Testing innovation, employment and distributional impacts of climate policy packages in a macro-evolutionary systems setting

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Authors: Bernhard Rengs (OEAW, TU WIEN),
Manuel Scholz-Wäckerle (WU), Ardjan Gazheli, Miklós Antal,
Jeroen van den Bergh (UAB)

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Contribution to the Project

Together with UAB we carried out a conceptual as well as formal model-based analysis (dynamic, multi-agent modelling), employing different bounded rationality specifications for particular agents. This allows for an analysis of policy response by various types of agents, and the influence of interactions between agents. The work explores the role of meso-rule for macroeconomic success.

Jel codes:

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Bernhard Rengs
Wittgenstein Centre for Demography and Global Human Capital (IIASA, VID/ÖAW, WU)
Vienna Institute of Demography
Austrian Academy of Sciences
and
Research Group Economics
Institute of Statistics and Mathematical Methods in Economics
Vienna University of Technology
Austria
bernhard.rengs@oeaw.ac.at

Manuel Scholz-Wäckerle
Institute for Ecological Economics
Vienna University of Economics and Business
and
Research Group Economics
Institute of Statistics and Mathematical Methods in Economics
Vienna University of Technology
Austria
manuel.scholz-waeckerle@wu.ac.at

Ardjan Gazheli
Institute for Environmental Science and Technology
Universitat Autònoma de Barcelona
Edifici Cn - Campus UAB
08193 Bellaterra (Cerdanyola)
Spain
a.gazheli@gmail.com

Miklós Antal
Institute for Environmental Science and Technology
Universitat Autònoma de Barcelona
Edifici Cn - Campus UAB
08193 Bellaterra (Cerdanyola)
Spain
antalmi@gmail.com

Jeroen van den Bergh
ICREA, Barcelona, Spain
& Institute for Environmental Science and Technology
Universitat Autònoma de BarcelonaEdifici Cn - Campus UAB
08193 Bellaterra (Cerdanyola)
Spain
& Faculty of Economics and Business Administration and Institute for Environmental Studies, VU University Amsterdam
jeroen.bergh@uab.es

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Abstract

Climate policy has been mainly studied with economic models that assume representative, rational agents. However, it aims at changing behavior associated with carbon-intensive goods that are often subject to bounded rationality and social preferences, such as status and imitation. Here we use a macroeconomic multi-agent model with such features to test the effect of various policies on both environmental and economic performance. The model is particularly suitable to address distributional impacts of climate policies, not only because populations of many agents are included, but also as these are composed of different classes of households driven by specific motivations. We simulate various policy scenarios, combining in different ways a carbon tax, a reduction of labor taxes, subsidies for green innovation, a price subsidy to consumers for less carbon-intensive products, and green government procurement. The results show pronounced differences with those obtained by rational-agent model studies. It turns out that demand-oriented subsidies lead to lower unemployment and higher output, but perform less well in terms of carbon emissions. The supply-oriented subsidy for green innovation results in a significant reduction of carbon emissions with a slight reduction of unemployment.

Keywords: Agent based modelling; climate change; bounded rationality; carbon productivity; environmental innovation; double dividend; other-regarding preferences.

1. Introduction

There is serious evidence that climate change is happening. Scientific research shows that now it is considered with more than 95% that human influence has been the dominant cause of the observed warming since the mid-20th century (IPCC, 2014). This underlines the need for developing and implementing climate policies.

The study and testing of such policies so far is predominantly executed using models that assume representative, rational economic agents. It is nevertheless widely accepted now that this is not an accurate approximation of reality. It is better described by heterogeneous agents, which are moreover showing behavior in line with bounded rationality and other-regarding preferences. Such types of behavior become even more important when people are stimulated, as by climate policies, to drastically change their decisions and even life styles, and facing societal changes surrounded by much uncertainty as is the case of a transition to a low-carbon economy (Grin et al., 2010; Safarzynska et al., 2012). Indeed, climate policy aims at a change in behavior associated often with the consumption of carbon-intensive goods that may be subject to bounded rationality and social preferences, such as status, imitation and even snob effects (Gowdy, 2008; Brekke and Johansson-Stenman, 2008; Gsottbauer and van den Bergh, 2010).

Here we offer a first study of climate policy that uses a macroeconomic multi-agent model (ABM) of an artificial one-country economy that accounts for different types of boundedly rational and other-regarding behaviors of agents (households, firms, banks, governments) in a macroeconomic systems setting (Rengs and Wäckerle, 2014). The model belongs to a very small set of agent-based models in macroeconomics and political economy, which respond to a call in economics to give more attention to heterogeneity and complexity in financial- and macroeconomics (LeBaron and Tesfatsion, 2008; Farmer and Foley, 2009; Delli Gatti et al., 2010; Stiglitz and Gallegati, 2011). Households consume subsistence goods (serving basic “needs”) and additional, luxury goods (serving additional “wants”), depending on their class and budget. The consumption of the first is necessary, while behavior anomalies such as status and imitation, associated with specific consumer classes (“poor workers”, “rich workers” and “capitalists”) motivate people’s consumption of the luxury goods. Status or snob effects make firm owners and upper class members to switch the consumption of extra goods and search for new firms, thus forming an important factor of economic innovation.

Firms decide to innovate on the basis of how well they performed in the last period. Two types of innovation are included in the model: green innovation, which may be subsidized by governments, and labor productivity innovation. The environmental extension of the general macro-evolutionary model further involves the specification of CO_2 emissions by firms. The carbon intensity (emissions per output in our model) of a firm can be reduced through green innovation. Banks provide loans to firms for investing in R&D, while the government decides about a policy package that comprises various types of taxes, including possibly a carbon tax, consumer price discounts, and subsidies on technological innovation or investment in green procurement.

We use the resulting ABM and its environmental extension to test different climate policies in terms of their impacts on a range of relevant environmental, economic and welfare indicators. Next to a business-as-usual (BAU - no policy) scenario, we undertake a further simulation by introducing a carbon tax, the revenues of which go to a “Carbon Fund”. Based on using this fund, six different climate policy packages are formulated and examined. This allows us, among others, to test the effect of an environmental tax on (un)employment, and address in a new, innovative way the well-known “double dividend” (realizing environment and employment goals) of environmental tax revision (e.g., Fullerton and Metcalf, 1997; de Mooij, 1999). This debate has been largely waged over general equilibrium effects without explicitly taking into account innovation impacts, consumer dynamics and income/wealth distributions. Here we re-examine its rather skeptical conclusions (a double dividend is unlikely) if the tax revision does two things: on the one hand it shifts the incentives for firms to innovate in improvements in carbon rather than in labor productivity; and on the other hand it shifts consumption by households to less carbon-intensive products. The question is how different the findings with traditional economic model studies are in terms of reduction of carbon dioxide emissions.

A first climate policy package (CPP) uses revenues from the carbon fund to subsidize green innovation. The second CPP considers a tax shift from labor to carbon, which essentially means using the carbon fund to reduce labor taxes. The third CPP examines the effects of a direct consumer price discount subsidized by the carbon fund to stimulate diffusion of green products. As a fourth CPP, we consider a carbon tax with revenues spent on green procurement. Finally, we conduct simulation experiments with various mixes of these climate policies.

We will investigate these policy packages in terms of environmental, economic and welfare performance. Environmental performance will focus on the time patterns of carbon intensity of production and CO_2 emissions and cumulative CO_2 emissions (a measure of global warming). Economic indicators include unemployment, average income and income distribution, demographic indicators of firms, and how these correlate with environmental performance. We will further consider a few social welfare functions to analyze broader conceptions of social welfare that combine some of these indicators (Botzen and van den Bergh, 2014). In addition, we will be able to compare whether climate sustainability can be made consistent with steady economic growth (average income increases). This issue is fundamental to the debate on green growth, which has not devoted much attention to climate constraints, and certainly not from the angle of macroeconomic multi-agent systems accounting for behavioral anomalies. In this context, the productivity trap is relevant: higher labor productivity due to innovation results in more unemployment which is compensated by more demand due to higher wages; but higher wages stimulate further labor productivity rises (Jackson and Victor, 2011). We can study this in relation to the policy involving a shift of taxes from labor to carbon.

The remainder of this paper is organized as follows. Section 2 introduces the basic ABM, including its general structure, the different agents, core parameters and unique features in comparison with similar model approaches. In section 3 we discuss the environmental extension, policy scenarios and performance indicators used. Section 4 presents the simulation results and interpretations of these. Section 5 concludes.

2. The basic macro-evolutionary multi-agent model

The model we present encompasses a full macro-economy that evolves from bottom-up according to agent-based methodology (Tesfatsion and Judd, 2006; Gilbert, 2007), building upon the framework presented in Rengs and Wäckerle (2014). Its computational simulation follows a stock-flow structure that is consistent with the so-called balance sheet approach (Godley and Lavoie, 2012). It includes the following sectors: households, firms, banks, central bank and government. All sectors are disaggregated, except central bank and government, in the sense that they are composed of a multitude of agents and their interactive dynamic relations. Our model is close in spirit to recent models by Cincotti et al. (2010), Delli Gatti et al. (2011), Riccetti et al. (2013) and Chen et al. (2014). Moreover, in terms of scale and scope it is roughly comparable with the models by Seppecher (2012) with a focus on labor markets, Dosi et al. (2013) emphasizing capital goods, banking and innovation, and Lengnick (2013) with a simplified general purpose model.

