anda et al. 2009; Gsottbauer and van den Bergh 2013). Going even beyond scientifically acknowledged uncertainties, some groups actively deny the existence of climate change (Hulme 2009; Dunlap 2013). Global CO_2 emissions are the result of the aggregate behavior of a world population encompassing different beliefs about the importance of climate change as well as appropriate measures to prevent it. In recent years, a number of authors thus suggested that such individual opinions, actions and ways in which they may change over time should be investigated more, and also be investigated using the tool of multi-agent modelling (Moss et al. 2000; Patt and Siebenhüner 2005; An 2012; Giupponi et al. 2013). Not being a prominent issue in climate-economics, the question is more often discussed in adjoining sciences such as behavioral economics (Gowdy 2008), sociology (O'Brien et al. 2007), disaster management (Etkin and Ho 2007), cultural theory (Adger et al. 2013) or others (Rachlinski 2000).

Some papers address the importance of learning or uncertainty without being evolutionary or agent-based. Kutasi (2012) e.g. discusses the applicability of game theory to climate issues and Baker (2004) models the effect of uncertainty on decision making in a game theoretic climate model. Castelnuovo et al. (2005) and Bosetti et al. (2006) describe two types of learning processes as being relevant to the development of a more climate friendly technology. A certain part of protection can be assured through Learning-by-Doing, because even technology not designed explicitly to save energy is assumed to get less energy intensive over time. Additionally, the model considers Learning-by-Researching as an explicit means to increase climate protection. The learning procedures are embedded in an economic optimization model, maximizing growth, subject to the ideal combination of both. Other non-evolutionary examples are Mandel et al. (2009) and Jaeger et al. (2012). They implement a positive effect of investments in climate friendly technology into an otherwise traditional macroeconomic growth model, without, however, describing the explicit learning process.

Agent-based climate economic models are still exceptional and most existing models address very specific questions. Hasselmann (2009), e.g., places some representative agents in a macroeconomic climate model and lets them decide between different policies to limit global warming. However, he does not address the possibility that some agents may not agree with the necessity of climate protection or at least not agree very much, such as the Free Market Advocates and Fatalists we are considering in our model. The model by Ackerman et al. (2013) wants to illustrate that contributions to climate protection do not primarily depend on the willingness to pay but more on the ability to pay. In their model, a more equitable distribution of wealth leads to a more efficient climate policy. Also addressing fairness issues are Gsottbauer and van den Bergh (2013): while studying the impact of bounded rationality on bargaining in international climate negotiations, they examine how deviations from perfect rationality affect cooperation and are particularly interested in the role of social preferences for fairness and the effect of framing.

Finally, there are agents-based models in which climate change is an aspect, but the focus is on other questions. Such are models on land use, farming or water management and coastal risk management (Ziervogel et al. 2005; Werner and McNamara 2007; Barthel et al. 2008; Entwisle et al. 2008; Filatova 2009; Aurbacher et al. 2013), UK energy consumption in housing (Natarajan et al. 2011), sustainability in an Arctic community (Berman et al. 2004), community gardening and food security in Africa (Bharwani et al. 2005), innovation (Beckenbach and Briegel 2010) or on the native American Anasazi culture (Dean et al. 1999). In the agent-based model by Nannen and van den Bergh (2010), climate change is chosen as a case to illustrate the effect of social networks on the acceptance of different policies. In their model, climate policies affect either the relative welfare or the interactions in a social network, and are accepted or rejected in relation to these. While there is no doubt that social interaction is an important element in shaping policies, the detailed socio-economic model in Nannen and van den Bergh (2010) is linked to a rather basic climate system.

The most advanced agent-based model thus far seems to be the ENGAGE model by Gerst et al. (2013). It includes decision makers, such as governments, consumption goods firms, capital goods firms and private households, its purpose being the analysis of international climate negotiations. The agents argue on the basis of their domestic constraints. The model illustrates how bargaining results in changes in the domestic policies, technological development and resulting economic development of the agents' countries. It is designed with the objective to give policy advice, but the authors write that "further progress is necessary for ENGAGE to provide useful support for climate policy evaluation and formulation" (Wang et al. 2013: 268).

Social networks, framing, wealth distribution and preferences regarding fairness are important aspects for the acceptance of climate policy and for energy consumption decisions. However, models investigating their influence are all very specific. Beside such specialized models, it is useful to have a general approach. The "battle of perspectives" model by Janssen (1996), which has been presented in a more concise form in Janssen and de Vries (1998), seems to be the only model addressing the question with an evolutionary approach, on a global scale and in a general form comparable to macro-economic climate or growth models. In a literature review on agent-based modelling of socio-ecosystems in the field of climate change, Balbi and Giupponi (2010) found no model other than Janssen and de Vries (1998), combining an evolutionary agent perspective with a world climate system in order to analyze the link between climate change and boundedly rational adaptive agents. Miller and Morisette (2014) also only name two papers except Janssen and de Vries (1998) tackling climate change with a focus on adaptive decision making (i.e. Ziervogel et al. 2005 and Aurbacher et al. 2013 which have been mentioned above as focusing on land use).

3 The battle of perspectives 2.0

In this section, the "battle of perspectives" model is updated and enriched. The original Janssen model has been written on the system dynamics platform *Vensim*. The version of the current paper is based on its published equations and implemented in *Mathematica*.

The core of the "battle of perspectives" (Janssen 1996; Janssen and de Vries 1998) consists of the same macro-economic climate-economy approach as in integrated assessment models. This structure has been maintained over model variations and can thus be considered as robust (e.g. Nordhaus 1992 and 2008; Nordhaus and Sztorc 2013). Linked to it is an agent-based model, controlling some variables that are otherwise determined by an optimization process. The agents adjust the values according to their personal beliefs and their interpretation of observed system behavior. For one type of agent, a temperature rise of 0.5° thus might not pose a problem while another takes it as a signal to cut economic growth to zero.

The world views or perspectives of the agents in the original model are based on the three most relevant of four types to cope with risk, identified by the cultural theory of risk (Douglas and Wildavski 1982; Wildavski and Sweditorlow 2005). This follows literature, arguing that they are the "active perspectives", while the fourth, the "fatalist", who believes processes cannot be steered anyway and is not willing to take action, is typically excluded from political processes (Martens and Rotmans 1999). The behavior of "fatalists" is not directed at a specific goal. Martens and Rothmans therefore argue they cannot be described by a characteristic function. Also, they don't regard them as relevant because they don't take part in political decisions. Their exclusion thus makes sense in a pure policy model. However, although climate change or protection is affected by political decisions, it is not solely determined by policy. The transition towards a lower carbon level of the world society depends on the sum of fuel consumptions of companies and households, subject to individual decisions. Such decisions are guided and restricted by policy but to a large extent are still dependent on individual choices. An agent type in our model does not only represent the influence of a political group that is, e.g., in favor of climate protection; the same climate friendly agent type also stands for all companies or individuals exhibiting a climate friendly behavior. The agent types are thus aggregate stylized representations of different ways to deal with climate relevant issues. Therefore, it makes sense to include "fatalist" agents who are not participating in any kind of active climate protection because their behavior determines a part of the world emissions. Thus, the four types we are using are:

- The "individualist", believing in the power of free market forces and a strong resilience of nature. Individualists think that nature tends to equilibria which, after perturbations, reinstall themselves. Thus, the individualist is translated into an agent type believing that the climate-economic system will fix itself and economic activity should not be restricted. For better understanding, we call this type *"Free Market Advocates"*.
- The "hierarchist" is integrated into society and accepts its current regulations and state of scientific knowledge. This type believes that nature can be exploited, but only within limits. His opinion is based on broadly accepted expert knowledge. In the climate-economy model, hierarchists rely on IPCC best estimates and opt for a moderate but stable economic growth. We call this type *"Scientifically Informed"*.
- The "egalitarian" is a fundamental environmentalist and very risk-averse. He believes imbalances in the natural equilibrium will lead to disaster and thus desires to prevent any strong impact on nature. He prefers living on a very basic but equally

distributed level of wealth, rather than risk disturbing nature with a growing economy. In the model, egalitarians opt for zero growth and high environmental protection. We call this type *"Environmentalist"*.

- The "fatalist" believes the world is erratic and cannot be directed towards desired outcomes. He is thus not interested in politics. Neither is he willing to contribute to any measures requiring sacrifices today for possible future advantages. In the model, he has no opinion on climate change and no economic growth objectives. As the name *"Fatalist"* is illustrative for that type, we keep it.

