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A note on climate change and growth dynamics☆

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ABSTRACT

Climate change is, perhaps, the most important of challenges currently facing humankind, with the potential to have health and welfare implications by imposing a sizeable aggregate risk to the economy. Given this, and in the wake of an ever-burgeoning literature on the nexus between climate change and economic growth, we develop an overlapping generations endogenous growth model characterized by climate change, with the latter being specified as a fraction of output lost due to changes in temperature anomalies. We show that growth dynamics arise in this model when changes in temperature anomalies are a positive function of current economic growth, i.e., considered to be endogenous unlike existing theoretical models on this topic, with this theoretical specification motivated through extensive empirical analyses involving 167 countries over a long span of historical data covering 1851 to 2018. In particular, two distinct oscillatory growth dynamics emerge: one convergent and the other divergent, contingent on the strength of the response of global warming, i.e., changes in temperature anomalies to current economic growth. Our theoretical results suggest that policymakers should be cognizant that unless economic growth is "green", rapid global warming can put economies in a fluctuating, divergent, balanced growth.

1. Introduction

This paper develops an overlapping generation (OLG) endogenous growth model characterized by climate change to analyze the growth dynamics in the presence of this augmentation. We endogenize growth by allowing for a Romer [1]-type production function. In line with the Dynamic Integrated Climate-Economy (DICE) model of Nordhaus [2,3,4], we introduce the role of climate change as the fraction of output that is lost due to changes in temperature anomalies (i.e., a departure of the temperature at a specific point in time from a reference value or long-term average). However, motivated by the basic understanding that changes in temperature anomalies are not exogenous but are driven primarily through emissions of Greenhouse gases resulting from the pursuit of rapid economic growth, primarily since the "Industrial Revolution" (see, for example, Fouquet [5], Kallis et al. [6], and Phella et al. [7] for detailed discussions in this regard), we endogenize the fraction of output lost due to process of climate change, i.e., changes in temperature anomalies, by making it a function of current economic growth itself, and in the process, we differ from the works of Greiner and Semmler [8], and Dietz and Stern [9], who treated the output loss as an exogenous function of the evolution of temperature. Since this is the pivotal component of our theoretical model leading to growth dynamics, we provide comprehensive empirical evidence of the endogenous nature of changes in temperature anomalies based on a long-span data set of a panel of 167 countries from 1851 to 2018.

With changes in temperature anomalies being a function of current economic growth, we show that convergent and divergent oscillatory growth dynamics arise depending on the strength of the response of changes in temperature anomalies to current economic growth, which is not possible otherwise in this theoretical construct. In the process, our paper adds to the vast literature of OLG endogenous growth models that analyze growth dynamics (see, for example, Gupta and Vermeulen [10], Gupta [11], Kudoh [12], Gupta and Stander [13], Gupta and Makena [14], Bittencourt et al. [15]) through an alternative channel, namely, by incorporating the role of global warming, for the first time, in a typical OLG endogenous growth model. In this regard, note that to create growth dynamics in their OLG models, Gupta and Vermeulen [10], Gupta [11] and Gupta and Stander [13] had to respectively introduce probability of survival as a function of private and public investment, and lagged inputs respectively, while Kudoh [12] had to rely on lump-sum, rather than income taxation, with Gupta and Makena

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[14] and Bittencourt et al. [15] having to incorporate the role of inflation targeting and socio-political instability, respectively. It must be pointed out that, these studies produces various types of growth dynamics ranging from convergent and divergent growth paths with and without oscillations, multiple equilibria with indeterminancy, and chaos.

Due to global warming, climate change is, perhaps, the most important of challenges currently facing humankind, with the potential to impact the health and welfare of everyone on the planet by imposing a sizeable aggregate risk to the economy [16]. Naturally, our theoretical observations should be important to global policy authorities aiming to transition into a green and sustainable economy to reduce the speed of global warming. The rest of the paper is organized as follows: Section 2 defines the economic setting of the theoretical model, with the solution detailing the process of the growth dynamics. In this Section, while outlining our production structure, we also present the empirical evaluation of the theoretical construct about the relationship between changes in temperature anomalies and economic growth. Section 3 offers some concluding remarks and policy advice based on the results.

