# INTERNATIONAL CORPORATE GOVERNANCE AND REGULATION

# ADVANCES IN FINANCIAL ECONOMICS

## Series Editors: Kose John, Anil K. Makhija and Stephen P. Ferris

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# INTERNATIONAL CORPORATE GOVERNANCE AND REGULATION

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# CLIMATE POLICIES WITH BURDEN SHARING: THE ECONOMICS OF CLIMATE FINANCING

Julia Margarete Puaschunder


## ABSTRACT

*Climate control needs have reached momentum. While scientists call for stabilizing climate and regulators structure climate change mitigation and adaptation efforts around the globe, economists are concerned with finding proper and fair financing mechanisms. In an overlapping-generations framework, Sachs (2014) solves the climate change predicament that seems to pit today's against future generations. Sachs (2014) proposes that the current generation mitigates climate change financed through bonds to remain financially as well-off as without mitigation while improving environmental well-being of future generations through ensured climate stability. This intergenerational tax-and-transfer policy turns climate change mitigation into a Pareto improving strategy. Sachs' (2014) discrete model is integrated in contemporary growth and resource theories. The following article analyzes how climate bonds can be phased-in, in a model for a socially optimal solution and a laissez-faire economy. Optimal trajectories are derived partially analytically (e.g., by using the Pontryagin maximum principle to define the optimal equilibrium), partially data driven (e.g., by the use of modern big market data), and partially by using novel cutting-edge methods – for example, nonlinear model predictive control (NMPC), which solves complex dynamic optimization problems with different nonlinearities for infinite and finite decision horizons. NMPC will be programed with terminal condition in order to determine appropriate numeric solutions converging to some optimal equilibria. The analysis tests if the climate change debt adjusted growth model stays*


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*within the bounds of a sustainable fiscal policy by employing NMPC, which solves complex dynamic systems with different nonlinearities.*

**Keywords:** Intertemporal decisions; climate bonds; climate change mitigation; economic growth; intergenerational burden sharing; nonlinear model predictive control; social discounting alternatives; truncated finite time horizons

## INTRODUCTION

Climate change accounts for one of the most pressing intertemporal problems in the age of globalization (Centeno & Tham, 2012). While classic economics portrayed balancing the interests of different generations as ethical problem of competitive markets requiring state governance on intergenerational transfers and some economists even opposed discounting of future utilities in the past (Allais, 1947; Harrod, 1948; Ramsey, 1928), climate change has leveraged intergenerational equity as contemporary challenge of modern democracy and temporal justice an ethical obligation for the future (Puaschunder, 2016a, 2017a, 2017b).

In general, resources are balanced across generations by social discounting to weight the well-being of future generations relative to those alive today. Regarding climate justice, current generations are called upon to make sacrifices today for future generations by mobilizing low-carbon energy to cut carbon emissions to avert global warming (Puaschunder, 2017c, 2017e; Sachs, 2014). As a novel alternative, Sachs (2014) proposes to fund today's climate mitigation with bonds financed through taxation faced by future generations. Shifting the ultimate costs of climate change aversion to later generations appears as powerful strategy to immediately instigate current climate change action. Within overlapping-generations, climate change mitigation thereby becomes Pareto improving for all generations.

While intergenerational burden sharing on climate change is a real-world relevant emergent risk prevention strategy (Centeno et al., 2013), we lack information on the impact of climate mitigation through debt on economic growth and the model's sustainability over time. The theoretical part of this paper therefore introduces Sachs' intergenerational burden sharing and outlines contemporary growth models with attention to public deficit spending. The methodological part integrates Sachs' model into contemporary growth models and tests the integrated model's sustainability by using the nonlinear model predictive control (NMPC) method. The results discussion derives conclusions.

## THEORETICAL BACKGROUND

### *Intergenerational Burden Sharing*

Society as a whole outlasts individual generations. Pareto optimality for society over time differs from the aggregated individual generations' preferences. As the sum of individual generations' preferences does not necessarily lead to overall societally overall favorable outcomes (Bürgenmeier, 1994; Klaassen & Opschoor, 1991), discounting based on individual generations' preferences can lead to suboptimal outcomes over time. On intertemporal problems, social discounting reveals an unjust advantage of living generations determining future living conditions (Rawls, 1971). In general, intergenerational balance is therefore accomplished through individual saving decisions of the present generation (Bauer, 1957). Policies curbing preferences and taxes distributing welfare between the present and future generation may, however, decrease economic growth.