The four perspectives are illustrated according to the two dimensions "Willingness to limit growth" and "Emissions resulting from their behavior" in Fig. 1. The illustration is an adaptation of the sketch of the "four rationalities" from cultural theory by Schwarz & Thompson (1990: 7). It may be interesting to note that the role and effect of Fatalists is a different here than for the usual dimensions "Freedom of choice" and "Group orientation". This is likely to be the case for more environmental problems. Although not caring and not being willing to contribute to their prevention, Fatalists are, at the same time, not investing in growth and are thus potentially less harmful than those with a growth target. We can assume there is a trade-off between these two characteristics, making the inclusion of Fatalists in the analysis worthwhile. Before elaborating on how these perspectives translate into specific beliefs and actions in the model, the climate-economic model itself is sketched in the next section.

3.1 The climate-economy model

The following climate-economy model is based on Janssen (1996) and Janssen and de Vries (1998), who in turn built it from existing climate-economy models, such as Nordhaus (1992), Manne et al. (1994), and others. For our model, some aspects have been changed and/or endogenized.

The model is a traditional macro-economic growth model, with an additional influence of the economy on climate (via emissions) and a feedback from climate to the economy (via economic losses due to climate change, or the costs of preventing it).

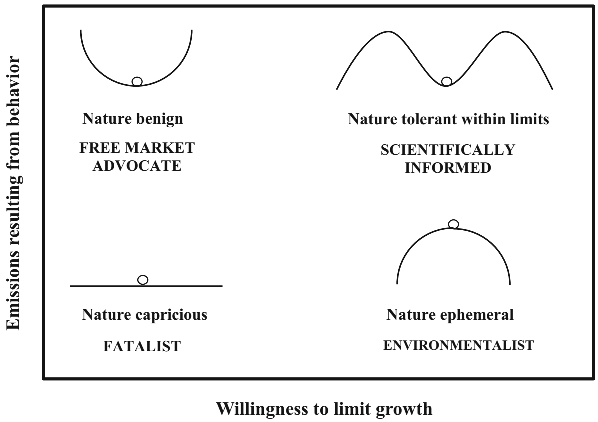

Fig. 1 The four perspectives, regarding the dimensions of emissions and willingness to limit growth

Economic output of a single commodity Y is defined as:

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

where output depends on capital K and labor (proportional to population P). Starting values for K (137) and P (6.883 billion) have been taken from Nordhaus and Sztorc (2013); c is a constant to calibrate output. The initial output has been calibrated to correspond to the Nordhaus model (Nordhaus and Sztorc 2013); c times a represents total factor productivity and increases with technological progress, which in turn depends on the perspectives. Using an indication from Nordhaus (2008), this increase is slowed down with a half-life of 60 years.

$$\begin{aligned} & a(t) = a(t) + \delta a(t) \\ & with \quad \delta a(t) = e^{\frac{\log e(0.5)}{60 \cdot t}} \end{aligned}$$

Following a suggestion from Castelnuovo et al. (2005), the productivity of the economy further depends on increasing returns to scale φ, linked to the capital stock, and is thus endogenously contingent on the investments of the agents. φ calibrates the model to be able to realize very high growth in the world, functioning according to the perspective of Free Market Advocates. This follows the most optimistic scenario among the “Shared Socioeconomic Pathways” developed by the Integrated Assessment Modelling Consortium, as described by the OECD authors Chateau et al. (2012). A weighted scale factor S, which is explained below, accounts for damages due to climate change or reduction measures to prevent it.[2]

Capital stock increases through investment I and depreciates with rate δ_K:

$$\begin{aligned} & dK/dt = I \cdot Y - \delta_K \cdot K \\ & with \ \ I = [0, 1] \end{aligned}$$

Investments I are a varying share of Y, determined by the investment decisions of the agents, as explained below.

The economy exerts an influence on climate by its emissions E, proportional to economic output and depending on declining energy intensity σ per output unit and on the transition M from fossil fuels to alternative energy sources, weighted by a coefficient α to calibrate emissions to the starting value:

$$\begin{aligned} & E(t) = \alpha M(t) \cdot \sigma(t) \cdot Y(t) \\ & M(t) = \frac{\varepsilon}{1-\varepsilon} \cdot \frac{1}{1 + e^{\rho M(t)\left(\frac{LM(t)}{LM(t-1)} \cdot (i-2005) - LM(t)\right)}} \\ & \rho M(t) = -\frac{1}{LM(t)} \cdot \log\left(\frac{\varepsilon}{1-\varepsilon}\right) \\ & \sigma(t) = (1-\delta) \cdot \frac{1}{1-\varepsilon} \cdot \frac{\delta}{1 + e^{\rho\sigma(t-2005-50)}} \\ & \rho\sigma = \frac{1}{50} \cdot Log\left(\frac{\varepsilon}{1-\varepsilon}\right) \end{aligned}$$

[2] Starting values and parameter specifications are given in table 1.

LM is endogenously changed by the agents according to the deviation of temperature change from their expectations, as explained in the following section. ρM corresponds to an "autonomous trend in decarbonisation" (Grübler et al. 1999) which, however, has been endogenized for our model as the different agents hold differing beliefs about the significance of this effect. Free Market Advocates assume an optimistic trend of $\varepsilon=0.01$, corresponding to recent US data. Scientifically Informed assume the average trend since 1850 of $\varepsilon=0.003$ (Grübler et al. 1999). Environmentalists assume a trend close to zero of $\varepsilon=0.00001$ and thus tend towards the "autonomous energy efficiency improvement" of zero, which Manne and Richels (1990) presume for the non-developed parts of the world. σ, the energy intensity of each unit of output, is logistically declining but also affected by the agents' perspectives because they hold different beliefs about the increase of energy efficiency δ through non-energy specific technological progress.

Emissions contribute to atmospheric CO_2 concentration pCO_2, based on a carbon cycle model by Meier-Reimer and Hasselmann (1987):

$$pCO_2 = pCO_2(t_0) + \int_{t_0}^{t} 0.47 \cdot E(t) \left(c_1 + \sum_{i=2}^{5} c_i \cdot e^{\frac{\tau - t}{al_{i-1}}} \right) d\tau$$

The c_i are fractions of carbon emissions, with $c_{i=2\text{ to }5}$ having different atmospheric lifetimes al_{i-1}. The multiplier of *0.47* has been introduced by Janssen to translate GT of atmospheric carbon in the original Maier-Reimer/Hasselmann model into atmospheric CO_2 concentration. This concentration enters the calculation of radiative forcing (the difference between incoming and outgoing radiation energy in a climate system, measured in Watts per square meter), with ΔQ_{2xCO2} being the expected radiative forcing for a doubling of CO_2 concentration, taken from the IPCC report.

$$\Delta Q_{CO2}(t) = \frac{\Delta Q_{2XCO2}}{\ln(2.0)} \cdot \ln \left(\frac{pCO_2(t)}{pCO_2(t_0)} \right)$$

Radiative forcing is assumed to influence the global mean surface temperature, calculated in relation to the expected temperature change for a doubling of CO_2 (ΔT_{2xCO2}):

$$\Delta Tp(t) = \frac{\Delta T_{2xCO2}}{\Delta Q_{2xCO2}} \cdot \Delta Q_{CO2}(t)$$

As oceans take longer to warm up, this is just a potential increase, while the actual temperature increase lags behind by β =20 years:

$$\frac{d\Delta T}{dt} = \beta \cdot (\Delta Tp(t) - \Delta T(t))$$

Finally, this temperature increase feeds back to economic output via the scaling factor *S*, depicting the relation of abatements costs to damage costs. The b_i and θ_I are the scale and non-linearity of the cost, resp. damage functions:

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

3.2 The agents' perspectives and their influence on the economy

3.2.1 Rule based behavior

In climate-economic cost-benefit analyzes, the parameters needed to determine technological progress, expected radiative forcing or costs and damages are estimated by the modeler and thus external. The idea of the battle of perspectives model is to introduce differing beliefs of relevant agents, by letting them assume these parameters according to their world view. Free Market Advocates assume low climate sensitivity, low damage costs in case of climate change, a high rate of technological progress that is expected to be less climate damaging, and relatively high costs of potential additional climate protection measures. Scientifically Informed agents believe in medium costs and technological progress and IPCC best-estimates for climate sensitivity. Environmentalists think that climate sensitivity is high and also believe in high damage costs but, on the other hand, low contributions of technological progress and low mitigation costs.[3] Fatalists do not have an opinion about the world's behavior except the conjecture that it cannot be predicted. There are thus no figures for progress or cost estimates for this type because, for them, they don't matter.

