Intergenerational Discounting and Market Rate of Return in OLG Version of RICE Model

by

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Abstract
In this paper we propose an extension of the Regional Integrated model of Climate and Economy (RICE), where we introduce overlapping generations (OLG) in the original model and consider competitive equilibrium with the regional governments, that follow Ramsey type optimal policy on greenhouse gases emissions reduction. In this framework it is possible to distinguish between subjective discount rate of individuals and social discount rate of the governments. Thus the model provides two discount rates in the OLG model: the social discount rate under which costs benefits analysis of climate projects are evaluated and the market discount rate for investments in physical capital. We analyze how calibration of the social time preferences influences outcomes on emission reduction and real returns in Nash equilibrium and in grand coalition.

1. Introduction

Considerable amount of economic models devoted to reduction of greenhouse gases emissions to prevent global warming have been developed in recent years. A very useful tool for policy analysis is integrated assessment modeling. Conclusions about the optimal reduction of greenhouse gases emissions in this kind of modeling are substantially dependent on discount rates, under which costs benefits analysis are evaluated. There is the international debate about appropriate discounting in policy analysis. If the future benefits discounted at a rate compatible with market real interest rates, the optimal reduction of GHG’s emissions should be moderate in the early period with more aggressive emission cuts later. One of the most influential integrated assessment models with high discount rates is the Dynamic Integrated model of Climate and the Economy (DICE) model of Nordhaus (2008). This model is the central planner problem where social welfare is maximized under economic and climate constraints.

Two crucial parameters which determine real returns on capital and discount for goods are the pure rate for social time preferences and elasticity of marginal utility of consumption. Nordhaus (2008) calibrates the pure rate for social time preferences equals to 1.5% per year and elasticity of marginal utility of
consumption equals to 2 to reproduce observable returns on capital. A key result of the DICE-2007 model (Nordhaus, 2008) is that efficient emissions reductions follow a “policy ramp” in which policies involve modest rates of emissions reductions in the near term, followed by sharp reductions in the medium and long terms. Therefore the main burden of emissions reduction along with damage from climate change will rest on future generations.

However the use of high time discount rates is inconsistent with classical utilitarianism, which holds that equal weights should be attached to the welfare of present and future generations (Arrow et al., 1996; Broome, 1992; Cline, 1992; Ramsey, 1928). This view is taken by Stern (2007) who calibrates the pure rate for social time preferences equals to 0.1% per year and elasticity of marginal utility of consumption equals to 1. Stern (2007) concludes about the need for extreme immediate actions in reduction emissions of greenhouse gases. The main critics of these assumptions are that results of the Stern (2007) model are not compatible with today’s real returns on capital and saving rates (see, for example, Dasgupta, 2007; Nordhaus, 2007; Wietzman, 2007, among others). Real returns are extremely low and saving rates are extremely high. Nordhaus (2007) shows possibility to replicate market returns on capital with Stern’s almost zero social discount rate, lifting marginal utility of consumption from 2 to 3. Under this calibration model reproduce observable market returns on capital but conclusions about optimal reduction become modest in comparison to the Stern’s point of view.

In fact, the true value of the marginal utility of consumption is unknown and the high market returns could be due to other important factors such as individual impatience of households and growth of population. For example, in the baseline OLG growth model of Daimond (1965) and Samuelson (1958) with two overlapping generations in the case of the logarithmic utility function the real return on capital in the competitive equilibrium is given by:

$$r^* = \frac{\gamma (2+\bar{\rho})(1+n^*)(1+g^*)}{1-\gamma} - \delta$$

(1)

where $\gamma$ - is the output elasticity with respect to capital, $n^*$ - population growth rate, $g^*$ - labor productivity growth rate, $\delta$ - depreciation rate.

However in the central planner problem the real return on capital is given by the following equation:

$$r^* \approx \rho^*+g^*$$

(2)

where $\rho^*$ - is the social time discount rate applied to different generations.