In order to avoid governmental expenditure on climate change curbing economic growth (Barro, 1990), Sachs (2014) introduces financing climate change mitigation through debt as a novel means to amend individual saving preferences in favor of future generations. In Sachs (2014) 2-period model, one generation works in period 1 and retires in period 2. Part of the disposable wage income is saved for consumption in the second period. $CO_2$ emission mitigation imposes immediate costs onto current generations and reduces wages. Greenhouse gas concentrations in period 2 are determined by the emissions in period 1. Wages of the young in the second period are reduced by climate change dependent on greenhouse gas levels. Disposable labor income of the young equals market wage net of taxes. Sachs (2014) proposes to mitigate climate change mitigation by debt to be repaid by tax revenues on labor income in the future. Leaving the current generation with unchanged disposable income allocates the burdens of climate change mitigation across generations without the need to trade off one generation's well-being for another's (Sachs, 2014). While today's young generation is left unharmed, the second period young generation is made better off ecologically. Taxes on later generations are justified as for the assumed willingness of future generations to avoid higher costs of climate change prevention and environmental irreversible lock-ins. Overall mitigation policy is thus Pareto improving across generations. All generations are better off with mitigation through climate bonds as compared to the business-as-usual (BAU) non-mitigation scenario (Sachs, 2014). While future generations enjoy a favorable climate and averted environmental lock-ins, the current populace does not face decreased growth.

### *Climate Justice*

In order to avoid governmental expenditure on climate change hindering economic growth (Barro, 1990), Sachs (2014) introduces financing climate change mitigation through debt to be paid back by future generations through taxation as a novel means to amend individual saving preferences in favor of future generations (Marron & Morris, 2016). Carbon taxes can raise substantial revenue until the economy is largely decarbonized (Marron & Morris, 2016). In Sachs (2014) 2-period model, one generation works in period 1 and retires in period 2. Part of the disposable wage income is saved for consumption in the second period. $CO_2$ emission mitigation imposes immediate costs onto current generations and reduces wages. Greenhouse gas concentrations in period 2 are determined by the emissions in period 1. Wages of the young in the second period are reduced by climate change dependent on greenhouse gas levels. Disposable labor income of the young equals market wage net of taxes. Sachs (2014) proposes to mitigate climate change by debt to be repaid by tax revenues on labor income in the future. Leaving the current generation with unchanged disposable income allocates the burdens of climate change mitigation across generations without the need to trade off one generation's well-being for another's. While today's young generation is left unharmed, the second period young generation is made better off ecologically. Taxes on later generations are justified as for the assumed willingness of future generations to avoid higher costs of climate change prevention and environmental irreversible lock-ins. Overall, this tax-and-transfer mitigation policy is thus Pareto improving across generations. All generations are better off with mitigation through climate bonds as compared to the BAU non-mitigation scenario (Sachs, 2014). While future generations enjoy a favorable climate and averted environmental lock-ins, the current populace does not face drawbacks on economic growth. At the same time, a carbon tax on top of the existing tax system should be used to reduce the burden of climate change and encourage economic growth through subsidies (Chancel & Piketty, 2015). Other options to promote growth include investing in infrastructure, education, research and development, and other activities that expand the productive capacity of the economy (Marron & Morris, 2016).

In the following integrated assessment model, a macroeconomic modeling approach calibrates climate change adaptation and mitigation and the optimal mitigation and adaptation policy mix with real-world relevance for climate protection. In addition, the model calibrated the development versus mitigation versus adaptation policy mix in order to retrieve efficient climate modeling strategies leading to important contributions for the international climate negotiations on the optimal climate policy mix. Using macro- and microeconomic modeling and building on the DICE Model, the outlined costs and benefits of mitigation and adaptation strategies are key in determining security strategies for vulnerable cities, communities, and countries and protect them from the variegated climate change risks (Nordhaus, 1994). The results achieved help multivariate stakeholders for shaping economic growth and sustainable development. The described models has the potential to become the basis for modeling climate change burden sharing through bonds. Another important aspect of this type of work is to also allow for compensation if the cost of mitigation has very uneven distributional effects.

### *Funding Climate Policies – Model Variants*

In order to implement an intra-and intergenerationally fair solution to ensure climate justice, a three-regime approach is proposed. Intragenerationally the issue is how a fair carbon tax can be achieved where some compensation of losers is integrated. Intergenerationally, the current generation may require that future generations also contribute to the cost of climate change. We first start with the latter issue, since this is a relatively new concept.

*Variant 1: Climate Bonds and Three Phases*
A three phase model describes intertemporal climate change burden sharing. In this three phase model, current costs of climate change abatement is partly shifted to future generations through bonds to be financed by taxing future generations. Though future generations will face some tax, they will also benefit in the sense that the externalities from $CO_2$ emission and climate change are removed. A simplified model version can be sketched as following.

The *model phase 1* of economic growth without mitigation effort is called BAU. We call this phase 1. The model economy of this type features households in a production economy that choose consumption in order to maximize a discounted stream of utility. Economic households maximize the discounted stream of utility arising from consumption, $C_t$, is subject to a budget constraint. The utility of this phase is maximized by:

$$\int_{t=0}^{T} \mathrm{e}^{-\rho} t U_t(C_t) \mathrm{dt} \tag{1}$$

in which $\rho > 0$ is the discount rate.