The individual prediction models can be matched with corresponding or non-corresponding environments. Note that this "real world" is hypothetical. Although a scenario based on IPCC best estimates (the scientifically informed world) may be considered as the most likely, it is not proven for sure. This view is not shared by all, which is precisely the reason to investigate the consequences of deviating world views and scenarios. It can be studied how the supposed real world develops if relevant decision makers have a realistic perception of it and what happens if they do not.

In the model, all agents have the same two possibilities to exert an influence on the model economy. They decide about the percentage of output that shall be invested into traditional capital (*I*), which constitutes their attempt to control economic growth. In addition, they decide about the transition speed from fossil to alternative fuels (*M*), by adjusting *LM*, reflecting their climate policy. All types of agents do so following the same logic: they predict how the economy and world temperature will develop according to their internal model and compare these data with the observation of the "real world". If their expectations are not fulfilled, they adjust their measures slightly, but remain within the bounds of their deep rooted beliefs. Free Market Advocates aim for continuous economic growth of at least 3.2 % per year (*min[dY]*). This corresponds to the average world GDP growth rate between 2005 and 2014, exempting the financial crisis years 2008 and 2009 (Worldbank 2015a). If that is not realized, they increase their investments according to the following rule, where I_I stands for investments of the Free Market Advocates and *I* for total investments of all types of agents:[4]

$$I_I(t) = \min\left[0.4, \min[dY]\frac{I(t-1)}{dY(t-1)}\right], \quad \forall\ dY(t) < \min[dY]$$
$$\textit{and}\ \ I_I(t) = I_I(t-1), \quad \forall\ dY(t) \geq \min[dY]$$
$$\textit{with}\ \ dY(t) = \frac{Y(t)-Y(t-1)}{Y(t-1)}$$

[3] The corresponding figures can be verified in table 2 below.

[4] *I* is the sum of investment decisions I_I of all agents, weighted by their share in the population. Note that all *I* are investment rates, not sums.

The starting value for the investment rate is 0.237, corresponding to gross capital formation in 2005 (Worldbank 2015b). It is needed because the former investment level is maintained if the agents are satisfied.

Due to their belief in climate robustness, Free Market Advocates opt for a very slow transition from fossil to regenerative fuels with a half-life time of 1000 years. They only adjust this if damage costs exceed a threshold of 1 % of GDP, because that is supposed to endanger long term growth. Fossil fuel transition is then accelerated moderately. There is a lower bound of a half-life time of 20 years for this transition:

$$LM_I(t) = 20 + (LM_I(t-1)-20)\cdot\ 0.99$$

Scientifically Informed agents aim at a stable economic growth (*D[dY]*) and stable investments and thus adjust their investments as a function of former investments and changes in economic growth:

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

They also try to avoid changes in temperature of more than plus 2° compared to 1900. If temperature rise is below plus 0.5°, they aim at a half-life time of 100 years for the transition from fossil fuels. If it rises further, this transition is accelerated. Again, the fastest possible transition has a lower bound of 20 years half-life time:

$$\begin{aligned} &LM_H(t) = 100,\ \ \forall\ M[\Delta T(t)] < 0.5 \\ &LM_H(t) = 20 + (LM_H(t-1)-20)\cdot 0.995,\ \ \forall\ M[\Delta T(t)] > 0.5 \wedge M[\Delta T(t)] < 1 \\ &LM_H(t) = 20 + (LM_H(t-1)-20)\cdot 0.99,\ \ \forall\ M[\Delta T(t)] > 1 \wedge M[\Delta T(t)] < 1.5 \\ &LM_H(t) = 20 + (LM_H(t-1)-20)\cdot 0.98,\ \ \forall\ M[\Delta T(t)] > 1.5 \end{aligned}$$

Environmentalists aim at zero economic growth. They only invest to compensate for depreciation (δ_K) and aim for the most rapid possible transition to alternative fuels with a half-life time of 20 years:

$$I_E = \frac{\delta_k\cdot K(t-1)}{Y(t-1)}$$

Fatalists do not have a climate target or economic growth objective. They thus are not willing to invest and stick to the lowest transition rate from fossil fuels. For the other three types, two further conditions have been introduced, deviating from the Janssen (1996) model. First, following evidence from the Worldbank (2013) and the IMF (2013), there is an upper threshold of 40 % of GDP for investments to guarantee a minimum level of consumption. Second, as all agents except Fatalists care about economic stability, they try to maintain the capital stock by compensating for depreciation.

The above specifications are used to run scenarios in which the model world works as the agents assume (utopia) and others in which the world's behavior is not in line with the agents' beliefs (dystopia) to analyze how wrong perspectives impact long term growth and climate development. Thus far, the agents are not learning. They merely carry out their predefined behavioral rules, allowing only for minor adjustments.

3.2.2 Learning

Following these perspective/real world matches and miss-matches we analyze mixed populations. The world is then ruled conjointly by a number of agents with contradicting beliefs. The actual policy is calculated as the average of the proposed measures, weighted by the number of agents adhering to them. Also, the agents are now allowed to learn from each other. They observe temperature development and compare it with their expectations. If the observations deviate from their prediction, there is a high probability for them to acknowledge their world view does not fit. In that case, they compare their accuracy of prediction with other agents and possibly change their perspective, if another one seems to fit better. This part of the model is implemented by a procedure using part of the operators known from Genetic Algorithms (Holland and Miller 1991; Geisendorf 2011). Such algorithms are used in Evolutionary Economics to depict learning.[5] They allow us to compare different problem solutions with respect to a fitness criterion (here accurateness of prediction) and adapt the solution with a likelihood to imitate better solutions relative to their performance.[6] The algorithm used here works with full imitation, not with a recombination of strategies. It could thus be questioned if it should be called a Genetic Algorithm. In Janssen (1996) and Janssen and de Vries (1998), it is called thus, but, lacking recombination as a representation of cross-over, it is not a full Genetic Algorithm in the proper sense.[7]

It has to be acknowledged that, in this simple form, there is no political process going on when perspectives change. The model illustrates how discrepancies between the conviction of agents and the climate system's actual behavior affect climate change, how, in such cases, the actors are not able to reach their own goals with the activities available when sticking to their convictions, and how time lags impact the long term trajectory, even if the actors are able and willing to learn.

3.3 Data

We distinguish between data relating to the climate-economy model and data relating to the agents' perspectives. Table 1 gives an overview of relevant starting values and parameters. It also shows how current data deviate from the Janssen (1996) model. Table 2 shows the input relating to the agents' perspectives.

Climate-economic dynamics deviate in several respects from the original model. Some figures, such as expected temperature rise for a doubling of CO_2, have increased (IPCC 2007), while others, such as population estimates for 2100, seem to be rather high in the original model (Lutz et al. 2008). So are the highest loss expectations of the Environmentalists that are considerably above the most pessimistic scenarios of the

[5] Arifovic (1991, 1994), Andreoni and Miller (1995), Birchenhall (1995), Dawid (1999), Geisendorf (2009).

[6] In case of an acknowledged misfit of the own perspective, adaptation occurs with 80 % probability and the chosen worldview is not necessarily the best or correct one. It is determined by a roulette-wheel-like procedure from all other perspectives with a higher likelihood to take a perspective with a relatively good prediction quality at the current stage. The procedure has been calibrated to replicate the speed of learning in Janssen's model.

[7] For a thorough description of the modelling details of Genetic Algorithms, other sources should be consulted (e.g. Goldberg 1989; Mitchell 1997).