If the social discount rate is greater than zero there is a controversy justification of such weightings of welfare of different generations in the social welfare function. On the other hand the recalibration of the pure rate for social time preferences equals to 0.1% per year and elasticity of marginal utility of consumption equals to 3 as in the paper (Nordhaus, 2007) also could be inappropriate. In the case of low value of this parameter the increase of marginal utility of consumption to 3 in order to replicate the market returns on capital in central planner problem of such normative issue is not well-grounded.

As well changes in marginal utility of consumption parameter could produce non invariant effects on labor supply decisions. In the case when the value of this parameter is high future generation could reduce
labor supply due to higher wealth effect. This effect reduces future outputs and damages caused by current emissions will not be so indifferent for future generations.

We argue that overlapping generations framework in integrated assessment modeling could resolve the issue about consistency of models with real returns on capital and more equitable treatment of different generations. We consider competitive equilibrium where government follows Ramsey (1927) type optimal policy and set emissions control rate maximizing utilitarian welfare function treating all generation equally. In fact, there are two discount rates in the model: the social planner discount rate under which costs benefits analysis of climate projects are evaluated and the market discount rate for investments in physical capital.

By distinguishing the two discount rates it is possible to give each generation equal consideration while still allowing for individual impatience. So this framework is a way to separate equity and efficiency. It should be noted that central planner problem in the OLG framework could not resolve this issue because it leads to virtually the same results as in the ILA model. The equivalence of the central planner problem in the OLG and ILA frameworks was pointed out by Calvo and Obstfeld (1988) and Howarth (1996) among others.

In the paper we introduce an OLG framework in the Regional Integrated model of Climate and the Economy (RICE) by Nordhaus and Yang (1996). We consider eight region specifications of the model and calibrate most of the parameters as in the paper (Ortiz et al., 2011). Regional specification of the model allows us to investigate regional-specific policies and to analyze welfare gains and losses of different generations in different regions in comparison to alternative policies of emissions reduction. We analyze how calibration of the social time preferences influences outcomes on emission reduction and real returns in Nash equilibrium and one possible grand coalition where benevolent planner maximizes the sum of regional welfares with equal treatment of all regions under the additional constraint to the baseline model of equalization of marginal abatement costs between regions.

The paper is organized as follows. Section 2 describes the model. Section 3 describes the calibration of parameters responsible for the extension of baseline model. Section 4 presents simulation results. Section 5 concludes.

2. The model

This section describes the model used to evaluate alternative policies of emissions reduction in overlapping generations extension of RICE model. In construction of overlapping generations model we use Diamond-Samuelson OLG framework with set up with seven generations as in the paper (Fougere et al., 2007). The model is very stylized. We will not examine in details aspects of differences in life expectancy in considered regions. We assume that in each region there is the same number of generations and in each region each generation lives during the same time period. Structure of preferences, technology, productivity and population projections may be different between regions.

*Households*

Each adult individual in each region lives seven periods of ten years, retiring after five periods. In each period, the eldest generation dies and a new generation enters the labor force, which implies that at any
point in time seven generations are alive. The working life begins at age 15; younger children are assumed to be fully dependent on their parents to which they constitute no extra burden nor provide any felicity and play no active role in the model. Individuals have perfect foresight and fully retire from the labor force at age 64 and die at age 84. We don’t consider bequest and pension system in this simple framework. So individuals make savings over the first five periods of life to ensure consumption in old age. A newborn generation’s problem consists of maximizing an inter-temporal utility function of consumption subject to lifetime income. The utility function is time-separable with the following CES form:

$$U_{R,t} = \sum_{g=1}^{7} \left( \frac{1}{1 + \hat{\rho}_R} \right)^{\theta - 1} \left( \frac{C_{R,g,t+g-1}^{1-\theta}}{1 - \theta_R} \right)$$

where $C_{R,g,t}$ is the consumption of individual of age group $g$ at time $t$ in region $R$, $\hat{\rho}_R$ is the pure individual rate of time preferences, $\theta$ is the inverse of the inter-temporal elasticity of substitution. This equation states that the welfare of an individual is a weighted sum of 7 periods of consumption from age group $g=1$ at period $t$ to age group $g=7$ at $t+6$. Leisure does not enter into the utility function since individual’s labor supply is assumed to be exogenous.