2. The model

2.1. Households

Let us consider an economy consisting of an infinite sequence of two period-lived OLG of individuals and the initial old generation. Time is divided into discrete segments with t =1,2, ... In each period, a new generation of unit measure is born. Each agent is endowed with one labor unit when young and retired when old. We preclude labor–leisure choices of the agents by assuming that young agents supply their labor endowment, n_t, inelastically in the labor market. The initial old agents are endowed with $k_1 > 0$ units of capital.

Let c_{1t} and c_{2t} denote a consumption when young and when old, respectively, corresponding generation-t of an agent. To rule out an endogenous saving decision, we, as in Gupta and Vermeulen [10], Gupta [11], Kudoh [12], Gupta and Stander [13], Gupta and Makena [14], Bittencourt et al. [15], assume that agents care about consumption only when old, i.e., $c_{1t} = 0$, so that all income is saved. Formally, even though the choice of the utility function is redundant due to only old-age consumption, with optimal decisions made from the budget constraint directly in the presence of one asset, i.e., capital, k_t, used for savings, for the sake of completeness, the decision problem of the consumers is as follows:

$$\max U\left(c_{2t}\right) \tag{1}$$

subject to:

$$k_{t+1} = w_t n_t \tag{2}$$

$$c_{2t} = r_{t+1} k_{t+1} \tag{3}$$

where U is a utility function of a general form but assumed to be twice-differentiable, such that $U'() > 0$ and $U''() < 0$; w_t and r_t are wages and gross return (rental) on savings (capital), respectively.

2.2. The production structure

The production technology employed in this note is motivated by Romer [1] and Nordhaus [2,3,4], whereby a single final good is produced using the production function:

$$y_t = (1 - \lambda_t) A k_t^{\alpha} \left(n_t \bar{k}_t\right)^{1-\alpha} \tag{4}$$

where $A > 0$ is a technology parameter, $0 < \alpha(1 - \alpha) < 1$ represents the elasticity of output with respect to capital, k_t, labor, n_t, or aggregate capital, $\bar{k}_t$, respectively. The aggregate capital stock enters the production function because of the production externality, implying that labor productivity rises as the society increases its capital stock, causing the tendency for diminishing returns on capital stock to be eliminated. More specifically, Romer [1] made two assumptions about productivity growth: (i) Learning-by-doing, which works through each firm's investment, whereby increases in a firm's capital stock result in a parallel increase in productivity, as the firm learns simultaneously to produce more efficiently, and; (ii) Firm's knowledge is a public good, thus, any other firm can access the same at zero cost. Naturally, once discovered, the knowledge spills over instantaneously across the economy, implying that changes in the technology of each firm translate into the overall learning of the economy, and is therefore proportional to change in the aggregate capital stock: $\left(n_t \bar{k}_t\right)$. In sum, while exogenous technological change is ruled out, the model here can be viewed as an equilibrium model of endogenous technological change in which long-run growth is driven primarily by the accumulation of knowledge by forward-looking, profit-maximizing agents, but which becomes a natural externality for other firms due to its public good nature. This focus on knowledge as the basic form of capital suggests natural changes in the formulation of the Cobb–Douglas-type production function, depicting diminishing returns to factors, in standard growth models.

Furthermore, $\bar{k}_t = k_t$ in equilibrium, i.e., after the optimization production decisions have been made, as all firms producing the output are identical in the representative agent economy, they will make the same choice, naturally leading to firm-level capital stock to be equal to average economy-wide value of the same. For expositional reasons, capital is assumed to depreciate completely between periods.