Our model differs from these other approaches in a number of ways, notably distinct ownership and consumer classes with unique behavioral features and a detailed financial sector. In addition, the model can generate emergence of specialization patterns of firms in terms of the needs and wants servicing goods. In other words, a firm can for example initially produce goods that mainly serve basic needs, and over time shift to serving more want-related goods. This avoids the more common approach of starting with a fixed classification of firms or sectors with particular goods that permanently retain their character. Our approach is parsimonious (simplified) without sacrificing richness in explanatory power.

The approach considers the economy as a complex evolving system that organizes itself endogenously. This is reflected by notions like non-equilibrium dynamics, (in)stability, systemic risk and vulnerability. The recent financial crisis has once more shown that these are central to understanding crucial macroeconomic issues. To add realism to the model, economic agents are described as being heterogeneous and boundedly rational, where we follow the heuristic and algorithmic concept of satisficing decision rules and adaptive behavior (Simon, 1987; March, 1991; and Winter, 2000). Next, we treat the government, the central bank, markets and organizations (firms, banks) as formal institutions and social norms as informal institutions. The latter are described as dependent on agent networks and their dynamics. This steers consumption behavior taking the form of imitation (bandwagon effects) and status seeking behavior by different consumer classes. In the case of status seeking behavior, we consider Veblen effects (conspicuous consumption) and snob effects; both with a focus on luxury goods, where the first is about high-price and the second about rare goods. Because of the population structure of the different agent groups (especially consumers and firms) the model can generate so-called co-evolutionary institutional change (van den Bergh and Stagl, 2003; Hodgson, 2006; Dopfer and Potts, 2008; Wäckerle, 2014).

In what follows we introduce the various types of agents in the model, which include households, firms, the banking system (commercial and central bank), and the government. Figure 1 provides an idea of the main structure of the model, focusing on monetary flows in the economy.

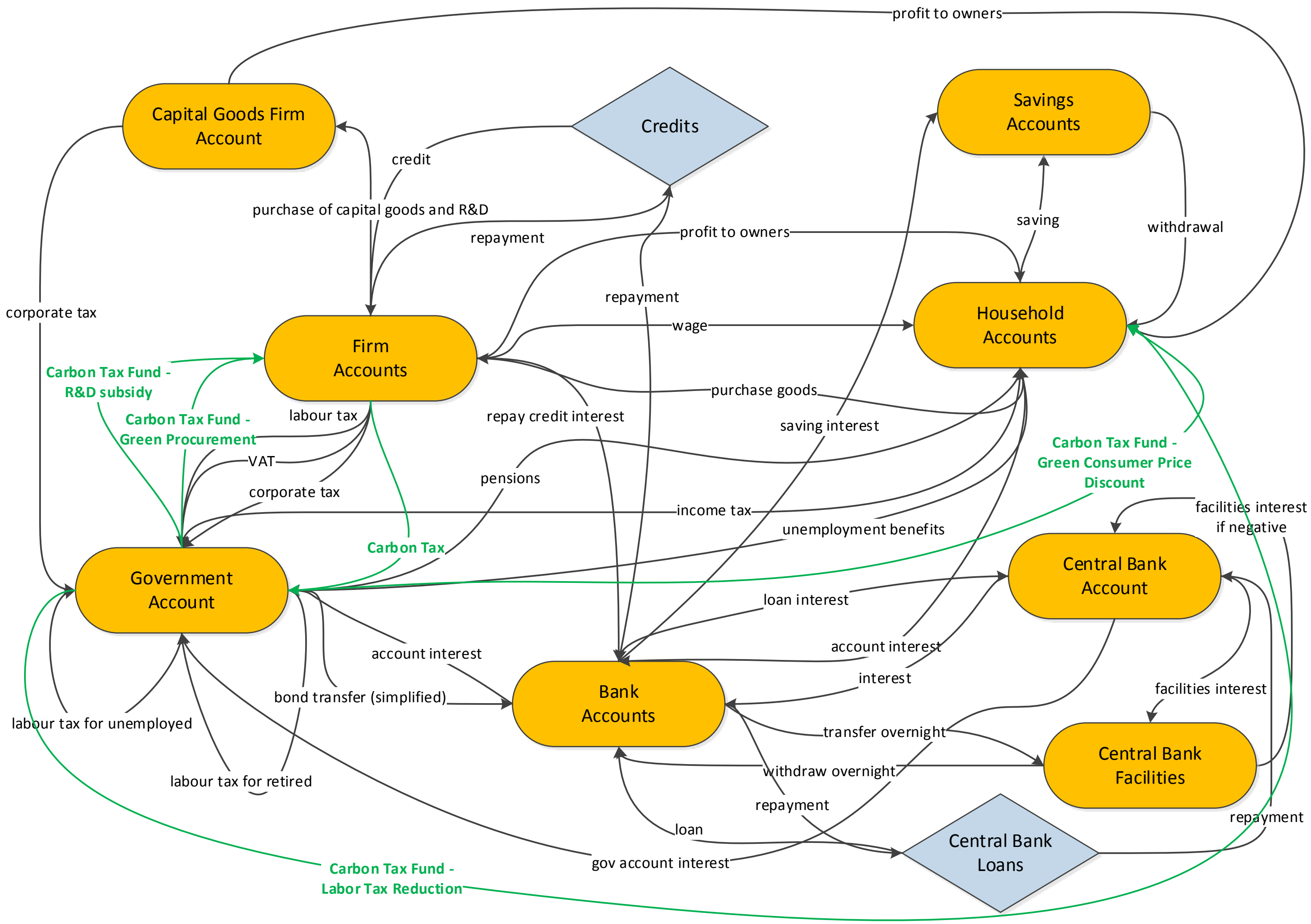

Figure 1: Monetary flows of the artificial economy

Households

Households don't optimize their consumption behavior, but are instead assumed to be rather loyal or rigid in their choice of vendors, while also being open to new opportunities that arise. Their decisions (namely, which firms' products to buy) are linked to two differently motivational aspirations: need and want consumption. The tendency to buy from a specific firm then depends on the respective aspiration, the current product's relative price and firm reputation. The latter two are based on well-documented consumer behaviors: bandwagon, Veblen and snob effects. The consumption decision differs with respect to social class; capitalist households and wealthy workers have a higher saving rate than workers.

Households choose their seller in a boundedly rational way, by having a short list of preferred "vendors" at any given time (following Lengnick, 2013). They try to buy equal amounts from each firm on their list, as firms' stock and household budgets permit. Households actually employ two lists, one for needs and one for wants. Initially, each of these lists consists of *n* randomly chosen firms. During the simulation, households change the composition of these lists based on their preferences, slowly improving them in each round. As preferences are assumed to be different for needs and wants, these two lists will tend to comprise different firms. In the case of need consumption, households replace a firm that did not deliver – because of insufficient production or inventory – by another, randomly chosen one. In the want case, households do not immediately replace a firm that could not deliver, as it indicates a highly sought after good. Instead, they wait up to three months before randomly choosing a new one.

If a seller (firm) is considered for potential replacement and is perceived to be better (by some small but noticeable degree) in terms of price and firm reputation (implying a utility premium for a household consuming its good) than the one selected for potential elimination from the list, the replacement is effectuated. The rules employed in this comparison partially depend on prices and firm reputation (market shares), following the dynamics of imitation and status-seeking behavior (conspicuous consumption à la Veblen, 1899). In this respect we follow on the one hand Veblen's general suggestion of trickle-down effects in social structure (Trigg, 2001) due to working class consumers imitating capitalist class consumers. And on the other hand we are inspired by Leibenstein (1950), who specified consumption dynamics as resembling a bandwagon effect (imitation of other consumers) and contrasted it to the status-seeking Veblen effect (luxury consumption) and snob effect (consumption striving for rare goods – "exclusiveness"). We model Veblenian consumer dynamics in a similar manner as Kapeller and Schütz (2014), but with substantially more details about the differences in quantity and price effects as well as about underlyin g population dynamics.

It is worthwhile to cite Leibenstein (1950, p.205) in this context: "Any real market for semidurable or durable goods will most likely contain consumers that are subject to one or a combination of the effects discussed heretofore.". Leibenstein concludes that there are four possible combinations dependent on price (normal price and Veblen effect) and firm reputation (bandwagon and snob effect). We extend his framework with need and want aspirations as well as social structure. This leads us to the following combinations of aspiration (want and need) and social structure (workers, wealthy workers, capitalists). This is illustrated in Table 1.