The dynamic budget constraint is given by:

$$C_{R,t,g} + lend_{R,t+1,g+1} = W_{R,t,g} + (1 + r_{R,t})lend_{R,t,g}$$

where $lend_{R,t,g}$ is the assets of individual of age group $g$ at the beginning of period $t$ in region $R$. $W_{R,t,g}$ is the labor earnings at time $t$, $r_{R,t}$ is the rate of return on physical capital. We could rewrite this equation in the following form:

$$lend_{R,t+1,g+1} - lend_{R,t,g} = W_{R,t,g} + r_{R,t} lend_{R,t,g} - C_{R,t,g}$$

(5)

Equation (5) implies that net savings of individual of age group $g$ during period $t$ is the sum of labor and capital income net of expenditures on consumption. Natural restriction on assets is that the individual has no assets at the beginning of the work and does not leave assets at death, i.e. consumes all of remaining financial assets in the last period.

Labor earnings depend on the individual’s age-dependent productivity profile $EP_{R,g}$ which is defined as a quadratic function of age $g$:

$$EP_{R,g} = \begin{cases} \gamma_R + \lambda_R g - \psi_R g^2, & 1 \leq g \leq 5 \\ 0, & g > 5 \end{cases}$$

(6)

with parametric values chosen to ensure that the maximum is reached between mid-life and retirement. Each individual in each region is endowed with the number of units $Lab_{0,R}$ of inefficient labor. The amount of efficient labor of individual of age group $g$ is defined as the product of the number of units of inefficient labor and age-dependent productivity:

$$Lab_{R,g} = EP_{R,g} Lab_{0,R}$$

(7)
For each unit of efficient labor in each region is paid a wage rate \( w_{R,t} \) and wage earnings of individual of age group \( g \) in region \( R \) at time \( t \) are defined as follows:

\[
W_{R,t,g} = w_{R,t} \text{Lab}_{R,g}
\]  

(8)

The total amount of effective labor \( L_{R,t} \) in the region \( R \) at time \( t \) is the sum of effective labor units offered by all individuals living in this period in considered region:

\[
L_{R,t} = \sum_{g=1}^{G} \text{Lab}_{R,g} \text{Pop}_{R,t,g},
\]  

(9)

where \( \text{Pop}_{R,t,g} \) is the population size of cohort of age group \( g \) at time \( t \) in region \( R \).

We assume the economy with perfect capital markets and without borrowing constraints. Individuals take wages and rates of return on physical capital as given. The problem of maximizing utility yields the following first-order Euler condition for consumption:

\[
\frac{C_{R,t,g+1}}{C_{R,t,g}} = \left( \frac{1 + r_{R,t+1}}{1 + \rho_R} \right)^{\theta_R}
\]  

(10)

Production

The production sector is fully based on RICE model. The regional aggregate output is assumed to be produced with Cobb-Douglas production function:

\[
Q_{R,t} = \Omega_{R,t} A_{R,t} K_{R,t}^{\gamma_R} L_{R,t}^{1-\gamma_R},
\]  

(11)

where \( Q_{R,t} \) is the regional aggregate output, \( K_{R,t} \) is the capital, \( L_{R,t} \) is the amount of efficient labor, \( A_{R,t} \) is the total factor productivity, \( \gamma_R \) is the output elasticity with respect to capital and variable \( \Omega_{R,t} \) represents the climate damages. The damage function assumes that damages from climate change are proportional to regional output and are functions of global mean temperature change:

\[
\Omega_{R,t} = \frac{1}{\left( 1 + \pi_{R,1} T_t^{AT} + \pi_{R,2} (T_t^{AT})^2 \right)},
\]  

(12)

where \( T_t^{AT} \) is the \( ^\circ \)C increase of global mean surface temperature from 1900.