Furthermore, and importantly in our context, λ_t is the climate change factor as in the DICE model, with:

$$\lambda_t = f(\Delta TA_t) \tag{5}$$

where ΔTA_t is the change in temperature anomalies, and $f'(\Delta TA_t) > 0$. Also, following the discussions in [5,6], and [7], we have:

$$\Delta TA_t = g(\Omega_t) \tag{6}$$

where $g'(\Omega_t) > 0$, and Ω_t being the gross growth rate at time t. Therefore, we can say that:

$$(1 - \lambda_t) = h(\Omega_t) \tag{7}$$

with $h'(\Omega_t) < 0$. In other words, higher economic growth is associated with changes in temperature anomalies, which in turn, results in loss of output due to the process of global warming. In this regard, it must be pointed out that, instead of using changes in temperature anomalies in Eqs. (5), (6), and (7), we could as well have used changes in Greenhouse Gas (GHG) emissions, which results from economic growth, and, in turn, drives the process of fluctuations in temperature. Our theoretical findings discussed below would, understandably, still continue to be exactly the same, but we use changes in temperature anomalies in the theoretical model, so that we have one-to-one correspondence with the empirical model that we present in the next sub-section, in light of availability of long span of temperature data, unlike that of GHG emissions, for the large number of countries that we consider.

2.2.1. Empirical motivation of the production structure

To empirically motivate that the changes in temperature anomalies depend on economic growth, we rely on an unbalanced panel data set fixed-effects estimation involving 167 countries from 1851 to 2018. The growth rate of these countries is based on the per-capita real Gross Domestic Product (GDP) derived from the 2020 Maddison Project Database, whereby the dataset produces a long-term trend of the GDP per capita in 2011 dollars using the purchasing power parities to harmonize the national income estimates.[1] The changes in temperature

[1] The data is available for download from: https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020.

Table 1
Panel data estimation results.

	First Stage:					
	Growth$_t$					
	All		AEs		EDCs	
ΔTA_t	−0.004*** (0.001)	−0.004*** (0.001)	−0.004*** (0.001)	−0.005*** (0.001)	−0.004*** (0.001)	−0.003** (0.001)
ΔTA_t Volatility$_t$		−0.028*** (0.006)		0.035*** (0.009)		−0.061*** (0.008)
Growth Volatility$_t$		−0.00001*** (0.00000)		0.00001** (0.00000)		−0.00001*** (0.00000)
	Second Stage:					
	ΔTA_t					
	All		AEs		EDCs	
Fitted Growth$_t$	33.142*** (8.123)	25.281*** (3.467)	30.392*** (10.316)	8.237*** (2.637)	34.753*** (11.475)	26.775*** (2.915)

Notes: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$, with standard errors in parentheses. The classification of countries into Advanced Economies (AEs) and Emerging and Developing Countries (EDCs) categories follows the classification of the International Monetary Fund (IMF).

anomalies are obtained from the land and ocean temperature deviation (in degree Celsius) from the 1991–2020 average, as reported by the National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA),[2] once we specifying the respective latitude and longitude for each of the corresponding countries. The data have been summarized in Table A.1 in the Appendix of the paper.

Empirically speaking, we adopt an instrumental variable (IV) two-step approach. This is because, it is well-accepted that climate change is not only affected by economic growth, but also impacts the latter (see, for example, Donadelli et al. [17], Gupta et al. [18], Huber et al. [19], and Sheng et al. [20] for detailed reviews). Naturally, to ensure that our estimation of the effect of economic growth on changes in temperature anomalies, does not suffer from endogeneity-bias, we need to resort to the IV-method, whereby in the first-step we need to obtain predicted values of economic growth arising due to climate risks, as well as growth volatility, i.e., macroeconomic uncertainties — the role of which being recently extensively reviewed by Tan et al. [21].