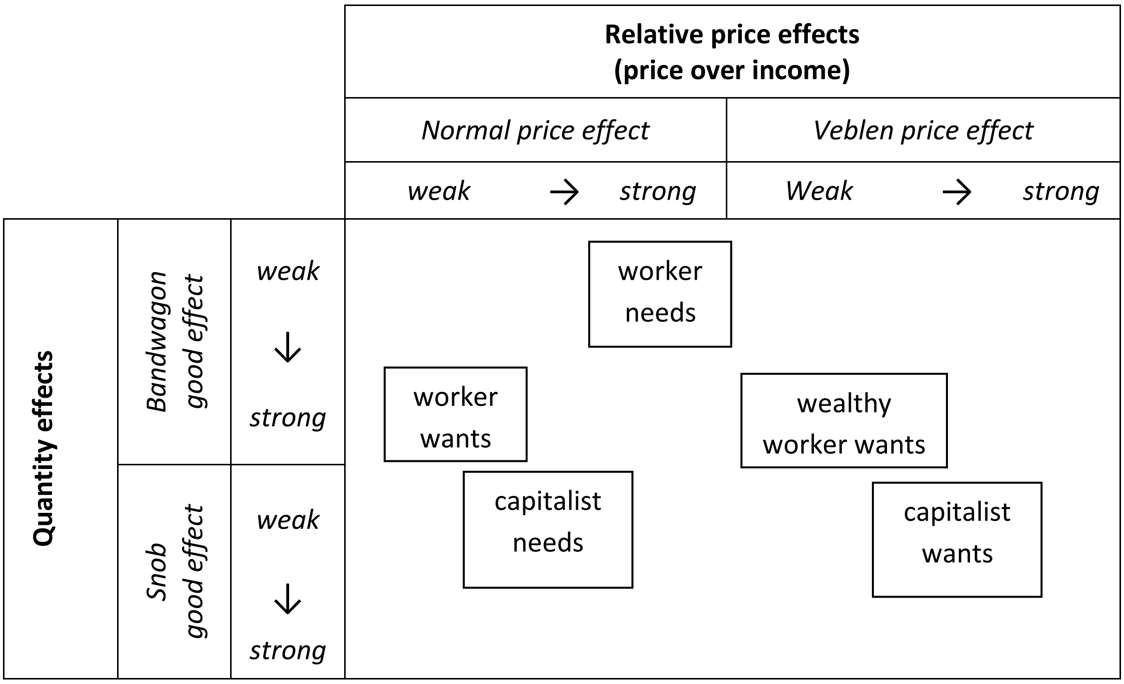

Table 1: Types of consumer behavior and classes represented in the model; characterized in terms of good and price impacts on consumers

The incorporation of the consumers as depicted in the table means that household consumption behavior is highly heterogeneous and dependent on social class. Changes within social class identification are endogenously possible (capitalist may go bankrupt with their firm, wealthy workers may found a firm, etc.), but it cannot appear abruptly; meaning in particular that if there is a change in social class it happens with a lagged duration (set at three months).

Workers, wealthy workers, capitalists have different preferences and behaviors. Workers' need consumption has a high normal price effect (indicating a strong preference for the cheap over the expensive) and a low bandwagon effect. Workers imitate the behavior of all need consumers. Worker want aspirations have a low normal price effect (indicating a weak preference for the cheap over the expensive) and a high bandwagon effect (they imitate the capitalist want aspirations). Whereas wealthy workers follow the same bandwagon, they further consume on behalf of a weak Veblen effect (weakly prefer the expensive over the cheap). Finally capitalist (firm and bank owners) needs are triggered by an average snob effect (searching for rare goods – inverted imitation) and an average normal price effect. Capitalist wants work with the same bandwagon but additionally with an average Veblen effect (they prefer the expensive over the cheap).

Consumption behavior is thus not static but a co-evolving process between behaviors of consumers and social structure; i.e. a dynamic interplay between individual aspirations (need/want), status-seeking behavior, wealth and imitation dependent on emergent social structure driven by interactive evolution of populations of different classes of consumers.

Firms

A second group of agents are firms, which produce final goods using inputs of capital and labor. They employ a firm-specific production technology, with respect total factor productivity and emissions per output unit being heterogeneous among firms. Firms start with a number of differently scheduled credits (each with their own duration) emulating the reinvestment necessary to uphold the constant capital level to counter depreciation. They can apply for loans at banks operating in a credit market to increase or maintain production capacity. Goods-producing firms acquire capital from a single firm that produces capital goods. Physical capital is complementary to the production factor of labor. The capital goods firm is owned (as a crude proxy) equally by all households, who receive profit shares in relation to their wealth. Every month, a full production cycle up to delivery to final demand is achieved.

The initial firm population starts with randomly (using a uniform probability distribution) assigned workers, resulting in slightly heterogeneous firms in terms of numbers of workers. These are then assigned a matching physical capital stock, in accordance with labor productivity and start with homogenous production technology.

Every round each firm adjusts its production by monitoring the level of goods left in the inventory after sales. If sales exceed expectations, i.e. the inventory contains less than the targeted reserve stock (Godley and Lavoie, 2012), the firm decides to increase its output. The reserve stock is calculated by multiplying the firm's sales in the previous period by the production reserve stock rate. Unsold stock depreciates over time since "old" goods are more difficult to sell over time. Prices are adjusted analogously to production, i.e. in relation to the level of under- or overestimation of sales. They are changed by small amounts and never fall below the estimated marginal cost per unit of output plus some mark-up. If the planned production requires more physical capital than available, the firm tries to get a loan to buy the additional machinery. Otherwise the firm maintains its current capital stock, since it cannot reduce it actively in this model, as opposed to the input of labor, which can be adjusted by hiring or firing workers, although with some delay (an interpretation of this could be protection by labor laws; cf. Seppecher, 2012). Physical capital depreciates annually so that the firm will need to reinvest if it desires to maintain the current level of physical capital. The profits of the firm accumulate in its current account over a whole fiscal year (12 months). At the end of the year funds are set aside for research and development (R&D) investments and corporate taxes are applied to the remaining amount. The rest is transferred to the firm owners. Firms adapt the wage based on the average increase of prices.

Firms make their investment decision based on their estimated profit rate, defined as the ratio between profit and physical capital. The estimated profit of the firm is given by expected revenues minus current wages, interest payments, fixed credit repayments and expected additional credit costs. If their estimated profit rate exceeds the interest rate of their bank, the bank will guarantee a loan with a fixed duration and a fixed interest rate. Moreover, banks only grant additional credit if the sum of unrepaid credit of that firm is smaller than the firm's production capital. If the profit rate is too low or the credit exposure is too high, the specific firm has to reduce its production output as much as possible. Obviously, if the profits become too low the firm needs to fire workers and reduce capital inputs, which together will lead to lower production output. In the process, firms may go bankrupt, in which case capitalist households owning the firm become unemployed.

Every period one new firm can be founded by the wealthiest worker household with a low probability. On founding, the owner of the new firm endows the firm with an operating budget for the first quarter and invests in initial machinery. The former are fully financed out of the households budget, the latter is equally financed out of own budget and in form of firm credits. If the household does not have enough savings to finance its part of the investment, the bank grants it a form of private credit (overdraft on its account). This is used as a proxy for risky private investment, and results in private debt which the owner cannot transfer to the firm. Newly founded firms start with production and emission reduction technologies that represent the average technology of the current firm population.

Banking system

Next we consider commercial banks and the central bank, which serve various roles in the model. Banks keep current accounts for firms, the capital goods firm and households (allowing for deficits) and savings accounts for households. In addition, they grant firm loans. They pay and charge interest for these different financial services applying distinct rates, limited by central bank interest rates. Banks have to refinance themselves, by monitoring assets (loans) and liabilities (savings). If banks lack liquidity they request loans at the central bank.

The central bank keeps current accounts for the government (including overdraft functionality) and banks, as well as deposit facilities for banks, involving the paying or charging of interest. Furthermore it acts as a lender of last resort, but for the presented simulation experiments it does not accommodate any monetary policies.

Government

The government serves various roles in the model. It makes transfers to unemployed and retired households, and collects taxes on labor, income and capital gains, corporate profits made by banks and firms and the capital good firm, and value-added of sales. The government budget in the model is never perfectly in balance because of uncertainty about both tax revenues and government expenditures – as is the case in reality. As unemployment benefits and pensions are downward rigid, the government has no means to cut costs and has to deficit spend if necessary. If indebted, it pays interest to banks and households (in relation to their wealth) as a proxy for government bonds.

3. Environmental extension of the model

The environmental extension of the previously described ABM involves modeling CO_2 emissions of the processes of firms producing goods, and policies to curb these emissions as well as stimulate relevant environmental innovations and achieve neutral or positive employment effects.

Firms emit CO_2 over the course of their production process depending on the employed emission reduction technology. Half of the initial firm population starts with slight emission reduction technology and the other half starts without emission reduction. The emissions per output (carbon intensity as a measure of pollutiveness) can alter over time through "green or environmental innovation". Investment in R&D leading to innovation is assumed to have an immediate effect either on carbon intensity of the respective firm's output or on total factor productivity. In other words, innovation is an individual process with a small role given to spillovers, a side effect of R&D. Since there are two different technology branches (emission reduction vs. total factor productivity), both may benefit from spillovers. The highest spillover effect will occur if all firms perform research on the same technology branch, and achieving a much higher improvement in technology than without spillovers. Spillover effects depend on the sum of R&D investments in that branch.

This represents the idea that knowledge creation regarding energy efficiency is relatively easily shared or transferred between sectors. This environmental extension allows us to test effects and consequences of pure climate policy (like a carbon tax) and a policy mix that can generate positive labor effects and contribute to climate goals.