Industrial production is associated with emissions of greenhouse gases (GHG), which subsequently leads to global warming with a long lag, which leads to losses in output. It is assumed that regional GHG emissions (its \( CO_2 \) equivalent) are proportional to regional output:

\[
E_{R,t}^{\text{ind}} = \sigma_{R,t} (1 - \mu_{R,t}) A_{R,t} K_{R,t}^{\gamma_R} L_{R,t}^{1-\gamma_R}
\]  

(13)

In this equation \( \sigma_{R,t} \) is the uncontrolled exogenous ratio of GHG emission to output which declines slowing. The variable \( \mu_{R,t} \in [0,1] \) is the emission-reduction rate which is imposed to firms in each region \( R \) by the regional governments. Firms take the emission-reduction rate as a given. The reduction of emission of green house gases is associated with abatement costs which are fully paid by firms. The abatement cost
function assumes that abatement costs $TC_{R,t}$ are proportional to regional output and to a polynomial function of the reduction rate:

$$TC_{R,t} = Q_{R,t} \alpha^{\theta_{R,t}} R_{t}$$  \hspace{1cm} (14)$$

where $\theta_{R,t}$ is the parameter which represents a backstop technology.

Equations (11) and (14) lead to firms’ production function of output net of abatement costs:

$$Y^{net}_{R,t} = Q_{R,t} - TC_{R,t} = (1 - \theta_{1,R,t} \mu^{\theta_{R,t}}_{R,t}) Q_{R,t} = (1 - \theta_{1,R,t} \mu^{\theta_{R,t}}_{R,t}) \Omega_{R,t} A_{R,t} K^{\gamma_{R,t}} L^{1-\gamma_{R,t}}$$ \hspace{1cm} (15)$$

We assume that there is a large number of identical firms. The firms hire workers and rent capital in competitive factor markets, and sell their output net of abatement costs in competitive output market. Firms take multiplier $(1 - \theta_{1,R,t} \mu^{\theta_{R,t}}_{R,t}) \Omega_{R,t} A_{R,t}$ in production function (15) as given. Profit maximization leads to the following first order condition:

$$w_{R,t} L_{R,t} = (1 - \gamma_{R,t}) Y^{net}_{R,t}$$  \hspace{1cm} (16)$$

$$R^{k}_{R,t} K_{R,t} = \gamma_{R} Y^{net}_{R,t}$$  \hspace{1cm} (17)$$

where $R^{k}_{R,t}$ is the rental price of capital.

**Geophysical equations**

Geophysical equations in our model are the same as in the RICE model. Total GHG emissions $E_t$ are the sum of industrial $CO_2$ emissions and the other GHGs $E_{R,t}^{Land}$ (including $CO_2$ arising from land-use change), which are exogenous in the model:

$$E_t = \sum_{R} \sigma_{R,t} (1 - \mu_{R,t}) Y_{R,t} + E_{R,t}^{Land}$$ \hspace{1cm} (18)$$

Next three equations (19-21) represent the carbon cycle of a three-reservoir model:

$$M_{t}^{AT} = E_{t} + \phi_{11} M_{t-1}^{AT} + \phi_{21} M_{t-1}^{UP}$$ \hspace{1cm} (19)$$

$$M_{t}^{UP} = \phi_{12} M_{t-1}^{AT} + \phi_{22} M_{t-1}^{UP} + \phi_{32} M_{t-1}^{LO}$$ \hspace{1cm} (20)$$

$$M_{t}^{LO} = \phi_{23} M_{t-1}^{UP} + \phi_{33} M_{t-1}^{LO}$$ \hspace{1cm} (21)$$

where $M_{t}^{AT}, M_{t}^{UP}, M_{t}^{LO}$ are masses of carbon in reservoir for atmosphere, upper oceans and lower oceans.

Accumulations of GHGs lead to warming at the earth’s surface through increases in radiative forcing. A positive forcing tends to warm the system, while a negative forcing tends to cool it. The resulting relationship between radiative forcing and greenhouse-gas mass in the atmosphere is given by:

$$F_{t} = \eta \left\{ \log_{e} \left( \frac{M_{t}^{AT}}{M_{1750}^{AT}} \right) \right\} + F_{t}^{EX}$$ \hspace{1cm} (22)$$

where $F_{t}, F_{t}^{EX}$ are total and exogenous radiative forcing (watts per square meter from 1900), $M_{1750}^{AT}$ is the mass of carbon in reservoir for atmosphere in 1750.