Economic activities generate emissions of greenhouse gases, as a by-product of capital used in production and expressed in $CO_2$ equivalents. Environmental economics implies that a higher capital stock goes along with higher emissions (Hettich, 2000; Smulders, 1995). Emissions of greenhouse gases indirectly affect the climate of the earth leading to higher surface temperature and weather extremes such as flooding, heatwaves, storms, desert formation, and so on.

In the model of phase 1, with an optimization horizon $[T_0, T_1]$, the BAU approach, no climate change mitigation effort $A_t$ is employed. It is a laissez-faire solution, in which there is environmental damage and no climate change mitigation. The evolution of per-capita capital over time is thereby determined by the following differential equation that represents the budget constraint of a household:

$$\dot{K}_t = D_t * Y_t - C_t - (\delta + n) * K_t, K(0) \ = \ K_0 \tag{2}$$

with the per-capita production $Y_t$ accounting for environmental damage $D_t$ being reduced by consumption $C_t$ and per-capita capital $K_t$ accounting for the depreciation of capital $\delta$ and population growth $n$. In the stylized model, growth leads to the increase of industrial emission.

In the BAU model, there are no climate change abatement activities. Yet, environmental damage reduces output by

$$D_t = (a_1 * M_t^2 + \ 1)^{-\Psi}, \tag{3}$$

with $a_1 > 0$, being a function that negatively depends on the temperature on earth as deviations from the equilibrium average surface temperature have feedback effects that influence the reflection of incoming energy (e.g., snow and ice reduction and water evaporation lead to a smaller amount of solar radiation tending to increase the earth temperature even further), $\Psi > 0$ and $M_t$ being the greenhouse gas concentration in the atmosphere (Henderson-Sellers & McGuffie, 1987; Nordhaus, 2008; Schmitz, 1991). The effect of emissions to raise the greenhouse gas concentration, $M_t$, in the atmosphere is determined by

$$\dot{M}_t = \beta * E_t - \mu * M_t \tag{4}$$

in which emissions $E_t$ factored by $\beta \in (0, 1)$, which is the part of greenhouse gas emissions that is not taken up by oceans, are reduced by $\mu \in (0, 1)$ as the inverse of the atmospheric lifetime of greenhouse gases or decay rate of greenhouse gases in the atmosphere (see Intergovernmental Panel on Climate Change, 2001).

The greenhouse gas emissions are described by

$$E_t = (a * K_t)^\gamma * \left(\frac{1}{d * A_t + p}\right)^\gamma \tag{5}$$

with $K_t$ being the stock of capital, $\gamma > 0$ representing the exponential growth rate in the emission function and the parameter $a > 0$ as constants. Emissions are a function of per-capita capital, $K_t$, relative to per-capita climate change abatement activities $A_t$ as indicated by the efficiency factor $\left(\frac{1}{d * A_t + p}\right)^\gamma$, whereby $d$ and $p$ are parameters. During BAU, the abatement $A_t$ is 0. The technology index $a$ describes how polluting a given technology is insofar as the larger $a$ is given a stock of capital and abatement, the higher the emission is, which implies a relatively polluting technology.

In contrast to the BAU scenario, *model phase 2*, with an optimization horizon in equation (1) of $[T_1, T_2]$, proposes an externality control to mitigate climate change through bonds extending Sachs (2014). In order to overcome output decline in the wake of externality control and the need for capital stock to produce renewable energy, social expenditure improving welfare regarding climate change is considered by issuing climate change mitigation bonds. Instead of assuming a lump-sum tax or a tax on consumption used to finance abatement spending, climate change burden sharing debt bonds are thereby issued by current generations, who are immediately compensated for their climate change abatement costs, to be paid-off by taxing future generations. In model 2, the government sells climate change mitigation bonds to reimburse the abatement costs $A_t$ from period $[T_1, T_2]$, when climate change abatement bond issuing stops and climate change mitigation bond repayment sets in through taxation in model phase 3. Overall, there is environmental damage but mitigation that is reimbursed to be paid back by later generations.

As in model 1, the greenhouse gas emission $M_t$ is determined by equation (4). In $K_t$(equation (2)), the production function $Y_t$ denoting per-capita output is given by

$$Y_t = \tilde{A}_t * K_t^{\alpha}, \tag{6}$$

with $\alpha \in (0, 1)$ being the capital share and $\tilde{A}_t$ being an efficiency index constant normalized to 1. The greenhouse gas emissions are, as in model 1, described by equation (5) but with $A_t > 0$.