Our model does not account for climate change and its feedback to the economy, causing economic costs in terms of lost production (agriculture), damage to infrastructure and buildings due to extreme climate events, increased resource scarcity (water), health effects, etc. its Studying this is the focus of the long-term climate-economy models like DICE, FUND and PAGE. Our approach is closer to the climate policy assessment models, often using a general equilibrium format (Jorgenson et al., 2008; Naqvi, 2014).

Household consumption behavior

Climate policies generally will raise prices for both more and less carbon-intensive goods and services. While these are subject to normal demand responses (less demand for higher price), higher prices of goods produced by processes with a lower carbon intensity ("greener goods") may in the short run attract conspicuous consumers. These then act in accordance with the Veblen (wealthy consumers looking for expensive goods that provide status) or snob effect (capitalists that look for rare goods; some "green goods" may become rare because of a very high price). All other consumer classes will slowly, in the medium run, imitate these richer classes (bandwagon effect).

Emission reduction and adoption of greener technologies by firms

As indicated, firms can improve either through total general ("non-green/non-environmental") factor productivity (i.e. a technological progress scale parameter in the production function) or via green innovation (affecting the carbon emissions per output). These two options are exclusive, with the firm decision about which type of R&D to invest in depending on past performance (profits). Basically this decision heuristic relies on a simple profit comparison among a chosen subset of firms. Firms consider a number of their competitors (randomly chosen) and compare the profit-rate of these firms at the end of a fiscal year. If one of the innovation strategies has delivered higher profit-rates for a greater number of competitors than the other one, then this strategy is decided upon for the observing firm in the next year, independent of the previous strategy. If the situation is indecisive, then the firm sticks to its former strategy. As all firms observe the technology chosen by their competitors in the past year, firms can also imitate a strategy that the observed firms themselves no longer follow. Generally firms engage in research and development only if there is enough money left within the firm or if the firm is profitable enough to get a credit from the bank. The costs of R&D are the same for both strategies (general and green innovation), defined as a fixed fraction of the firm's current production capital. Innovation takes the form of upgrades of machinery, which is bought at the end of the year and is effective immediately at the beginning of the new fiscal year (bought from the capital goods firm). The cost is financed partly by profits and partly by loans, should profits not suffice to cover the costs. This reflects the reality that some (notably large, established or successful) firms finance their innovation completely out of profits, while others (notably starters) fully depend for this on loans, while a third category will combine the two funding sources.

The cost of innovation is based on a constant relation to capital stock. To simulate the increasing technical difficulties and costs of reducing emissions per output unit, we assume that consecutive reduction of emissions gets less effective in a non-linear way. That is, the more effective the emission reduction technology that a firm currently employs already is, the smaller the next improvement from its R&D efforts will be. This is in line with the widely accepted assumption in economic analysis of environmental policy that marginal abatement costs are rising in the level of abatement. Arguably, this depends on assuming rational behavior, at least cost-minimizing or ranking of costs-effective abatement options. Furthermore all R&D efforts are subject to early mover advantages for both R&D branches.

Government: carbon tax, environmental tax revision, producer and consumer subsidies, and green procurement

To stimulate reduction of emissions by firms, the government can implement a price incentive via carbon taxes. The total revenues of these are the product of emitted units of carbon times the per unit carbon tax. These revenues accumulate in a "carbon tax fund" during the fiscal year, which is used to fund a number of policy instruments that are carried out in the following fiscal year, which will be described in a later section. The above mentioned carbon tax gains are however assumed to be dedicated to finance the indicated climate policy instruments exclusively, thus the overall balance of the government has no influence on these policies. To execute some of these policies, the government offers subsidies either to households or to firms if they take specific actions. As the government has to announce the amount of the subsidy before households and firms take decisions (as they will base their decision on the extent of the subsidy), it does not know how many subsidies will actually be requested every month. As the government has to take the number of subsidies as given, it has to vary the amount that it will pay per subsidy on a monthly basis. To do so it bases the estimate for this period's (a month) number of requested subsidies on the number of subsidies paid in the previous period. This may cause a cyclical movement of budget deficits and surpluses (i.e. under/overshooting the carbon tax fund) on a monthly basis but leads to a nearly balanced carbon tax fund budget on a yearly basis.

The government can thus employ various policy instruments to either reinforce or complement the effect of the primary climate policy (carbon taxes), such as: directly support (subsidies) of green innovation, reducing labor taxes (creating employment), stimulating diffusion of less carbon-intensive products through (product subsidies to consumers), or even combining these instruments. Since the carbon taxes are collected in the first year of simulation for the first time, the additional policy instruments are not applied until the second year.

Governments can use the subsidy instrument as part of environmental policy. This takes the form of stimulating green inventions, innovations or market applications (adoption and diffusion) of environmental technologies, such as renewable energy or more energy-efficient technologies. Innovation subsidies are widely regarded as an instrument of technology policy that is complementary to carbon taxes, in the sense that both are needed to foster a transition to a low-carbon economy. The reason is that carbon taxes alone will select the most cost-effective current technology (e.g., wind instead of solar PV, or a particular type of PV over another, even if it is uncertain whether this is the (environmental or economically) best technology in the long run. To keep a potentially attractive technological trajectory (e.g., solar PV) open, i.e. avoiding early lock-in, one can subsidize its R&D. Private companies typically underinvest in such R&D as returns on investment are too (s)low or uncertain, implying the need for public support. Formulating a policy package with carbon taxes and innovation subsidies will allow us to test to what degree these are complementary or substitutes in an evolutionary multi-agent context.

Basically the government has two different options to foster a certain technological trajectory or even changing a technological paradigm, namely *"supply-push" and "demand-pull"* (Dosi, 1982). The former strategy in our case aims to change technologies in a more sustainable direction by subsidizing "environmental innovation". Firms then "push" the technological trajectory in a certain innovation direction, and demand is hoped to follow. The second option relates to the idea that technological change is largely driven (or "pulled" in a certain direction) by the demand side. This takes the form of the government providing product subsidies to lower consumer prices so as to stimulate the diffusion of less carbon-intensive products. Since in reality both supply-push and demand-pull mechanisms are continuously at work, in our model we include both mechanisms and associated policy instruments (where different scenarios will experiment with specific combinations of such instruments).

Basic and policy scenarios

The first step is to run the model without any policy setting in business-as-usual (Scenario 1), which serves as a reference scenario for assessing the various policy scenarios. A first policy scenario is aimed to test a carbon tax, i.e. a tax on CO_2 emissions without employing any additional climate policies (Scenario 2). As the government has no means to reduce or increase its general spending (unemployment subsidies and pensions) willingly, these additional tax revenues have no effect on its behavior:

- Research & development (Scenario 3): if a firm follows a green innovation trajectory, its R&D costs are subsidized. This can take the form of subsidies for the installation of green filters, for example. The total amount of R&D subsidies provided by the government will be approximately equal to the revenue of the carbon tax. Individual firms receive subsidies in relation to their R&D costs, weighted by the marginal effectivity of the improvement. Thus, if two firms have equal R&D costs (i.e. who have the same production capital), the firm that will achieve a higher emission reduction by R&D will get a higher subsidy.

- Labor tax reduction (Scenario 4): this is the much discussed idea of a shifting from labor taxes to carbon (CO_2) taxes. This would alter the incentives for innovation from stimulating improvements in labor to carbon productivity, with potentially beneficial effects for environment and labor market.
- Consumer product subsidy (Scenario 5): a subsidy to lower consumer prices for less carbon-intensive products, to stimulate their rapid diffusion.
- Green procurement (Scenario 6): the government buys relatively much less carbon-intensive (greener) products. This is operationalized by letting the government search randomly half of the population of firms producing relatively clean products, and sorting them according to carbon intensity. The lower the distance to the cleanest firm the more the government purchases (and it buys thus the most from the cleanest product).
- All climate policy instruments actively used (Scenario 7): the carbon tax revenues are divided in equal parts among the different climate policy instruments at the end of each year.

Simulation settings and performance indicators

Simulations are run with 2000 households, 100 firms and five banks, one government and a central bank. Every simulated time step represents a full month. The time horizon of simulations is 25 year time span, therefore we look into annual aggregated data to compare the different policy scenarios. Additionally, we zoom in on a few performance measures and show the more fine-grained monthly dynamics as well. In general we look into annual simulated data for GDP growth, the unemployment rate, evolution of consumer price (in relation to the base year), emissions per GDP, the ratio of sold “wants goods” over sold “need goods”, the profit-rate of capitalists, the long-term capitalist wealth in relation to total wealth, and dynamics of production as well as of emission reduction technology. Annual data is derived as the average of monthly data over the year. Table 2 gives an overview about the main simulation parameters used for experiment.

The model parameter which regulates the maximum credit exposure of firms was set to a fraction of firm’s capital. To this extent banks are acting rather carefully than greedy regarding the issuing of credits. As a consequence, newly founded firms can only grow slowly at best, whereas they could multiply their capital and output very fast if banks were assumed to be less risk-averted.