And the next two equations relate radiative forcing with temperatures of the atmospheric layer and the deep ocean:
\[
T_i^{AT} = T_{i-1}^{AT} + \xi_1 \{ F_i - \xi_2 T_{i-1}^{AT} - \xi_3 (T_{i-1}^{AT} - T_{i-1}^{LO}) \} \\
T_i^{LO} = T_{i-1}^{LO} + \xi_4 (T_{i-1}^{AT} - T_{i-1}^{LO})
\]

**Government**

We assume that government in each region cares about generations currently alive (7 generations) and generations to be born in future (\(T_{\text{max}} - 1\) generations). The welfare function is the sum of discounted utilities of all generations, as measured from the moment of birth:

\[
W_R = \sum_{t=-5}^{T_{\text{max}}} \frac{1}{(1 + R)^t} Y_{R,t}^{\text{pop}} \left\{ \sum_{g=1}^{7} \left( \frac{1}{1 + R} \right)^{t-g} \left( \frac{C_{R,g,t}}{1 - \theta_R} \right) \right\}
\]

where \(R\) is the social rate of time preferences. The first six terms in the sum (\(t = -5:0\)) correspond to the generations born in the past. If the government cares less about future generations, it would set \(R > 0\). If the government cares equally about all generations, it would set \(R = 0\).

A separate issue is the formulation of the problem of social planner on a finite or infinite time interval. If we consider the infinite interval, when using social discount rate \(R = 0\) sum in (25) will not converge. To ensure the convergence it is necessary to use any positive discount rate.

In the paper we consider two solution concepts of the model: Nash equilibrium and grand coalition. In Nash equilibrium solution we assume that government in each region sets regional emission control rate maximizing own social welfare treating emission control rates of the other regions as a given. In grand coalition solution we assume that benevolent planer maximizes the sum of regional welfares with equal treatment of all regions under the additional constraint to the baseline model of equalization of marginal abatement costs between regions.

**Market and Aggregation Condition**

The goods market equilibrium requires that the aggregate demand for goods for consumption and investment in each period in each region be equal to the supply of net output:

\[
Y_{R,t}^{\text{net}} = I_{R,t} + \sum_{g=1}^{7} \text{Pop}_{R,t,g} C_{R,t,g}
\]

The capital formation process is described by the standard equation:

\[
K_{R,t+1} = (1 - \delta_R) K_{R,t} + I_{R,t}
\]

The capital market equilibrium requires that the stock of capital accumulated in each period is equal to the demand expressed by firms and is equal to the sum of assets of all individuals lived in period \(t\):

\[
K_{R,t} = \sum_{g=1}^{7} \text{Pop}_{R,t,g} \text{lend}_{R,t,g}
\]

And the labor market equilibrium requires that the total supply of efficient labor is equal to the labor demand by firms.
3. Calibration

For demonstration purpose of the discounting issue in Regional Integrated model of Climate and the Economy we calibrate all parameters that do not correspond to overlapping generations as in the DICER model (Ortiz et al., 2011). Thus we consider eight region specification of the model with the following regions: USA (USA, Puerto Rico and the US Virgin Island), OECD1 (EU OECD countries), China (and Hong Kong), India, OECD2 (Australia, Canada, Japan, Korea, Mexico, New Zealand, Turkey), FOREST (Brazil, Indonesia, DR Congo and Malaysia), FSU_EE (Former Soviet Union countries), and Rest of the World (143 more countries).