Table 1 Original and updated input data for the economy and the climate model

	Janssen (1996)	Battle of perspectives 2.0
General data		
World population 2100	11.3 billion	10.1 billion
GDP 2005 (in billion $)	Approx. 25 (in 1990 $)*	66.95 (in 2005 $) (48.59 in 1990 $)
Elasticity of output with respect to capital (γ)	0.25	0.3
Increasing returns so scale depending on investments in the capital stock (φ)	–	0.1
Capital stock 2005	?	137
Initial investment rate	0.215	0.237
CO_2-Emissions 2005	Approx. 7.5–8 GtC*	8079 GtC**
Radiative forcing W/m^2 for $2xCO_2$	4.3	3.7
Carbon intensity of output (α)	0.32	0.12

* depending on development, according to persperctive

** multiply by 3.7 to get the more commonly found CO_2 values

Table 2 Original and updated parameters for personal beliefs and strategies (original data taken from Janssen 1996, p. 209 and put into parentheses when they have been updated)

	Free Market Advocate	Scientifically Informed	Environmentalist
Technological development			
δ_{a_Start}	0.04*	0.012	0.002
δ	0.4**	0.5	0.6
ϵ	(0.01) 0.01	(0.01) 0.003	(0.01) 0.00001
Attempted transition rate rom fossil fuels at start			
LM	1000	100	20
Climate sensitivity			
$_{\Delta}T_{2CO2}$	(0.5) 1.5	(2.5) 3	(5.5) 7.7
Economic losses for +3°			
	(0 %) 1.5 %	(1.3 %) 3 %	(32 %) 20 %
Resulting damage costs			
θ_1	(0) 0.00166	(0.0014) 0,0011	(0.004) 0.0025
θ_2	(0) 2	(2) 3	(4) 4
Mitigation costs			
b_1	0.25	0.11	0.05
b_2	3.5	2.9	2.3

* This value has been corrected, as the original value of 0.004 must be a mistake

** Free Market Advocates believe in solving growth problems by technological progress. But they do not think the energy transition will be cheap, which is why this value is lowest for them

Stern Report (Stern 2007), which in turn has been criticized for its too dramatic position. CO_2 emissions, after having declined for some periods before 2000, drastically increased by +41,8 % between 2000 and 2013 (Statista 2015). This is reflected in higher starting values for CO_2 in 2005 than the Janssen model predicted. World GDP has been calibrated to fit Nordhaus' figure of 66.95 billion in 2005 US \$. The strong deviation from the Janssen model has two reasons. First, we calculate in 2005 values instead of 1990 US \$. In 1990 US \$, it corresponds to 48.59 billion. Second, world GDP measures vary between sources (Nordhaus 2008; Worldbank 2015a; IMF 2015). The Nordhaus base value has been chosen because other figures also have been calibrated to fit his data. Table 1 summarized the updates for the climate-economic part of the model.

The agents' perspectives are still in agreement with present work on the effect of uncertainty about climate change. Uncertainty is likely to shape not only the intensity, but also the type of reaction, according to individual beliefs (Watson 2008). Agents believing in a dramatic rise of temperature are likely to favor mitigation, whereas Free Market Advocates believing in moderate change will favor adaptation. This is implemented in the model. The perspectives only have to be altered, where new data suggests an update of the beliefs. This is the case for estimates on climate sensitivity and damage costs.

Also, as described above, the autonomous energy efficiency improvements have been linked to the perspectives, to reflect the optimism or pessimism about automatic efficiency improvements. Note that there is a contradiction between these estimates—which are optimistic for Free Market Advocates—and the belief concerning the increase of energy efficiency through innovations. The latter is less optimistic for Free Market Advocates, reflecting the fact that they consider energy saving technology to be expensive. This contradiction is a puzzle, reflecting an ambiguity of technocrats. On the one hand, they trust technology to be able to solve all problems and assume a strong growth of technological progress and a tendency of new technology to be more efficient without explicit development efforts. On the other hand, they argue against mitigation investments. They thus, at the same time, believe such investments to be too expensive, as well as not much needed. Table 2 provides the parameters and starting values used to individualize the equations described above.

4 Results

Two kinds of experiments are run. In the first series, the agents are non-adaptive, i.e. they stick to their worldview and only make minor adjustments in case their expectations are not met. As a reference case, we first analyze how the "active" types (Martens and Rotmans 1999) deal with utopian and dystopian worlds. We thus place each agent type in a world corresponding to his expectations. Then we place some of them in worlds not behaving as they assume. This cannot be done for Fatalists because they do not have an opinion about the world's specific behavior; we could place them in an erratic world but there are not many insights to be gained thereby. Fatalists are only considered for the second kind of experiments where different agent types live together in worlds corresponding to the perspective of only one of them. Before switching to that mixed population, we investigate two further questions. First, we compare the performance of Free Market Advocates in non-conforming worlds with the respectively fitting perspective, to see how long it takes until their overexploitation of the system hits back. And second, we test whether we can observe a freeriding effect when Free Market Advocates live together with Environmentalists in a sensitive environment.

This first, non-learning part of simulations is followed by a second part with adaptive agents, where mixed populations are placed together in a world corresponding to the assumptions of one of them. The actual policy and behavior at each time step is a mix of the actions chosen by each type, weighted by the number of agents adhering to that perspective. If the outcome deviates from the perspective of the agents, they have a potential to change it to the one of the more fitting types, with a higher probability to imitate the fittest one. This experiment is done first for a majority of Free Market Advocates in a scientifically informed world, together with small groups of Scientifically Informed and Environmentalists. Arguably, the scientifically informed world can be considered to be the most likely one (it is the one behaving according to scientific evidence, i.e. best estimates) and the Free Market agent type to be the most prevalent, as observable behavior is concerned. Stating that, we have to keep in mind that the model agents do not just represent declared ambitions for climate protection but the actual decisions and doings.[8] This is compared with the opposite, where a majority of Scientifically Informed are placed in the more robust environment of the Free Market Advocates. This test is done to examine the consequences of unnecessarily careful policies, in case the climate sceptics or those supporting investments to foster economic growth above other considerations would be right. Finally, the role of Fatalists is analyzed, by placing them in the most likely case where a majority of Free Market Advocates lives in a scientifically informed world with minorities of Scientifically Informed and Environmentalists and different proportions of Fatalist.

4.1 Non-learning agents

4.1.1 A world working according to the agent's beliefs

In the "battle of perspective 2.0", differences in economic growth are driven to a large extend by the endogenization of technological progress. We introduce increasing returns to scale, linked to the capital stock. The growth potential thus depends on the investments the agents decide to make in the capital stock. Free Market Advocates believe in a higher rate of progress per dollar spent on technology. Therefore, a world functioning according to their world view has a higher growth potential as such. At the same time, they also aim for high growth rates. Thus, even when placed in their utopian world, they start investing more money into growth than do the other types.

Figure 2 represents results for the three perspectives with an active world view in their corresponding environment. Differences in output and temperature change are thus not only dependent on the different actions they take—Free Market Advocates, e.g., invest much more money in building up the capital stock than Environmentalists, who

[8] While there have, e.g., been ambitious climate goals in the Kyoto protocol (UNFCCC 2011), emissions of subscribing countries only went down because of a decline of the former Soviet Union, while they increased for the western, industrialized subscribers, as well as for non-subscribing USA or China and worldwide (UNFCCC 2014; Statista 2015). Unfortunately, it is also already clear that the "intended nationally determined contributions" to CO_2 emission reductions, agreed on at the Paris COP21 climate conference, would – even if realized – not even suffice to keep global warming within the self-intended maximum warming, declared in the same agreement (UNFCCC 2015).

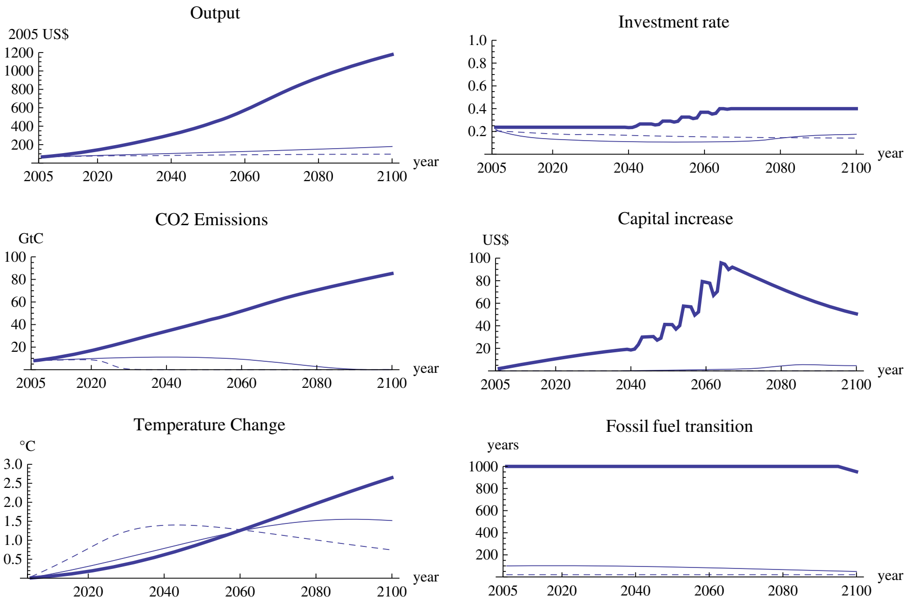

Fig 2 Utopian worlds for Free Market Advocates (*thick black line*), Scientifically Informed (*black line*) and Environmentalists (*dashed*)

only want to maintain it constant, or even Scientifically Informed, who only invest to maintain a moderate growth rate – they also depend on the different inherent growth potentials of these three worlds. Growth in a free market world is thus impressive, but as