Table 2. Main simulation parameters

Households	
Number of vendors on preferred lists	7
Number of replacements per month	1
Reserves of need consumption goods	1 month
Savings rate worker households	0.1
Savings rate wealthy worker households	0.15
Savings rate capitalist households	0.2
Initial savings endowment of worker households	$\gamma_1 * annualwage_{\text{household}}$ $\gamma_1 \sim U(1,2)$
Initial savings endowment of capitalist households	$10 * (initial\ minimum\ wage)$
Firms	
Initial ratio capital (individual firm level) to wages (annual)	2
Returns to scale (production function)	1
Production reserve stock rate	0.1
Unsold stock depreciation rate (monthly)	0.5
Capital depreciation rate (annual)	0.1
Firm founding probability (monthly)	1/18
R&D costs as a fraction of capital	0.1
Number of firms regarded during R&D imitation	5
Maximum improvement of R&D efforts (w/o spillovers & FMA)	0.2
Maximum spillover effect (based on achieved improvement)	0.5
Banks	
Credit runtime	5 years
Credit runtime for newly founded firms	15 years
Credit interest rate (annual)	0.04
Account interest rate (annual)	0.00125
Account overdraft rate (private credit)	0.05
Savings interest rate (annual)	0.015
Central bank deposit interest rate (annual)	0.01
Central bank loans interest rate (annual)	0.02
Government	
Initial minimum wage	1000
Initial unemployment subsidy	1000
Minimum wage increase minimal interval	5 years
Employment protection duration	2 months
Value added tax rate	0.1
Labor tax rate (flat for all worker households)	0.2
Income tax rate (flat for all capitalist households)	0.2
Capital gains tax rate	0.3
Corporate tax rate (banks, firms, capital goods firm)	0.3
Emission tax (in relation to average initial price)	0.1

4. Results

Simulation results are presented below in a format that allows direct comparison of the various scenarios formulated in the previous section. Basically we go stepwise through the central macroeconomic measures plus emissions and technology coefficients and compare the scenarios with BAU: GDP, unemployment, price inflation, carbon emissions, purchasing power, firm profit rates, wealth distribution, technology and emission reduction coefficient.

Figure 2 shows the annual development of real GDP. Real GDP is measured as the aggregated final demand by households and the government, adjusted by the weighted mean price for every year. At a first glance we see that the introduction of a carbon tax dampens GDP over the whole course of the simulation, in comparison to BAU. However, the collected revenues from this tax can bring back GDP to BAU once it is used for R&D subsidies (scenario 3). All other policy scenarios work as a demand shock for the economy and boost GDP up in contrast to BAU. In scenarios 4-7, even the initial value of GDP is significantly higher than BAU, since expectations of all actors are adjusted correspondingly from the start. The highest real GDP development is reached within scenario 4, i.e. the flat labor tax reduction on the household side that translates into higher purchasing power, a result that is confirmed by figure 6 later on.

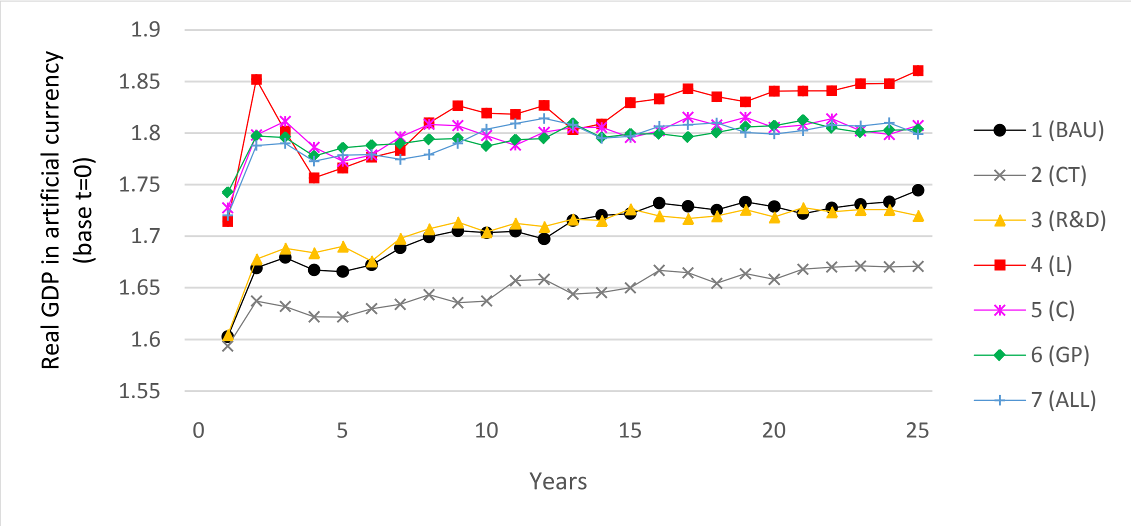

Figure 2: Real GDP under each policy scenario

Figure 3 shows the monthly development of real GDP in comparison to figure 2 which shows annually aggregated data for the same simulation runs. As can be seen in both figures the artificial economy needs one or two years to stabilize into the long term trajectories, though it takes up to five years for scenarios of policies that cause strong increases in demand. The reason for the initial perturbations is that it is nearly impossible to create initial conditions that perfectly match the model's endogenous dynamics. This is common with more complex ABM simulations, some even need a prolonged "warm-up" phase of simulation periods, compare e.g. Lengnick (2013). Furthermore, figure 3 indicates small seasonal effects within annual periods, which are a result of profit distributions and interest payments at the end of every fiscal year, which cause households' behavior to change and requires firms to adapt. As figure 3 shows, fluctuations within years are relatively small, revealing stable dynamics. Still, displaying monthly data reduces readability of the figure, without gaining additional insight. Thus, we will only show annual data in the following figures.

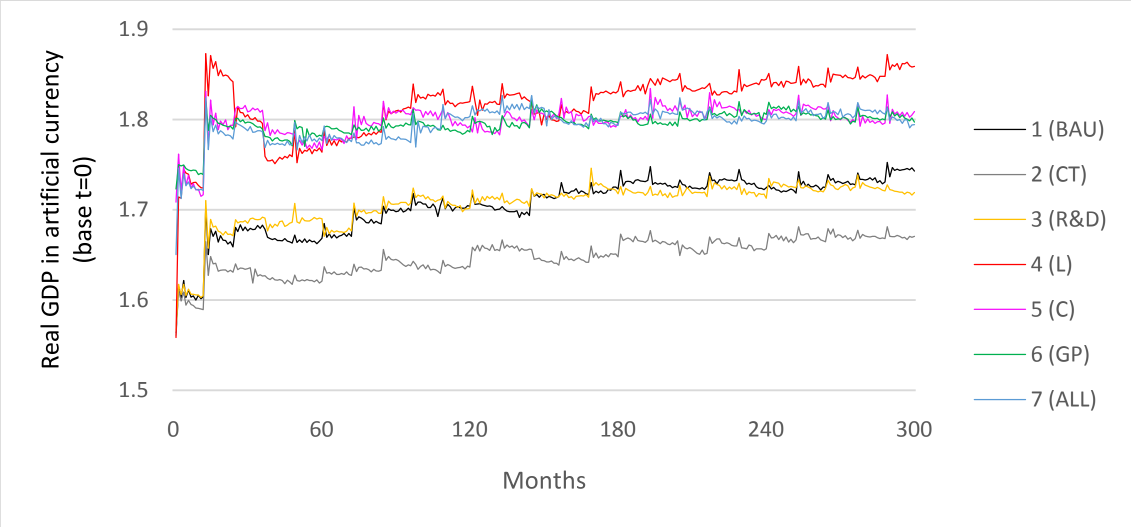

Figure 3: Real GDP under each policy scenario – (monthly data)

In terms of unemployment we can immediately observe strong differences among the chosen scenarios. Figure 4 highlights that the unemployment rate has a bandwidth for fluctuations up to 4% among the scenarios. The carbon tax scenario 2 (CT) has the highest unemployment rate starting with 18% and developing till 24% after 25 years. This notion indicates that a carbon tax without any particular dedication for its revenues creates a significant problem for the labor market that needs to get addressed. The tax makes the price of carbon-intensive products more expensive and aggregate demand is shocked by this policy, translating into lower production as we have seen in figure 1. In our case all scenarios 3-7 with a combined policy perform even better than BAU, a surprising result in face of the diversity of economic channels we have addressed with them. The best performing scenario in terms of employment (lowest unemployment) is given in scenario 4 (L), using all carbon tax revenues to reduce labor taxes. This is what one might expect, but it should be noticed that the difference with 5-7 are not that huge. The latter three are performing quite similarly in terms of unemployment, which is intuitive as they all contribute to stimulating diffusion, whether through private or public consumption, or both. Finally scenario 3 (R&D) performs very well in terms of unemployment, more than we have expected. In the first 10-15 years of simulation the unemployment rate is quite close to BAU, but then the R&D subsidies pay off and the scenario catches up with 5-7. Still, scenario 7 (ALL) does not stand out that much. The reason is that (equally) distributing carbon tax revenues over all mentioned complementary instruments dilutes the impacts of each compared to their effect in policy scenarios were all revenues are spent on a single instrument.