We calibrate age-dependent productivity profile $EP_{R,g}$ as in the paper (Fougere et al., 2007):

$$EP_{R,g} = \begin{cases} 
1 + 0.25g - 0.0285g^2, & 1 \leq g \leq 5 \\
0, & g > 5 
\end{cases} \tag{29}$$

Model results are not sensitive to these parameters. And the number of units $Lab0_R$ of inefficient labor in each region that belongs to each individual is calibrated under the assumption that the total efficient labor in the particular region in OLG model is equal to the labor force in that region in the DICER model in the first period. We calibrate population dynamics of different age cohorts in different regions under condition that total population dynamics in particular region in OLG framework be as close as possible to total population dynamics in that region in ILA framework in the DICER model.

The separate issue is the choice of parameters for the utility function: the pure individual rate of time preferences $\hat{\rho}_R$ and the inverse of the inter-temporal elasticity of substitution $\theta_R$ of the individual. In the infinitely-lived agent framework of the DICE-2007 model Nordhaus (2008) calibrates the pure rate of time preferences equals to 1.5 percent per year and the inverse of the inter-temporal elasticity of substitution equals to 2 under requirement that the rate of return on capital be calibrated with observed market data. With this pair of assumptions, the real return on capital averages around 5.5 percent per year for the first half century of the projections in DICE-2007 model (Nordhaus, 2008). We follow the same logic. At first, we fix the inverse of the inter-temporal elasticity of substitution in each region equals to 2. Then we chose the value for the pure individual rate of time preferences (the same for all regions) to ensure that the average regional returns on capital for the first half century of the projections in OLG model are approximately equal to the corresponding projections of ILA specification of DICER model. The resulting value for the pure rate of time preferences is calibrated to 2.5 percent per year.

The computations for the model are performed in the GAMS modeling system. We use the length of estimate period for model $T_{\text{max}} = 60$ periods which is equal to 600 years. We compare simulation results under two alternative values for social rate of time preferences: 1.5% per year and 0% per year.
4. Numerical results

We now describe major results of the OLG extension of the RICE/DICER model. First we analyze how calibration of the social time preferences influences outcomes on emission reduction and real returns in Nash equilibrium. Figures 1 and 2 show regional emissions control rates in Nash equilibrium under two alternative values for social time preferences: 1.5% per year and 0% per year. Figures 3 and 4 show regional emissions of industrial GHG. The solid line corresponds to the scenario with a positive social time preferences, the dashed line — a situation in which governments in regions care about the welfare of present and future generations equally. One period of the X axis corresponds to the decade. Thus, the time interval of the X axis is 200 years. The calibration with social rate of time preferences equals to 1.5% per year in OLG framework produces virtually the same results as in ILA framework and we do not present results of ILA framework in the paper.

The results of the projections with social rate of time preferences equals to 0% per year are in favor for a more drastic reduction in emissions compared with calibration of social time preferences equals to 1.5% per year. For example the emissions control rate in China is 53% after 100 years under zero social rate of time preferences and this is 20% higher than in the run with the social time preferences equals to 1.5% per year. In the second scenario GHG emissions are rising in China during the first 150 years and emissions increase from 2 billion ton per year to 3.2 billion ton per year. In the first scenario emissions are stabilized at the current level over the next century.

Similarly there is a big difference in GHG emissions paths for the USA. In the case of social rate of time preferences equals to zero the USA emissions stabilizes at a level slightly lower current emission values during the first 150 years and then begins to decline. In the case of positive value for the social rate of time preferences emissions increase from 1.7 billion ton per year to 3.3 billion ton per year during next 200 years. FSU countries increase emissions in both scenarios. Some reduction in emissions begins to emerge only after 160 years with zero social rate of time preferences. This dynamics is due to relatively low damages from temperature increase in FSU region.

Figures 5 and 6 show regional real returns on capital. As follows from the figures, parameterization of social rate of time preferences doesn’t have a significant effect on real returns on capital dynamics. In the medium term real returns are virtually the same between scenarios and there is some slight difference in long term. Paths of capital-output ratios and saving rates demonstrate the analogous stability to the calibration of social rate of time preferences (we don’t present corresponding figures for briefness).