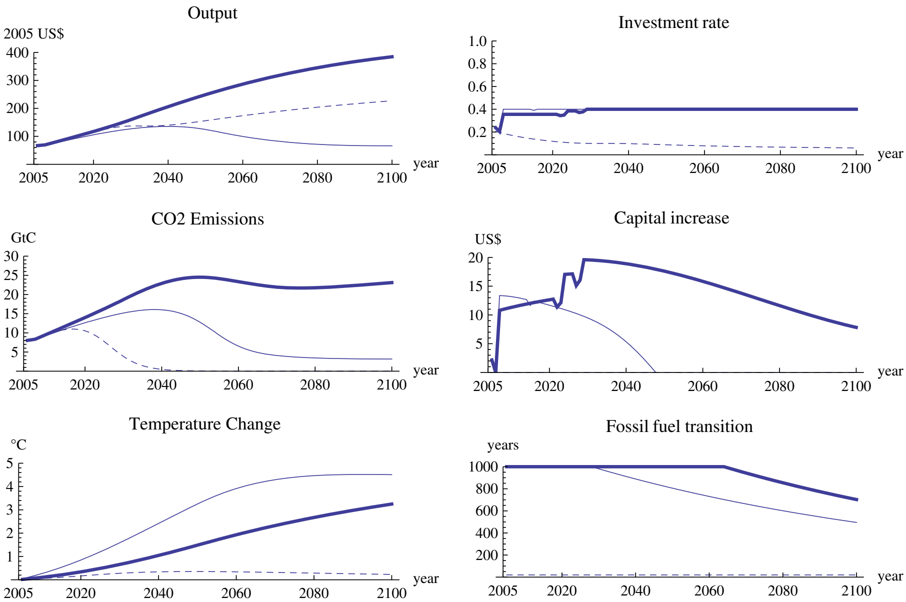

Fig 3 Dystopian worlds for Free Market Advocates in a scientifically informed world (*thick black line*), Free Market Advocates in an environmentalist world (*black line*) and Environmentalists in a free market world (*dashed*)

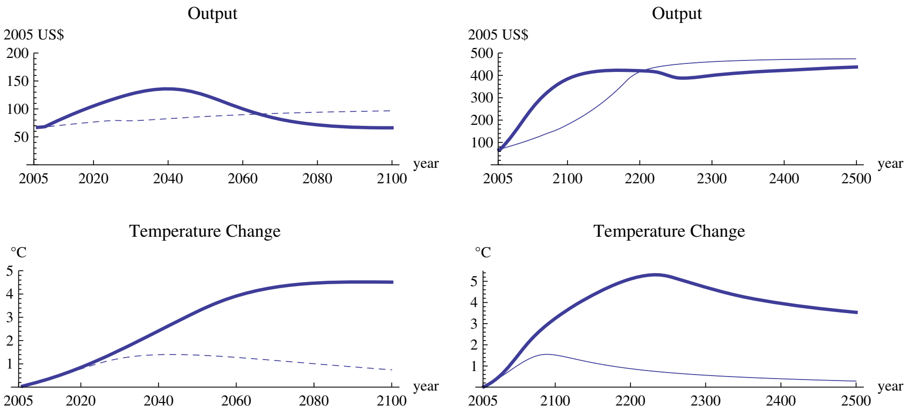

Fig 4 Output and temperature change for Free Market Advocates (*thick black line*) in environmentalist (*left*) and scientifically informed (*right*) dystopias compared to the respectively correct perspective (Environmentalists = *dashed*, Scientifically Informed = *black line*)

Free Market Advocates aim at permanent growth rates of 3.2 %, it reaches its limits. Approaching the 2070th, investments are not able to increase the capital stock as much as before any more. As the basic capital stock already is very high, most of the investments are needed to replace depreciation. Temperature increases above the maximum of plus 2°, recommended by the IPCC. But the free market world is not very climate sensitive. Therefore, temperature at the end of the century is only about 2.7° above the 1990 value. Also, the economy is not much affected by temperature increase. Only at the end of the century, do Free Market Advocates see a necessity to decrease their emissions. The other

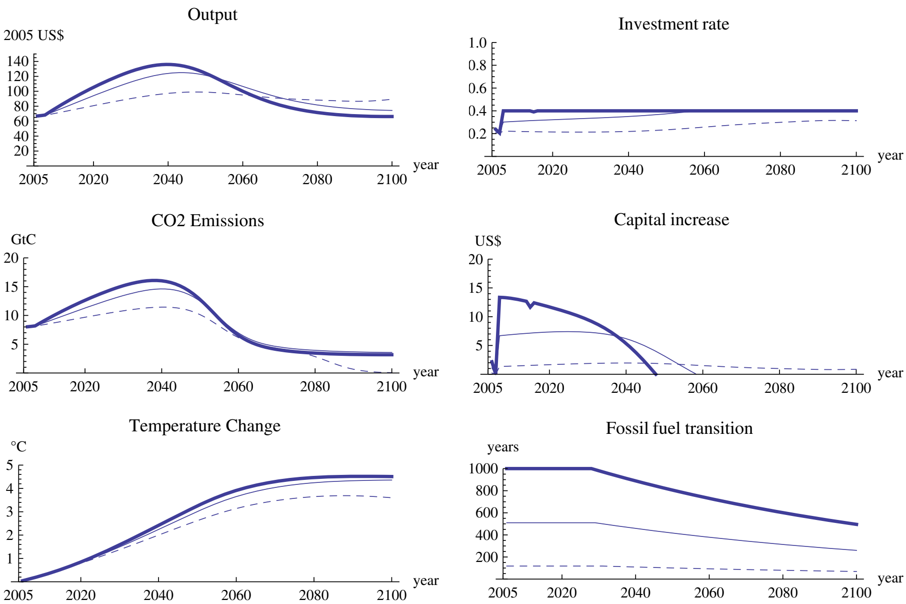

Fig 5 Free Market Advocates living in an environmentalist world (*thick black line*) compared to mixed populations with 50 % Free Market Advocates and 50 % Environmentalists (*black line*) and only 10 % Free Market Advocates living with 90 % Environmentalists (*dashed*)

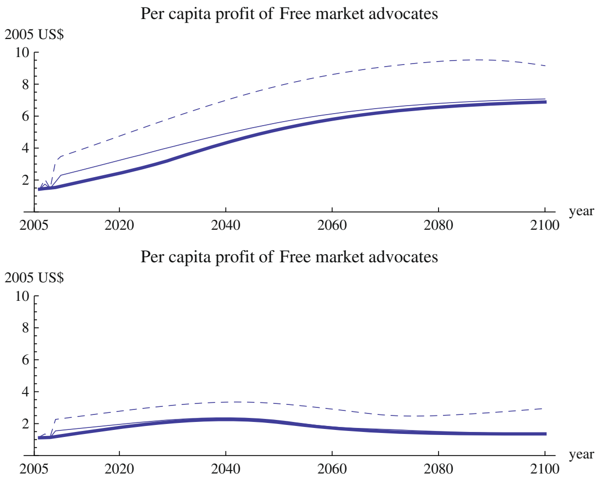

Fig 6 100% Free Market Advocates (*thick black line*) compared to mixed populations with 50 % Free Market Advocates and 50 % Environmentalists (*black line*) and only 10 % Free Market Advocates living with 90 % Environmentalists (dashed) in a scientifically informed world (*upper graph*) or an environmentalist world (*lower graph*)

two types assume a much more sensitive environment. Environmentalists aim for a fast reduction of fossil fuels from the beginning on, and even Scientifically Informed accelerate their transition rate. They thus manage the transition from fossil to regenerative fuels until 2035 and 2095, respectively. Scientifically Informed more than double GDP until the end of the century. Even Environmentalists, not aiming for growth, reach a moderate GDP growth, because after their fossil fuel transition lets temperature decline, the existing capital stock is more productive, due to lower damage costs.