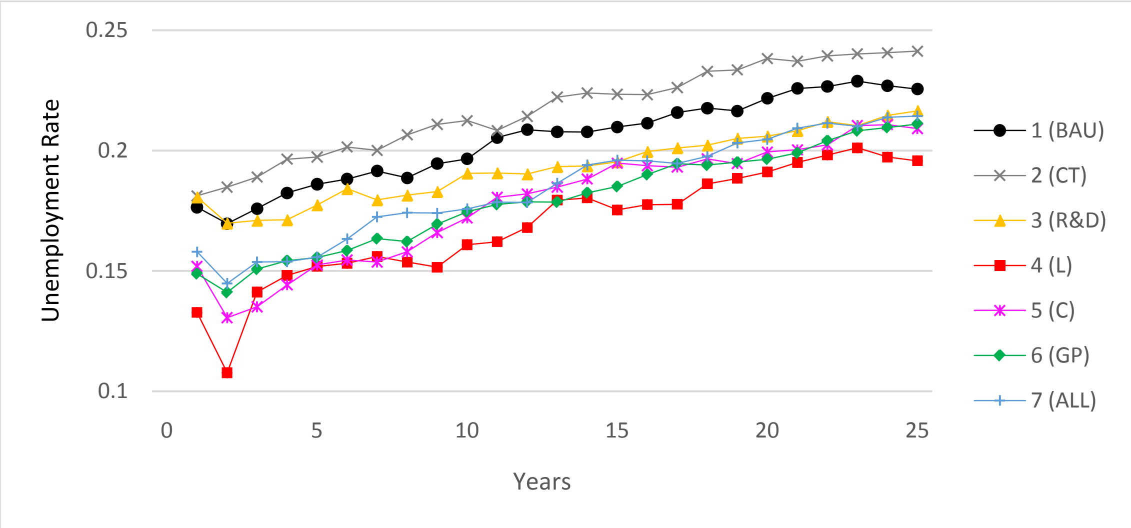

Figure 4: Unemployment rate under each policy scenario

In figure 5, we are dealing with consumer price inflation, i.e. the composite weighted average price for all need and want sales on the market. In this figure we are showing the data in relation to the BAU scenario which then represents the base line. We have chosen this mode of visualization for figures 5, 6 and 9 to 12 to highlight the difference with the BAU scenario, without the figure being visually dominated by a common simulation trend of the respective indicator. Scenario 4 (L) deflates the consumer price significantly in comparison to BAU via the labor tax reduction. Where scenario 3 (R&D) shows the same behavior in the first 15 years, consumer prices recover afterwards slightly below BAU. The highest inflationary dynamics (still just 6% higher than BAU after 25 years) are given by scenarios 5 (C) and 6 (GP). This effect results from the demand shock driven by either direct consumer price subsidies or via government activity enhancing green procurement.

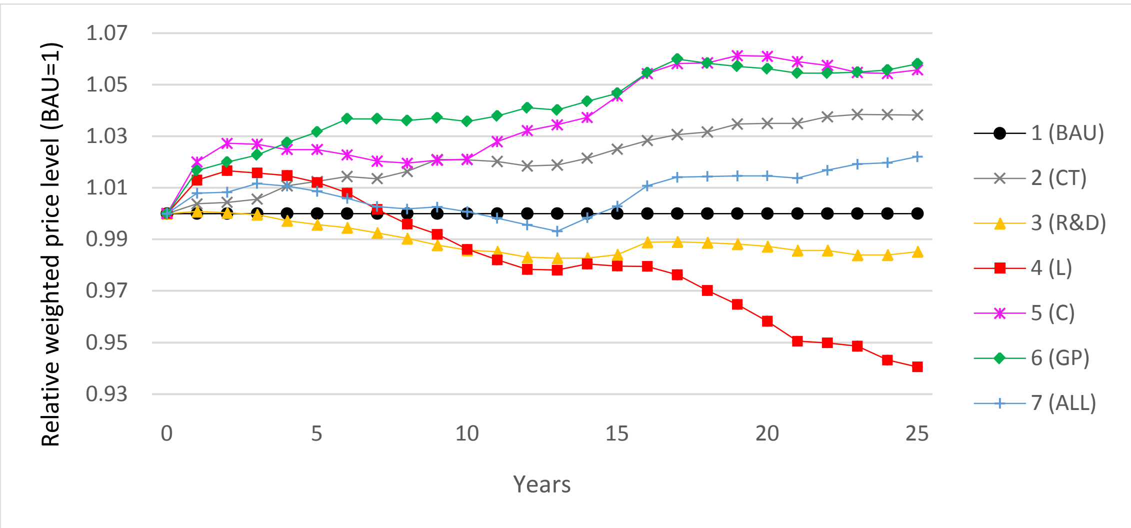

Figure 5: Weighted consumer price level under each policy scenario (price inflation relative to BAU)

Figure 6 shows the development of the stock of carbon emissions in relation to BAU for all given scenarios. The results are somewhat surprising. The only scenarios that are pushing carbon emissions down are given by the simple introduction of a carbon tax – scenario 1 (CT) – and the double dividend policy with R&D subsidies – scenario 3 (R&D). All other policies perform even worse than BAU. By far the dirtiest scenario in comparison to BAU is indicated by the labor tax reduction – scenario 4 (L). An explanation for this case needs to compare the growth effect on GDP driven by higher purchasing power in scenario 4 that outperforms the market selection on less carbon-intensive products. This aspect is again connected, as already mentioned, to the lending behavior of firms in our model. Since we do not allow for too risky lending, green firm selection does no out-compete the general growth effect.

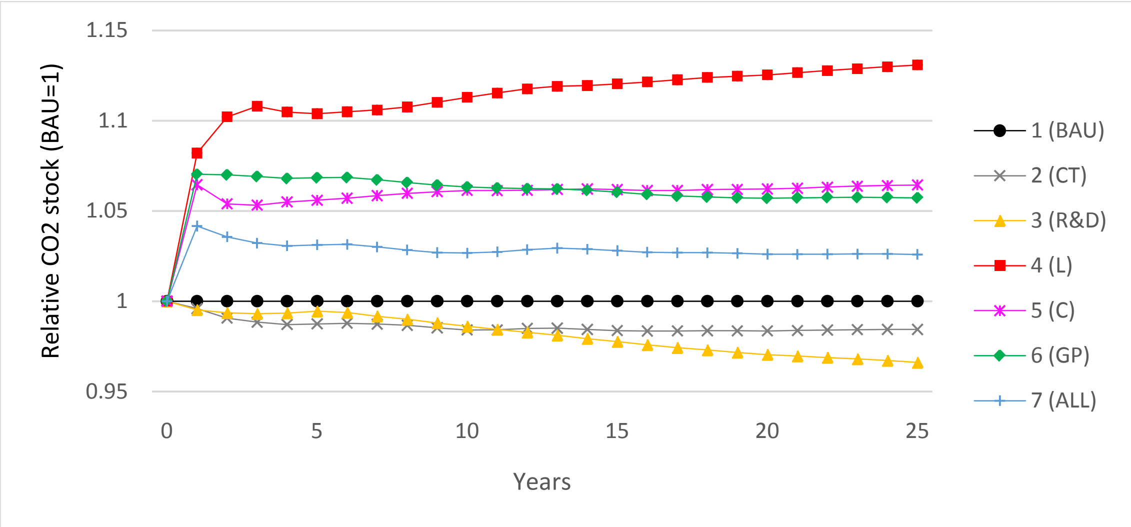

Figure 6: Stock of carbon emissions under each policy scenario (relative to BAU)

Figure 6 shows that scenarios 2 (CT) and 3 (R&D) lead to a lower carbon stock level than BAU, while scenario 3 ends at the lowest level. However figure 7 represents the development of absolute carbon stocks and indicates the corridor of emission reduction we are dealing with in the simulation.

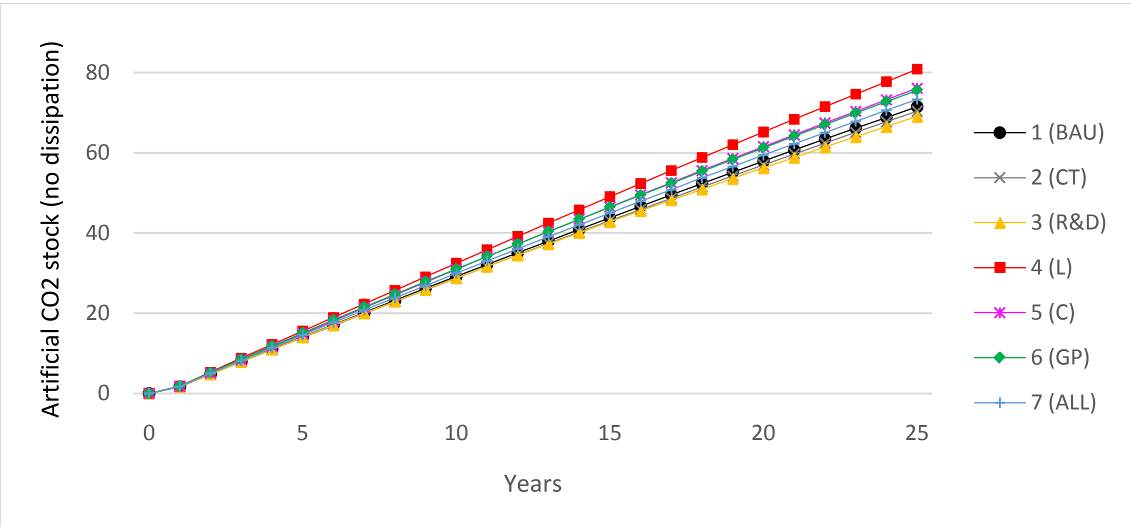

Figure 7: Stock of carbon emissions under each policy scenario

Figure 8 substantiates the aforementioned results with a closer look on market dynamics. It shows the development of the annual shares between need and want sales. Basically in our model this measure serves as an indicator for purchasing power, the higher the relative income/wealth the higher the want sales that are boosting the economy. Of course as we have already seen – especially within scenario 4 (L) and 5 (C) – this has a significant impact on the stock of carbon emissions if market selection does not steer in direction of less carbon-intensive products. Obviously the high-price firms have not significantly shifted to low-carbon intensive products. We have expected that this pulling of consumers of the higher social classes with Veblen and snob effects drives the economy on a low-carbon path. This is not an obvious case in this picture now, which can get explained through this particular market selection. Generally, a mere introduction of a carbon tax does influence purchasing power quite direct, shifting it below the BAU case.