In light of the above-mentioned extensive literature on the effect of climate risks, as captured by changes in temperature anomaly, ΔTA, in the first stage, we report the effect ΔTA on growth, while also controlling for the volatilities of ΔTA and economic growth, capturing second-moment effects, i.e., uncertainties [22–25]. Note that the volatility of ΔTA and growth are both derived based on a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model [26] fitted to these two variables for each country. As can be seen from the first panel of Table 1, inline the existing studies on the global warming-economic growth nexus, ΔTA tends to negatively impact economic growth at least at the 5% level of significance, with the result holding even when we categorize countries based on the level of their development, and with and without the controls of uncertainty involving changes in temperature anomalies and economic growth. In the second step, we regress ΔTA on the fitted growth from the first stage, thereby ensuring robust inference in the wake of endogeneity. As observed from the second panel of Table 1, the fitted value of fitted economic growth consistently increases ΔTA at the 1% level of significance across the alternative model specifications with and without second-moment effects involving all the countries in the sample,[3] as well as those categorized as advanced, emerging, and developing. In other words, we provide comprehensive empirical evidence of the theoretical specification relating ΔTA_t to Ω_t. More importantly, in terms of theory, since this empirical relationship holds independent of the level of development of the countries in the sample, we can develop a uniform theoretical model that does not need to be specific to whether the model-economy under consideration is advanced, emerging, or developing.

2.2.2. Back to theory

Turning now back to the theoretical model, factor markets are perfectly competitive, and hence, the factors of production receive their respective marginal products. When maximizing profits, firms take the aggregate stock of capital, $\bar{k}_t$, as given, and recalling $n_t = 1$, we have:

$$\begin{aligned} r_t &= (1-\lambda_t)\alpha A k_t^{\alpha-1}\left(n_t\bar{k}_t\right)^{1-\alpha} \\ &= (1-\lambda_t)\alpha A \end{aligned} \tag{8}$$

$$\begin{aligned} w_t &= (1-\lambda_t)(1-\alpha)A k_t^{\alpha} n_t^{-\alpha}\bar{k}_t^{1-\alpha} \\ &= (1-\lambda_t)(1-\alpha)A k_t \end{aligned} \tag{9}$$

2.3. Growth dynamics

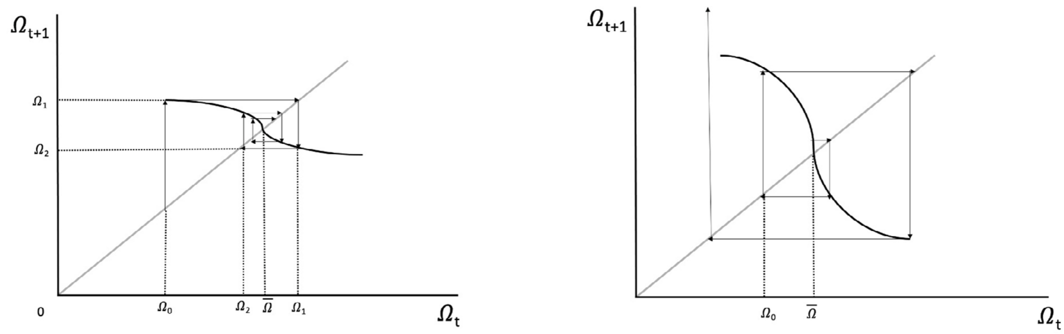
A competitive equilibrium for this economy is characterized as a sequence of prices $\left\{w_t, r_t\right\}_{t=0}^{\infty}$, allocations $\left\{c_{2t}, n_t, k_{t+1}\right\}_{t=0}^{\infty}$, and initial conditions $k_1 > 0$, such that each household maximizes utility, asset and factor markets both clear, resulting in the following growth path at time $t+1$ for the gross growth rate, $\Omega_{t+1} = \frac{k_{t+1}}{k_t}$, using Eqs. (2), (7), and (9):

$$\begin{aligned} \Omega_{t+1} &= h(\Omega_t)A(1-\alpha) \\ &= m(\Omega_t) \end{aligned} \tag{10}$$

where $m(\Omega_t) = h(\Omega_t)A(1-\alpha)$ Understandably, without the role of climate change in the model, i.e., $\lambda_t = 0$, $(1-\lambda_t) = 1$, we will not have the term $h(\Omega_t)$ in Eq. (10), suggesting non-existent growth dynamics, which forms the departure from previous studies, such as, Greiner and

[2] The data can be retrieved from: https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series.