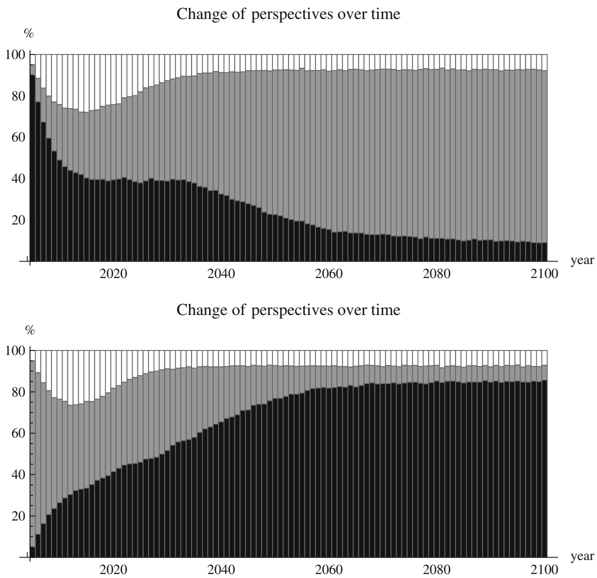

Fig 7 Change of perspectives: An initial majority of Free Market Advocates in a scientifically informed world (*above*) and Scientifically Informed in a free market world (*below*). Average over 100 runs

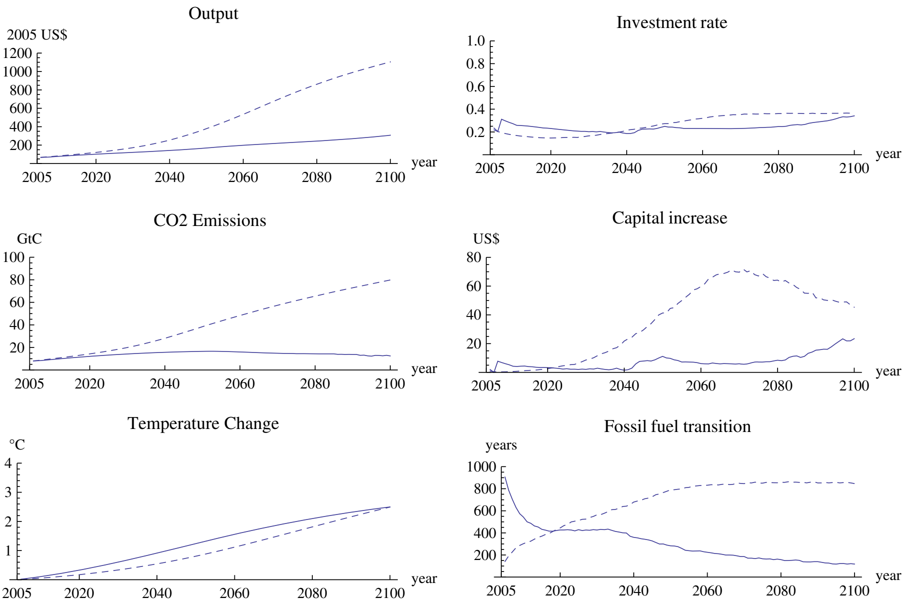

Fig 8 An initial majority of Free Market Advocates in a scientifically informed world (*black line*) and Scientifically Informed in a free market world (*dotted*), both living with initially 10 % of the other active perspectives. Average over 100 runs

4.1.2 Non-fitting world views and their consequences

When Free Market Advocates are placed in a scientifically informed world, economic growth is only 1/3 of what they could achieve in their ideal word. Temperature increases by 3.2° and the economy is affected much earlier by damages, inciting even this careless type to decrease fossil fuel consumption around 2065. In an environmentalist world, they feel compelled to increase the transition even before 2030, but still have to live with the consequences of their too careless behavior in the beginning of the century. From 2040 on, their economy is declining and after 2091, GDP is lower than at the beginning of the simulation, illustrating the long lasting effects of an overexploitation of the climate system (Fig. 3).

Environmentalists in the free market world, on the other hand, more than double their GDP until the end of the century, but stay considerably below the growth potential of this robust world, in which they could have reached six times as much (Fig. 3).

The effect of wrong perceptions, in comparison to the corresponding right perception, can be seen in Fig. 4. Temperature increases about plus 5° in both cases, when Free Market Advocates are placed in the two unfitting environments. In an environmentalist world it happens quickly, although growth is very moderate, even for the high investment, Free Market Advocates are willing to make. Also, economic growth suffers from high damage costs, letting it decline below the initial values at the end of the century. In the scientifically informed world, which is depicted until 2500, not just 2100, temperature increase of more than plus 5° takes longer. For a long time, Free Market Advocates perform better than the well adapted agent type, but eventually the Scientifically Informed agents overtake. The long initial phase of higher GDP makes it hard to recognize that the free market governance style is provoking a problem. However, the decades after the turning point should not be taken lightly in the interpretation of the scenario. More than 50 years of first moderate, than sharper decline of GDP would pose a dramatic problem for a real world population.

4.1.3 Free-riding effects within mixed populations

Free Market Advocates living in a scientifically informed or an environmentalist world overexploit these environments, which are more sensitive than they assume. They overinvest, pushing up economic growth and eventually enter a phase of economic decline. However, when living together with Environmentalists, both effects are dampened. The more Environmentalists they share the world with, the higher and more stable the long term output of this world (Fig. 5). It can thus be assumed that Free Market Advocates benefit from a free-riding effect due to the more ambitious climate protection of the Environmentalists, but the effect cannot be isolated at the aggregate level we are observing thus far. For Free Market Advocates, living in a world working according to the Environmentalist perspective, the aggregate shows an overtaking of output for the group with lower shares of Free Market Advocates, but that alone is no proof of free-riding benefits.

We thus attribute GDP shares in proportion to the investments made by each group to this group and compare per capita GDP for different population mixes. The free-riding effect now becomes clearly visible for both cases. Even in the moderate scientifically informed world, a small group of Free Market Advocates is able to make a considerably higher profit than if they would govern that world alone, due to the careful policy of the Environmentalists (Fig. 6 upper graph). The effect is even stronger in the environmentalist world, if we look at it in percentages—although, obviously, the general profitability of this world is lower (Fig. 6 lower graph).

4.2 Learning agents

The results for learning populations are subject to stochastic influences. The general tendencies are thus discussed based on Monte Carlo simulations over 100 runs, to portray average tendencies. However, as the real worlds' development will not be an average outcome but one specific "run" out of the range of likely scenarios, we also discuss exemplary runs to illustrate the possible raggedness of such an evolutionary process.

4.2.1 Adaptive agents placed in worlds not working according to their beliefs

The real world is populated by people with differing beliefs. If the world view of some is very incorrect, there is a chance for them to learn from others and adapt to a more fitting perspective. This case is investigated now. We place a majority of Free Market Advocates in a scientifically informed world and vice versa and let them adapt.[9] The agents do not just differ in their ambitions; depending on their expectations, they

[9] In the original model, Janssen (1996) mentions having placed 50 agents in the learning model. However, when illustrating the shifts in their proportions, 10 % of the agents are initialized as belonging to the two minority groups (Janssen 1996: 224–226). As it is not possible to include 2.5 agents per perspective, the present paper works with 60 agents, including 3 agents for each minority group. Note, however, that the total number of agents is not decisive for the results.

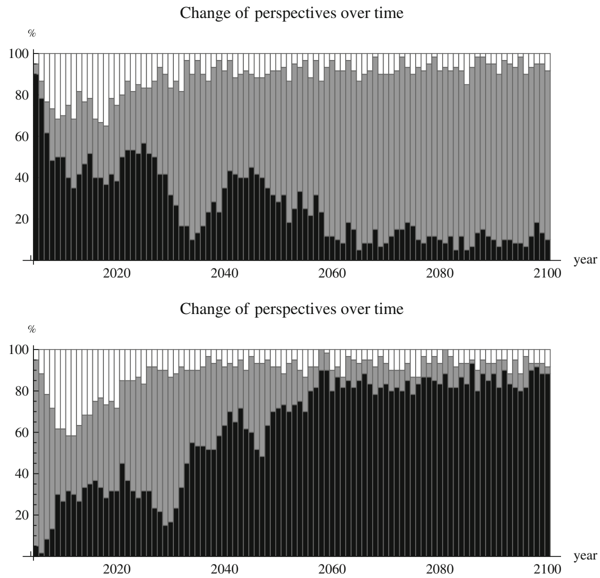

Fig 9 Change of perspectives: An initial majority of Free Market Advocates in a scientifically informed world (*above*) and Scientifically Informed in a free market world (*below*)

also have different criteria to check the accuracy of their predictions. If the expectations are not met, there is a likelihood to adapt their beliefs and behavior. This likelihood gets stronger, the more the observed data deviate from the agents' predictions. In the