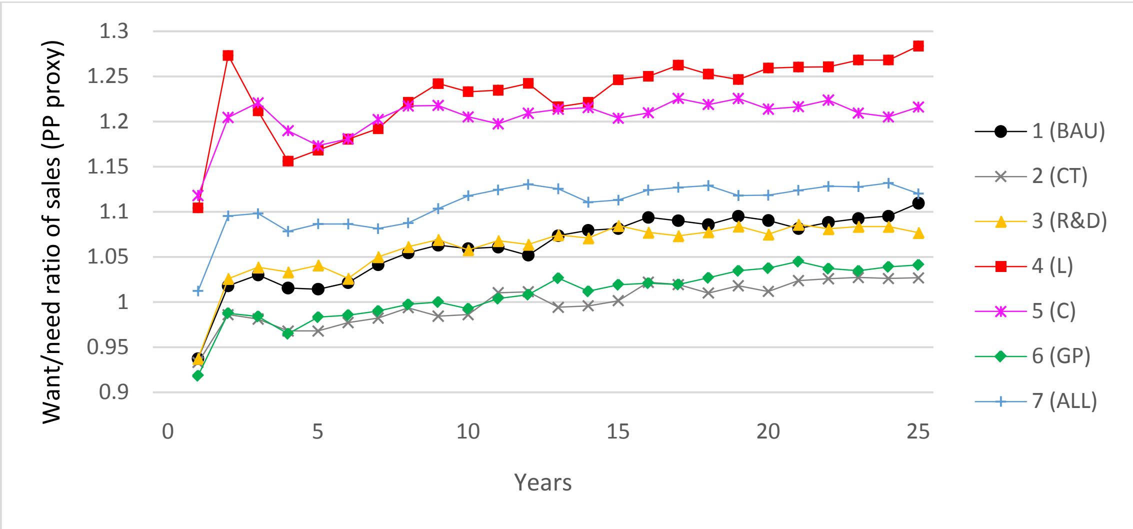

Figure 8: Want/need ratio of sales under each policy scenario

Figure 9 shows the development of firm profit rates in comparison to BAU. Obviously all scenarios 2-7 translate into lower firm profit due to the introduction of the carbon tax. Scenario 3 (R&D) keeps up with the higher costs at best due to the subsidies for further technological investment in emission reduction. All other scenarios – instead of scenario 4 (L) – catch up after 25 years of simulation.

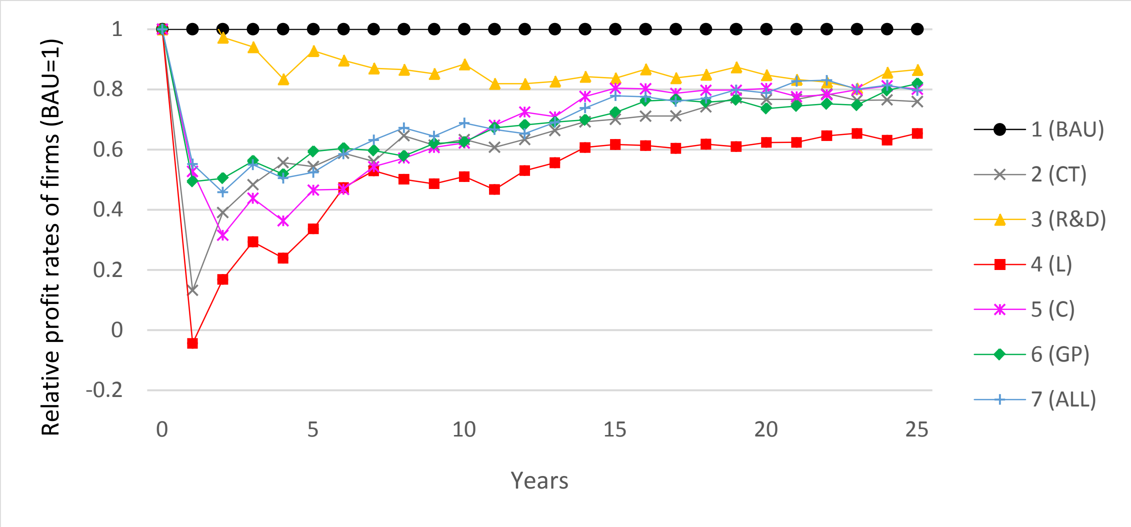

Figure 9: Profit rates of firms (relative to BAU) under each policy scenario

Figure 9 shows the direct impact of losses in firm profit for the capitalist class thereafter. Since firm owners are not able to transfer bigger shares as dividends, the development of their wealth decreases significantly in comparison to BAU. In scenario 4 (l) capitalist wealth decreases even more than with a pure introduction of a carbon tax – scenario 1 (CT). All other demand-driven scenarios of the double-dividend policy program lead to higher capitalist wealth as the simple carbon tax but significantly lower than the supply-driven scenario 3 (R&D). In this regard all scenarios redistribute wealth within households from the capitalist class to the working class, but the demand-driven "pull" policies at most.

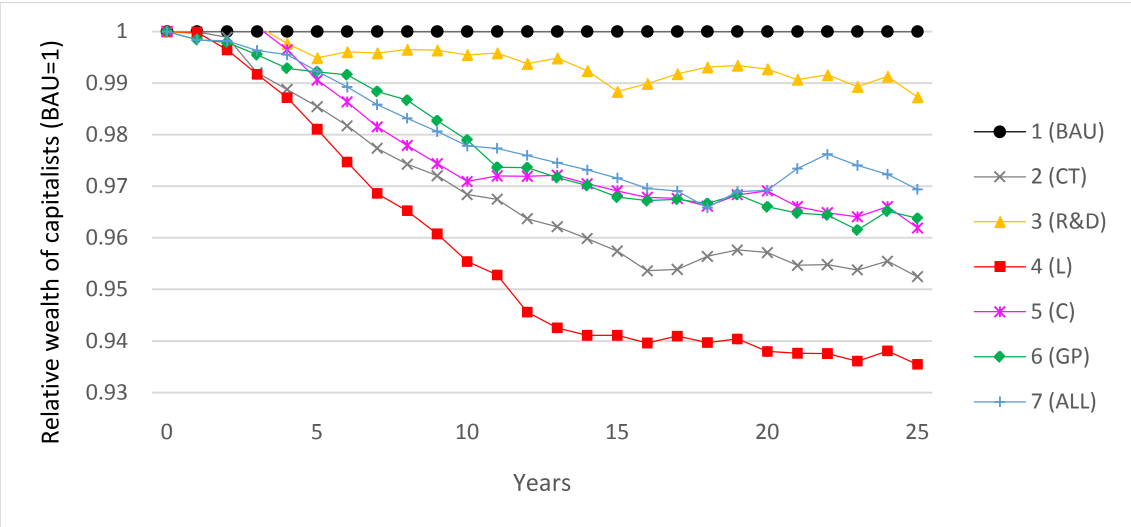

Figure 10: Wealth of capitalists in relation to overall wealth (relative to BAU) under each policy scenario

Finally we want to show the changes in the two technology branches (emission reduction vs. total factor productivity). Figure 11 visualizes the innovation in total factor productivity relative to the BAU case. Here scenario 3 (R&D) indicates a reduction in innovative activity for total factor productivity (TFP). Scenario 4 (L) and 5 (C) do not shift adequately away from BAU in terms of TFP. These two scenarios increase household's purchasing power, but the market selection for less carbon-intensive products is not strong enough. Surprisingly, scenario 6 (GP), shifts away from TFP innovation in the first 15 years.