In model 2, bonds are issued from the beginning to period to period $T_2$ arising

$$\dot{B}_t = r_t * B_t + g_t * B_t(0) \tag{7}$$

whereby $g_t$, denotes public debt and $r_t$ is the interest rate paid on climate change abatement bonds. $B_t(0)$ denotes the starting point of public debt at time 0. We now have a model with three state variables and the abatement cost being reimbursed by the issuing of public bonds. Note that in this period, the government subsidizes the generation to compensate for the upfront costs of climate change mitigation. The government reimburses climate change aversion until a regime-change switching, when taxes become positive and later generations pay for earlier climate change abatement through taxation. The later generations are assumed to be willing to pay to avoid the higher costs of climate change relative to a BAU path.

In the *model phase 3*, the optimization horizon in (1) is ($T_2$, $T_3$), when no further climate change abatement costs exist and the debt of bonds is to be repaid from period $T_2$ on, after switching to the model 3, when we then have the repayment of bonds described by equation (7):

$$\dot{B}_t = r_t * B_t - T_{t_{\mathrm{N}}} \tag{8}$$

where by $T_{t_{\mathrm{N}}} = \tau Y_{\mathrm{N}}$ is used for describing the repayment of bonds.

From that period on, the capital stock over time, $\dot{K}_t$, is also reduced by $\tau_{t_{\mathrm{N}}}$ in

$$\dot{K}_t = Y_t\left(1 - \tau_{t_{\mathrm{N}}}\right) - C_t - (\delta + n_t) * K_t \tag{9}$$

Note that in the model phase 3, neither an externality effect, $D_t$, nor climate change abatement cost, $A_t$, are present. There is no environmental damage but taxation for climate change abatement bonds repayment. Only the previously raised bonds of equation (7) will have to be repaid by the generation existing from that period on. These future generations will benefit from the absence of damages from externalities of previous periods. The negative externalities are removed by agents from the previous periods.

*Variant 2: Carbon Tax, Climate Bonds, and Three Phases*

Next, we are describing the research and solution strategy to deal with the issue when from *model phase 2* on a carbon tax is also introduced, in addition to the climate bonds. The subsequent two model phases are very similar to the models phase 2 and 3 above and thus only the ideas need to be described here.

In the budget equation of the households in phase 2, equation (2), a carbon tax, representing an abatement cost, is introduced that reduces households' income. The tax rate and abatement effort affect equation (5) by increasing the denominator by the amount of the abatement effort. The complication is, however, that the tax rate should only be levied on the remaining polluting capital, and as the capital stock becomes more and more green capital, the tax income and abatement effort will shrink and eventually disappear.

This carbon tax for the model phase 2 will be set to zero when *model phase 3* is reached and only the tax rate for the model phase 3 generation that is repaying the bonds issued in phase 2 will affect the budget equation of the households. The repayment of the issued bonds will in this phase 3 decline the same way as described in equations (8) and (9). The phase by phase solution can also be obtained by our numerical algorithm, the NMPC algorithm which will briefly discussed next.

## SUSTAINABILITY OF THE MODEL

In an optimal control solution, the model's feasibility over time was calculated. For the simulations, MATLAB was employed in order to solve the resulting static optimization problem. Sustainability is measured by planning horizon $[0, T]$, $T > 0$ terminal time in years. In addition, the NMPC method displays the dynamics of the transition process regarding a regime switch from BAU to climate change bonds payments.

In MATLAB, the welfare function is lowest with the BAU Model solution. If the interest rate ($r = 0.03$) is equal to the discounting rate of the welfare function ($\rho = 0.03$), bonds are not an economically efficient means to financing climate change abatement and therefore do not appear in the optimal control solution (Fig. 1). If the interest rate of the bonds is below ($r = 0.01$) the discounting rate of the welfare function ($\rho = 0.03$), bonds are an efficient market solution to abate climate change. The results of the stylized model underline that after about

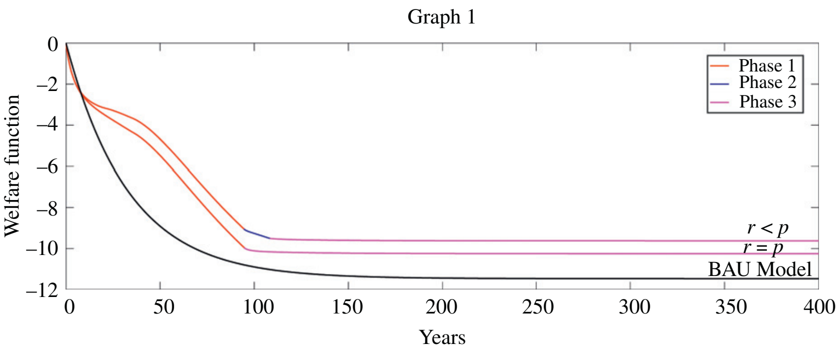


*Fig. 1.* Stylized Function Graph Maximizing Welfare of the Different Model Variants.