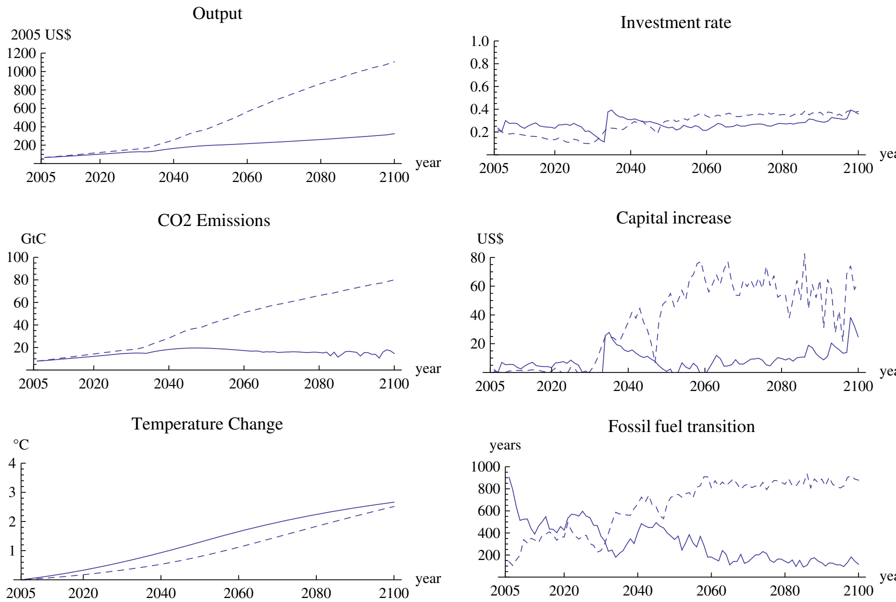

Fig 10 An initial majority of Free Market Advocates in a scientifically informed world (*black line*) and Scientifically Informed in a free market world (*dotted*), both living with initially 10 % of the other active perspectives

simulation this is modelled by a learning procedure, based on some operators from Genetic Algorithms, as explained above. Figure 7 illustrates the results from the learning processes in terms of percentages of perspectives. The incorrect worldview is reduced step by step, while the correct one eventually takes over.

As growth prospectives in a free market world are far above the other scenarios, it seems as if adapting Scientifically Informed would do not much worse than an initially correct population, but GDP at the end of the century is about 12.5 % below the one possible for the initially correct world view. Unfortunately, this is different for adapting Free Market Advocates in a scientifically informed world because, as discussed above, their performance is even better than for the correct world view for a long time, making it difficult to understand the long run disadvantage of this strategy (Fig. 8).

The general tendencies, identified in the Monte Carlo simulations, are also true for individual runs, but the systems' behavior is much more ragged, as Figures 9 and 10 illustrate. Note that economic output is only relatively stable, because we did not

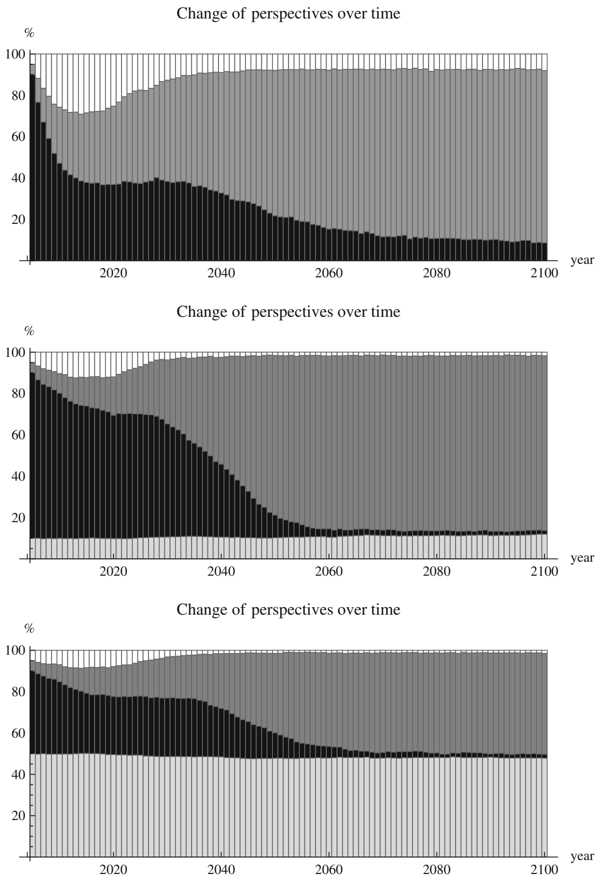

Fig 11 Change of perspectives: An initial majority of Free Market Advocates in a scientifically informed world, living with initially 10 % of Scientifically Informed and Environmentalists (*above*) and 10 % (*middle*) or 50 % (*below*) of Fatalists. Average over 100 runs

include more realistic stochastic elements in the links between investment and capital formation, as well as between capital and output.

4.2.2 How do Fatalists influence GDP and climate?

Fatalists are a population group not believing in the effectiveness of active politics. They do not have confidence in the usefulness of either investments into economic growth, or the renouncement of economic growth for the sake of the energy transition. Thus Fatalists do not contribute to investments at all, and they are portrayed as sticking to an unchanging transition half-live time of 1000 years. Including them in our analysis is motivated by the fact that people acting as Fatalists exist in the real world. There are large parts of the world population that either do not have the means to contribute to growth or climate protection, because they are living below the poverty threshold (e.g. 14,2 % in 2011 or 9,6 % in 2015, Worldbank 2015a), or feel their investments will not pay off in an unsecure world and are thus not willing to contribute to an active policy. The relevant percentage for this type can thus be assumed to be at least as big as 10 %, but actually higher. Figure 11 illustrates how different percentages of Fatalists affect the changes of perspectives over time.

Fatalists are assumed to be non-learning. In order to capture the possibility that they still change their mind, or that one of the other types converts to being a Fatalist, we allow small fluctuations between groups, not motivated by a fitness comparison. It can be observed how Fatalists slow down the learning process. The incorrect perspective is reduced much slower, the more Fatalists are in the population (Fig. 12). This effect becomes even more visible in some individual runs, as Figs. 13 and 14 illustrate. For

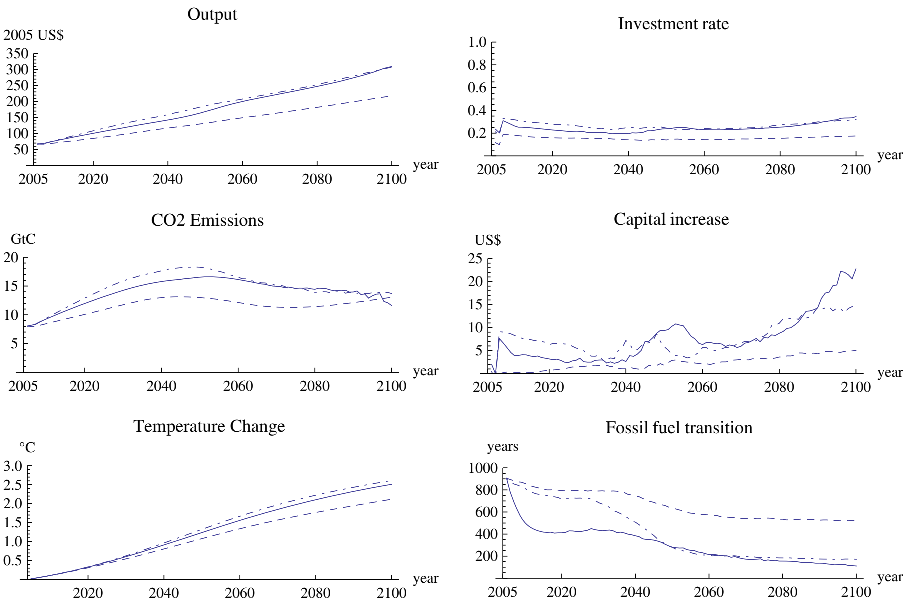

Fig 12 An initial majority of Free Market Advocates in a scientifically informed world (*black line*), living with initially 10 % of Scientifically Informed and Environmentalists and a non-learning proportion of 10 % (*dash dotted*) or 50 % (*dashed*) Fatalists. Average over 100 runs

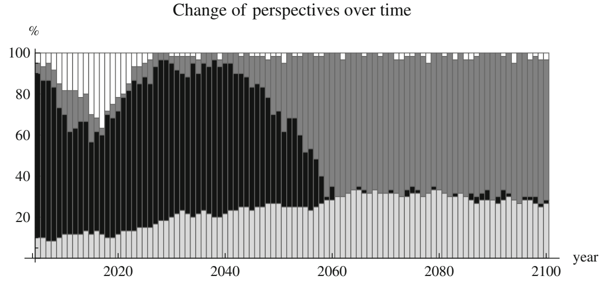

Fig 13 Change of perspectives: An initial majority of Free Market Advocates in a scientifically informed world, living with initially 10 % of Scientifically Informed and Environmentalists and 10 % Fatalists

a high percentage of Fatalists, the explanation is straightforward, because their unengaged behavior translates into less investment, lower economic growth and therefore less climate change and necessity to reduce the contribution of Free Market Advocates. A lower percentage of Fatalists creates an interesting effect. As the initial selection against Free Market Advocates is slowed down, they overinvest and increase economic growth above a world without Fatalists. In case of a high percentage of Fatalists, their ambiguous role becomes visible. They are not willing to contribute to climate protection, and the transition rate remains far above the one usually needed in a scientifically informed world. However, having them in the world, the higher transition rate is actually not needed, because they are also not willing to invest in the capital stock, and the smaller proportion of Free Market Advocates cannot make up for the lack of money. Both growth and temperature increase are thus reduced. Figure 12 illustrates how different percentages of Fatalists affect the outcomes.