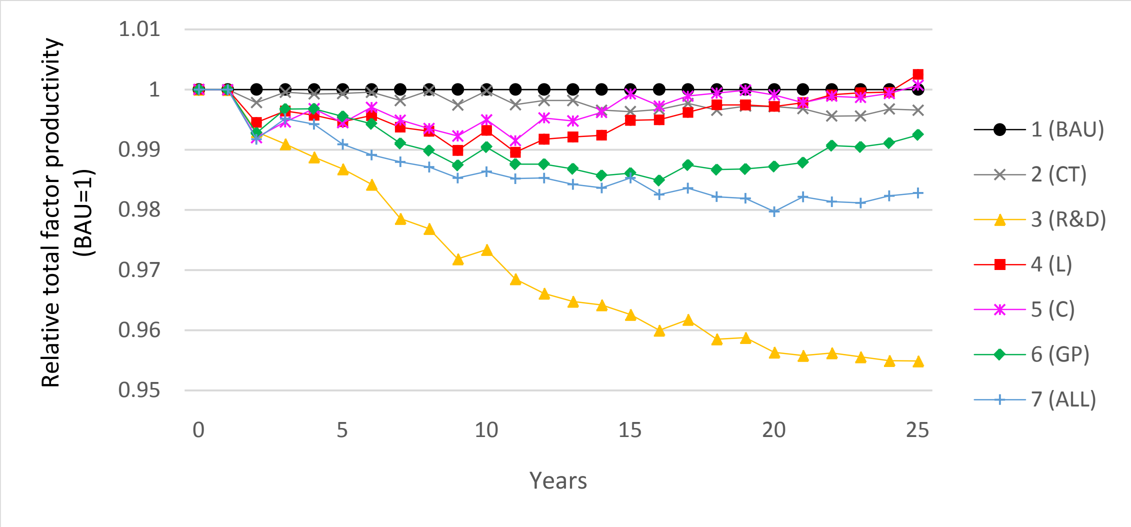

Figure 11: Technological change – total factor productivity (relative to BAU) under each policy scenario

Figure 12 shows the development of emission reduction and its diffusion over time. It is worthwhile to note that figure 12 does not simply represent an inverse of figure 11, but offers additional results, because firms do have the option not to innovate as well. Scenarios 2 (CT), 4 (L) and 5 (C) shifts the economy towards higher relative carbon intensity relative to BAU. The demand-pull strategy has favorable macro impacts for GDP growth and unemployment, but this picture changes when we are concerned with technological innovation. Here the supply-push scenario 3 (R&D) performs best, the subsidy for R&D works and firms take the second technological branch as a serious option. This effect is still visible in the combination of all scenarios 7 (ALL), where we can see that a quarter of the money allocated to R&D subsidy for emission reduction leads roughly into a 5% lower emission reduction coefficient than single R&D, in comparison to BAU at the end of the simulation run. Otherwise green procurement – scenario 6 (GP) – does not select well enough for less carbon-intensive firms and we can see that it even supersedes BAU after 25 years.

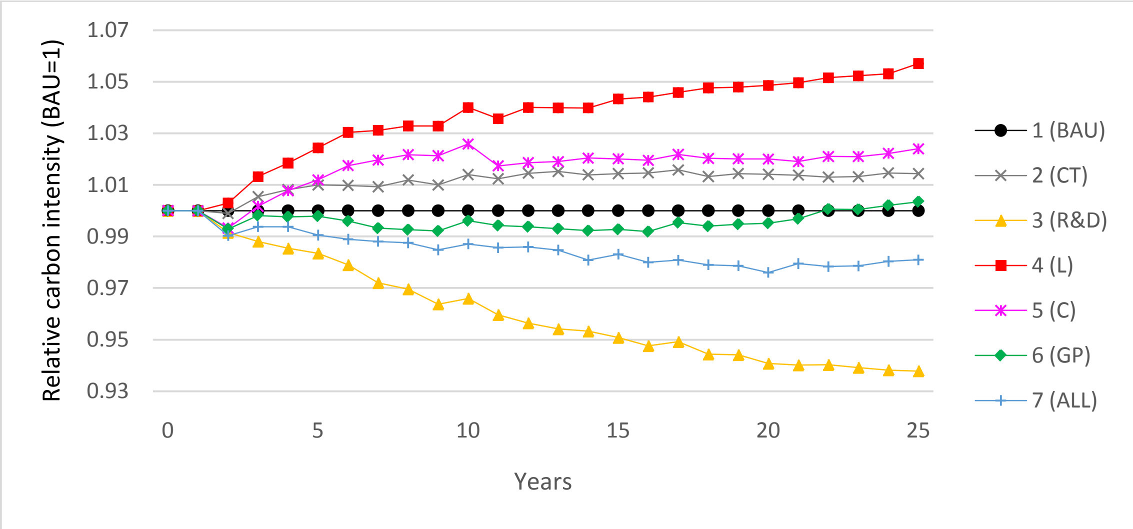

Figure 12: Technological change – carbon intensity (relative to BAU) under each policy scenario

5. Conclusions

We developed a macro-evolutionary model of an artificial one-country closed economy to study a range of climate policies. The model accounts for a variety of observed behavioral features of consumers, such as imitation, status and snob effects. With the model we simulate 2000 households, 100 (initial) firms, five commercial banks, one capital goods firm, one central bank and one central government. The model describes improvements in carbon intensity of production due to innovation and diffusion of associated greener products, under the influence of various policies.

We examine a basic policy scenario with a carbon tax which generates revenues (a “carbon fund”) that can be used to create and finance various additional instruments of a climate policy package: a shift from labor to carbon taxes, a direct consumer subsidy for greener (less carbon-intensive) products, subsidizing green innovation, and green procurement (governmental spending on greener products). In addition, we consider a policy package consisting of a combination of consumer product subsidies and green procurement, and one comprising all the mentioned policy instruments.

The results show that the scenarios generate similar trends for most variables but with different levels. The simulations show that GDP is quite constant with variations of 1%, meaning a stable economic development under all scenarios. The results for the unemployment rate show a wider bandwidth, namely up to 4%. The best scenario, having the lowest unemployment rate is shifting taxes from labor to carbon tax, while the worst is only implementing a carbon tax. Policy packages with carbon tax revenues used to support innovation, diffusion or both perform in between. Generally all simulation experiments are characterized by steadily rising unemployment, mainly because of the combination of technological progress and resulting increasing labor productivity with wages increasing slower than productivity. As a consequence the government faces increasing cost of social welfare benefits to unemployed.

As expected, the policy package subsidizing R&D with the revenues from the carbon tax was the best to perform in terms of stock of carbon emissions. The second best policy package is CT or the carbon tax scenario, which simply taxes carbon emissions. Unfortunately, even if it showed a good performance in reducing unemployment, the policy package shifting carbon revenues to labor tax reduction does not perform well in terms of carbon emission stocks.

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Appendix

Monthly Simulation Phases

Founding phase

Households evaluate and initiate firm founding

Production phase

Firms demand estimation and pricing

Firms credit adjustment and production

Firms adapt prices

Sales and consumption phase

Government purchases products with low carbon intensity

Government calculates consumption subsidy base pre consumption

Households check financial status

Households decide consumption budget

Households buy need goods

Households (capitalists) buy want goods

Households (workers) buy want goods

Households update need vendor lists

Households update want vendor lists

Households balance accounts with savings if indebted or declare bankruptcy

Wages payment phase

Firms pay wages

Government pays pensions

Government pays unemployment subsidies

Saving phase

Households transfer money to savings accounts

Interest and consolidation phase

Banks collect credit interest

Banks collect credit repayments

Banks calculate accounts interest

Banks calculate savings interest

Banks pay central bank loans interest

Banks pay central bank loans repayments

Firms’ monthly accounting

Banks verify firms’ solvency

Banks monthly accounting

Banks calculate refinancing demands

Banks refinance at central bank

Banks transfer funds to facilities at central bank

Central banks pay reserve interest

Central banks pay deposit facilities interest

Government refinancing phase

Update macro indicators

Banks monthly accounting

Central banks monthly accounting

Government monthly accounting

Country updates macro indicators

Annual Simulation Phases

Annual accounting phase

Banks collect and pay accounts interest

Banks pay savings interest

Firms calculate profits and pay taxes

Banks calculate profits and pay taxes

Firms distribute profits

Banks distribute profits

Capital goods firms distribute profits

Government calculates annual emission tax redistribution funds

Firms decide R&D activities

Government update annual statistics (annual taxes)

Country compile annual report

Government check minimum wage increase

Government increases unemployment subsidies if minimum wage increased

Government evaluates pension increase based on CPI

Firms evaluate wage increases based on CPI

Capital goods firm adapts prices based on CPI

Firms depreciate production capital

Firms engage in R&D activities

Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs change. The financial crisis has exposed long-neglected deficiencies in the present growth path, most visibly in the areas of unemployment and public debt. At the same time, Europe has to cope with new challenges, ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundation for a new development strategy that will enable a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four-year research project within the 7th Framework Programme funded by the European Commission was launched in April 2012. The consortium brings together researchers from 34 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). The project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

Contact for information

Kristin Smeral

WWWforEurope – Project Management Office

WIFO – Austrian Institute of Economic Research

Arsenal, Objekt 20

1030 Vienna

wwwforeurope-office@wifo.ac.at

T: +43 1 7982601 332

Domenico Rossetti di Valdalbero

DG Research and Innovation

European Commission

Domenico.Rossetti-di-Valdalbero@ec.europa.eu

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Aston University	ASTON	United Kingdom