As noted in introduction the main critics of Stern Review discounting (Stern, 2007) is that results of the “utilitarian” calibration of the model are not compatible with today’s real returns on capital, capital output ratios and saving rates. As follows from the above analysis in the competitive equilibrium in OLG model it is possible to distinguish between two discount rates: the social planner discount rate under which costs benefits analysis of climate projects are evaluated and the market discount rate for investments in physical capital. Thus it is possible to rationalize more radical emissions reduction keeping real returns on capital virtually unchanged.
Fig. 1. Regional emission control rates: Nash equilibrium

Fig. 2. Regional emission control rates: Nash equilibrium
Fig. 3. Regional emissions of industrial GHG: Nash equilibrium

Fig. 4. Regional emissions of industrial GHG: Nash equilibrium
Fig. 5. Real returns on capital: Nash equilibrium

Fig. 6. Real returns on capital: Nash equilibrium
Fig. 7. Global mean temperature change relative to the 1900 average: Nash equilibrium

Figure 7 shows global mean temperature change in Nash equilibrium under two alternative values for social time preferences: 1.5% per year and 0% per year. There is a very similar dynamics of the temperature change in the medium term because of high inertia in the climate system. In the long run the difference between two scenarios is about 1 Celsius degree.

Let us move on to comparison of results of GHG emissions reduction between the Nash equilibrium solution and the grand coalition solution. For brevity we only present the results for the calibration with zero social rate of time preferences. Figures 8 and 9 show regional emissions control rates. The solid line corresponds to the scenario of the grand coalition, the dashed line — the Nash equilibrium solution. As follows from the figures there are very radical emissions reduction paths in grand coalition solution. The emissions controlled rates increase rapidly to values between 40 and 60% depending on the region over next decade. Further the emissions controlled rates increase monotonically without any jumps. As shown in figure 9 the more radical emission reduction in grand coalition could substantially prevent global warming. The global mean temperature change demonstrates hump-shaped dynamics with peak of 2.2 Celsius degrees increase in 100 years period.

And which generations are better off from more aggressive emission reduction in the grand coalition solution compared with Nash equilibrium solution? Figure 11 shows welfare gains of different generations in different regions from this more aggressive emission reduction policy. The X axis is responsible for the moment when the generation is born. Gains and losses are very unevenly distributed between regions and
generations. Results show that from more aggressive policy would suffer currently alive people and people to be born in near future primarily in developed regions and in FSU. Major beneficiaries from the grand coalition solution are generations to be born in the poor countries in the next century. These results are consistent with Schelling (1995).

Interesting result is that under zero value of the social rate of time preferences all regions are better off in the grand coalition compared to the Nash equilibrium. On the other hand under calibration of the social rate of time preferences to 1.5% per year some regions are better off in the Nash equilibrium compared to the grand coalition. The utilitarian specification of regional welfare functions potentially could increase incentives of regions to collaborate in prevention to global warming. But the solution of the considered specification of the grand coalition is not stable. All regions have benefits from joint effort of climate mitigation, but freeriding incentives for each particular region are very high. Special case is China, which has the higher benefits of avoiding climate change, and also has highest incentives for exit from grand coalition.

![Emission control rates](image_url)

*Fig. 8. Regional emission control rates: Nash equilibrium vs. coalition (zero social time preferences)*
Fig. 9. Regional emission control rates: Nash equilibrium vs. coalition (zero social time preferences)

Fig. 10. Global mean temperature change relative to the 1900 average: Nash equilibrium vs. coalition (zero social time preferences)
Fig. 11. Welfare gains of different generations from grand coalition compared to Nash equilibrium (zero social time preferences)

5. Conclusions

The limitations in calibration of the integrated assessment models to the market rate of return can be avoided by switching from infinitely lived agent (ILA) to overlapping generation framework, and from centrally planned to the market economy. We argue that OLG framework in integrated assessment modeling could resolve the issue about consistency of models with real returns on capital and more fair treatment of different generations. The model can well reproduce the path of real returns of RICE model and the results of the analysis are in favor for a more drastic reduction in emissions compared with baseline run of RICE model. Assumptions used in the model could rationalize more radical GHG emissions reduction without significant influence on real returns, saving rates and capital-output ratio.
References