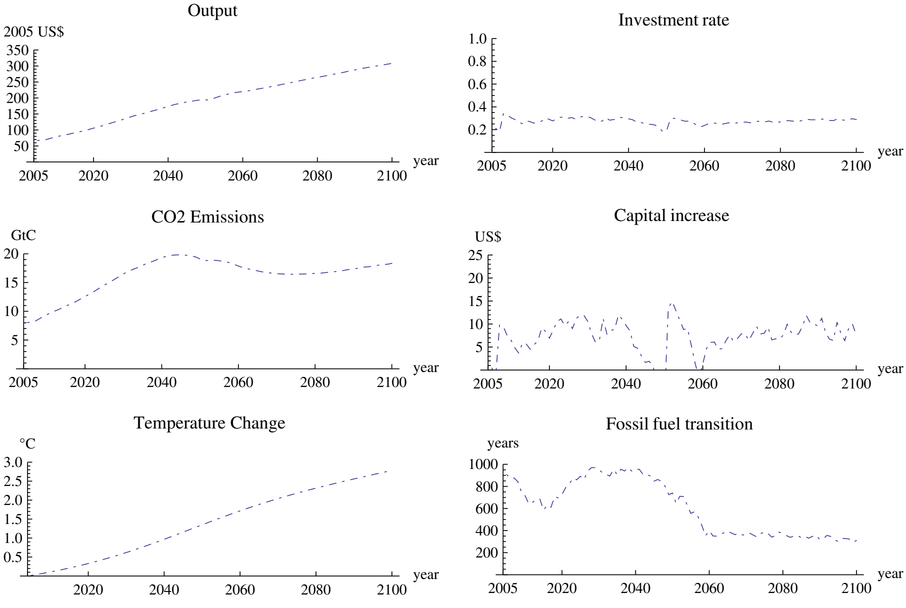

Fig 14 An initial majority of Free Market Advocates in a scientifically informed world, living with initially 10 % of Scientifically Informed and Environmentalists and a non-learning proportion of 10 % Fatalists

5 Conclusions and possible next steps in agent-based climate-economic modelling

The main contribution of agents-based climate-economy models, such as the one presented in this paper, is the creation of awareness for the effect of perceptions on climate policy. "Optimal climate policy is a utopia" (Van den Bergh 2004, p. 385). Climate policy is determined by the way climate change is perceived by relevant actors or institutions. "There is, in short, no 'climate change' outside of a socially constructed framework" (Jordan and O'Riordan 1997: Abstract before page 1). The model results illustrate how substantial the impact of wrong or belatedly corrected perceptions can be on the long run climate-economic development. A late recognition of a too optimistic point of view, e.g., entails the danger of long lasting consequences in the form of rising temperature and economic damages. This is not saying that the corresponding scenario with a very sensitive environment is the most likely, or that it proves the necessity for immediate action. The most likely scenario is the one based on IPCC best estimates, i.e. the scientifically informed world one, but others have a probability of being correct as well. Therefore, it is interesting to study their dynamics.

The climate-economy part of the model is a rather simple abstraction, which might be criticized. It has to be noted, however, that this part is an only slightly adapted version of the corresponding parts of current optimization models à la Nordhaus, which are still considered as state of the art in climate-economic modelling (Nordhaus and Sztorc 2013). Therefore, the debatable part is mostly the way the perceptions, the derived actions and the learning process have been implemented.

The perceptions are based on the cultural theory of risk. Its insights and typology are still valid (Wildavski and Sweditorlow 2005). Of course, it might be questioned whether the types have been translated correctly into the model's perspectives, but on balance they seem to represent good fits. However, the problem of current international climate policy does obviously not depend on such perceptions alone. Judging from surveys in the European Union, 62 % of the citizens are convinced that climate change is the second most pressing issues of the world, right after poverty and food or water scarcity (European Commission 2008). The problem awareness agreed upon in the world governments seems to fit largely with the scientific knowledge of the IPCC reports and thus with the Scientifically Informed type. However, actual climate protection lags far behind the measures taken by the corresponding agents in the model. Empirical studies, such as Leiserowitz (2006) on US American perceptions of the climate problem, suggest that learning is much slower in reality. The proposed scenarios underlying Figures 2, 6 and 7 are thus quite optimistic in that they let Scientifically Informed act on their convictions and allow for immediate learning of a high percentage (80 %) of those holding erroneous beliefs, when their expectations are not fulfilled. Compared to real world climate policy and observable emissions, this seems quite ambitious. Current data on rising CO_2 emissions show that a lot of countries do not stick to their own proclaimed intentions, fixed in the Kyoto protocol. Weyant (2008) points out that, thus far, even the least ambitious propositions for climate protection, advocated by reports such as that of Nordhaus (2008), who has been largely criticized for underestimating the problem, have not been carried out. Between 2000 and

2013 worldwide CO_2 emissions have increased by 41.8 % (Statista 2015). The model thus does not depict this actual increase of the problem. In turn, it illustrates how costly belated adaptation is, even if it would start soon.

Janssen (1996) and Janssen and de Vries (1998) do not consider reasons for institutions or governments to fall behind their proclaimed convictions about necessary abatement measures. Yet, in international negotiations these are plenty. Climate stability is the most exemplary common good and thus associated with the typical provision and maintenance dilemma. Even agents convinced of an immediate pressure for action might refrain from it, because of the marginal impact of their isolated measures, or because of distributional and justice issues. Some will only renounce to short term profits, if others do so as well or if they are compensated. The actual willingness to act is thus likely to result in less action than could be expected from the perspectives alone. These aspects have been addressed by several of the above discussed papers and could be integrated in a future version of the "battle of perspectives".

A second point, regarding the modelling of the agents' activities, concerns the quite simplistic way in which actions are taken in the model. The agents only have two ways to influence climate policy and rely on only one or two indicators of success. However, as a proxy for the more complex underlying dynamics, these values are still fairly reasonable. Temperature change is the most obvious check whether the intended climate policy works. Production output is the typical indicator of macroeconomic growth models, and GDP, which it approximates in the model, is the most locked at indicator for economic success. The most critical point may be the transition from fossil to regenerative fuels, as a proxy for climate policy, because a large part of CO_2 reductions may come from increased energy efficiency, instead of from a change of fuel. However, at the current level of abstraction, this is mainly a question of denomination. In the model, the classification of climate protection as a transition from fossil to renewable fuels has two consequences. It reduces the energy intensity in production and it reduces production itself via the scaling factor, because it is costly. Both could just as well be interpreted as resulting from more efficiency than from an energy transition. We partially took care of the consideration concerning energy efficiency, by including agent specific increase rates. However, we are aware that this is still a simplistic view of the complex aspects contributing to greenhouse gas reduction in reality. This level of abstraction, however, is typical for macroeconomic models, where the world output is represented by an aggregate production Y and every production input as capital (K). The legitimate criticism of such an approach could be counterbalanced by the fact that it is otherwise very difficult to design a general model on a large scale with the ability to derive general conclusions. Models concentrating on empirical cases of limited reach or investigating specific aspects of climate policy, which are discussed in the literature review, illustrate that difficulty.

Compliance with ethical standards I declare, that I complied with my ethical responsibilities as an author. The submitted paper has been written by the author alone and has not been previously published by another journal. It has not been submitted to more than one journal for simultaneous consideration. No data, text, or theories by others are presented as if they were the author's own. No data have been fabricated or manipulated. There are no conflicts of interests and no research involving human or animal participants had been conducted for the purposes of this paper.

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