[3] One must realize that monthly data is available for global temperature anomalies (from NOAA) and quarterly world (GDP-based weighted average of the United States (US) and World excluding the US) economic growth (from the Database of Global Economic Indicators maintained by the Federal Reserve Bank of Dallas: https://www.dallasfed.org/research/international/dgei/gdp, though for a relatively shorter sample, i.e., over April 1981 to September 2023. Given this, to check for the robustness of our results, we estimated a Reverse-Mixed Data Sampling (MIDAS) model, as proposed by Foroni et al. [27], whereby we regressed global ΔTA on its own lags and that for world economic GDP growth. As seen from Table A.2 in the Appendix, there is clear evidence that longer lags of economic growth, in particular, do tend to significantly increase ΔTA.



(a) Convergent Oscillatory Growth Path (-1< $m'(\Omega_t)$ <0) (b) Divergent Oscillatory Growth Path ($m'(\Omega_t)$ <-1).

Fig. 1. Model growth dynamics.

Semmler [8], and Dietz and Stern [9]. But now, with $A(1-\alpha) > 0$, we can have two scenarios, given that $h'(\Omega_t)$ <0, as is $m'(\Omega_t)$ <0:

$$-1 < m'(\Omega_t) < 0 \tag{11}$$

$$m'(\Omega_t) < -1 \tag{12}$$

In light of Eqs. (11) and (12), the growth path is subjected to convergent and divergent oscillations, respectively, as shown in the phase diagrams in Fig. 1. Economically speaking, the stronger the negative influence of the current economic growth on climate change through changes in temperature anomalies, the more likely the economy can end up on a divergent growth path with fluctuations.[4]

3. Conclusion

We develop an overlapping generations endogenous growth model characterized by climate change and analyze the resulting growth dynamics when temperature anomalies change, capturing global warming as a positive function of current economic growth, leading to a fraction of the production being lost. Our assumption involving the endogenous positive effect on the changes in temperature anomalies due to economic growth is vindicated empirically using a fixed-effects panel data estimation of 167 countries at various stages of development from 1851 to 2018. The model produces two distinct oscillatory growth dynamics: one convergent and the other divergent, informed by the responsiveness of changes in temperature anomalies, and hence the part of output lost to current economic growth. In the process, our paper depicts for the first time the role of climate change in producing growth-cycles, which, in turn, is a well-established empirical phenomenon [28,29].

While growth fluctuations are unavoidable in our model set-up, our theoretical findings tend to suggest that unless the growth process is “green” (i.e., reduce the strength of growth on changes in temperature anomalies), resulting climate change due to rapid global warming can put economies in a divergent balanced growth path with oscillations. In the process, our paper indicates that policy authorities must strive towards the adoption of environmental-friendly technologies as intensively as possible and communicating such changes in a transparent manner to reduce uncertainties associated with climate policies, so that the positive link between growth on global warming is dampened to ultimately reduce the loss of output due to climate change emanating from rapid economic activities.

In our model, fluctuations arise because current growth is, in some sense, always “bad” by driving climate change. As part of future research, it would be interesting to develop a more detailed theoretical framework wherein a positive influence of current economic growth on future growth can arise through seigniorage driving productive public expenditures in an inflation-targeting economy, along the lines of Gupta and Stander [13], and Gupta and Makena [14]. The positive and negative effects are likely to lead to multiple equilibria, indeterminacy, and possibly even chaotic behavior. At the same time, future analysis could involve the extension of the existing theoretical model to account for the role of climate change on asset markets and efficiency of corporate investment, as has been recently stressed in multiple empirical studies [30–33], something ignored in our framework involving just the real-sector of the economy.

[4] At the same time if two economies have similar responses of changes in temperature anomalies to current economic growth, i.e., $h'(\Omega_t)$, the economy with relatively higher values of A and/or $(1-\alpha)$ is more likely to demonstrate divergent growth oscillations.

CRediT authorship contribution statement

Rangan Gupta: Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Sarah Nandnaba:** Software, Methodology, Investigation, Data curation. **Wei Jiang:** Writing – review & editing, Software, Methodology.

Declaration of competing interest

The authors have declared no conflict of interest

Appendix

See Tables A.1 and A.2.

Data availability

Data will be made available on request.

Table A.1
Descriptive statistics.

(a) For All Countries				
Statistic	Growth	Growth Volatility	ΔTA_t	ΔTA_t Volatility
Min.	−6.051531	0.01861	−3.94500	0.6399
1st Qu.	−0.003908	0.03649	−0.29583	0.7691
Median	0.021935	0.04895	−0.01417	0.8340
Mean	0.000013	0.06019	−0.01791	0.8498
3rd Qu.	0.047332	0.06927	0.26250	0.9124
Max.	2.234564	0.44970	4.26833	1.7488
Sd	0.248265	0.039484	0.561636	0.116412

(continued on next page)

Table A.1 (*continued*).

(b) For Advanced Countries

Statistic	Growth	Growth Volatility	ΔTA_t	ΔTA_t Volatility
Min.	−3.351561	0.01861	−3.945000	0.6399
1st Qu.	0.000905	0.03243	−0.372500	0.7879
Median	0.023279	0.04329	−0.008333	0.8580
Mean	0.011069	0.05383	−0.014944	0.8782
3rd Qu.	0.045763	0.06208	0.365000	0.9494
Max.	1.574620	0.42820	4.268333	1.7488
Sd	0.171859	0.035816	0.700794	0.130159

(c) For EDC Countries

Statistic	Growth	Growth Volatility	ΔTA_t	ΔTA_t Volatility
Min.	−6.051531	0.01976	−2.99500	0.6468
1st Qu.	−0.006725	0.03864	−0.27000	0.7598
Median	0.021209	0.05113	−0.01500	0.8251
Mean	−0.004973	0.06306	−0.01925	0.8370
3rd Qu.	0.048075	0.07302	0.22750	0.8977
Max.	2.234564	0.44970	3.20667	1.4275
Sd	0.275753	0.0407093	0.4860646	0.1072193

Table A.2
Reverse-MIDAS Results for ΔTA_t.

Variable	Coefficient	Standard Error
Intercept	0.001	0.018
Growth_{t-1}	−0.008	0.006
Growth_{t-1}	0.002	0.011
Growth_{t-1}	0.014*	0.006
Growth_{t-1}	−0.007	0.008
Growth_{t-1}	−0.015*	0.007
Growth_{t-1}	0.017**	0.005
ΔTA_{t-1}	0.364***	0.078
ΔTA_{t-2}	0.236*	0.100
ΔTA_{t-3}	0.032	0.098
ΔTA_{t-4}	0.056	0.087
ΔTA_{t-5}	0.019	0.115
ΔTA_{t-6}	0.082	0.094
ΔTA_{t-7}	−0.023	0.083
ΔTA_{t-8}	0.002	0.081
ΔTA_{t-9}	−0.224*	0.097
ΔTA_{t-10}	−0.123	0.066
ΔTA_{t-11}	0.114	0.085
ΔTA_{t-12}	−0.474***	0.073
ΔTA_{t-13}	0.112	0.085
ΔTA_{t-14}	0.250*	0.106
ΔTA_{t-15}	0.127	0.084
ΔTA_{t-16}	−0.067	0.074
ΔTA_{t-17}	−0.101	0.105
ΔTA_{t-18}	0.037	0.078

Notes: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

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