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Book

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University of Pretoria
Department of Economics Working Paper Series

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Working Paper: 2024-04
February 2024

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Climate Change and Growth Dynamics

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Abstract

We develop an overlapping generations endogenous growth model characterized by climate change, with the latter being specified as a fraction of output lost due changes in temperature anomalies. We show that growth dynamics arise in this model when changes in temperature anomalies is a a positive function current economic growth, 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 policy makers should be cognizant of the fact that unless economic growth is "green", rapid global warming can would put economies in a fluctating divergent balanced growth.

JEL Classification: C23, O41, Q54
Keywords: Climate change, endogenous growth, dynamics.

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1 Introduction

This paper develops an overlapping generations (OLG) endogenous growth model characterized by climate change to analyse the growth dynamics in the presence of this augmentation. We endogenize growth by allowing for a Romer (1986)-type production function. In line with the Dynamic Integrated Climate-Economy (DICE) model of Nordhaus (1992, 1993, 1994), 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 is not exogenous, but is driven primarily through emissions of Greenhouse gases resulting from the pursuit of rapid economic growth, primarily since the "Industrial Revolution" (see, for example, Fouquet (2019), Kallis et al. (2020), and Phella et al. (2024) 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. 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 over the period of 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 analyse growth dynamics (see, for example, Gupta and Vermeulen (2010), Gupta (2011), Kudoh (2013), Gupta and Stander (2018), Gupta and Makena (2020), Bittencourt et al. (2022)) 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 (2010), Gupta (2011) and Gupta and Stander (2018) had to respectively introduce probability of survival as a function of private and public investment, and lagged inputs respectively, while Kudoh (2013) had to rely on lump-sum, rather than income taxation, with Gupta and Makena (2020) and Bittencourt et al. (2022) having to incorporate the role of inflation targeting and socio-political instability, respectively.

Climate change, due to global warming, is, perhaps, the most important of challenges currently facing humankind, with the potential to impact the health and welfare of every person on the planet by imposing a large aggregate risk to the economy (Giglio et al., 2021). Naturally, our theoretical observations should be importance 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 unit of labor when young and is 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 (2010), Gupta (2011), Kudoh (2013), Gupta and Stander (2018), Gupta and Makena (2020), Bittencourt et al. (2022), 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 $U^{'}(\dot{}) > 0$ and $U^{''}(\dot{}) < 0$; 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 (1986) and Nordhaus (1992, 1993, 1994), 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, labour, n_t, or aggregate capital, $\bar{k}_t$, respectively. The aggregate capital stock enters the production function because of the production externality, which implies that labor productivity rises as the society increases its stock of capital. In particular, $\bar{k}_t = k_t$ in equilibrium. 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 Fouquet (2019), Kallis et al. (2020), and Phella et al. (2024), 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.

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 over the annual period of 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 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.

In light of the large literature on the effect of climate risks, as captured by changes in temperature anomaly, ΔTA, (see, for example, Donadelli et al. (2021), Gupta et al. (2023), Huber et al. (2023), and Sheng et al. (forthcoming) for detailed reviews), in the first step, 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 (Donadelli et al., 2022; Alessandri and Mumtaz, 2022; Sheng et al., 2022, Cepni et al., 2023). Note that, the volatility of ΔTA and growth are both derived based on a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model (Bollerslev, 1986) fitted to these two variables for each country. As can be seen from the first panel of Table 1, in accordance with 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 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, and emerging and developing. In other words, we are able to provide comprehensive empirical evidence of the theoretical specification relating ΔTA_t to Ω_t.

[INSERT TABLE 1 HERE.]

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

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

[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. (2018), whereby we regressed global ΔTA on its own lags and that for world economic GDP growth. As seen from Table A1 in the Appendix, there is clear evidence that longer lags of economic growth in particular do tend to significantly increase ΔTA.

profits, firms take the aggregate stock of capital, $\bar{k}_t$, as given, and recalling $n_t = 1$, we have:

$$\begin{aligned} r_t &= (1-\lambda_t)\alpha A k_t^{\alpha-1}\left(n_t \bar{k}_t\right)^{1-\alpha} \\ &= (1-\lambda_t)\alpha A \qquad (8) \\ w_t &= (1-\lambda_t)(1-\alpha) A k_t^{\alpha} n_t^{-\alpha} \bar{k}_t^{1-\alpha} \\ &= (1-\lambda_t)(1-\alpha) A k_t \qquad (9) \end{aligned}$$

2.3 Growth Dynamics

A competitive equilibrium for this economy is characterised as a sequence of prices $\{w_t, r_t\}_{t=0}^{\infty}$, allocations $\{c_{2t}, n_t, k_{t+1}\}_{t=0}^{\infty}$, 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 equations (2), (7), and (9):

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

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 equation (10), suggesting non-existent growth dynamics. But now, with $A(1-\alpha) > 0$, we can have two scenarios, given that $h'(\Omega_t)$ <0, as is $m'(\Omega_t)$ <0:

$$-1 < m'(\Omega_t) \qquad (11)$$

$$m'(\Omega_t) < -1 \qquad (12)$$

In light of equations (11) and (12), the growth path is subjected to convergent and divergent oscillations, respectively, as shown in the phase diagrams in Figure 1. Economically speaking, 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]

[INSERT FIGURE 1 HERE.]

3 Conclusion

We develop an overlapping generations endogenous growth model characterized by climate change, and analyze the resulting growth dynamics when changes in temperature anomalies, capturing global warming, as a positive function of current economic growth leads to a fraction of the production being lost. Our assumption involving the endogeneous 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, over 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.

[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 oscilations.

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 would put economies in a divergent balanced growth path with osccilations.

In our model, fluctuations aris 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 (2018), and Gupta and Makena (2020). The positive and negative effects are likely to lead to multiple equilibria, indeterminancy, and possibly even chaotic behavior.

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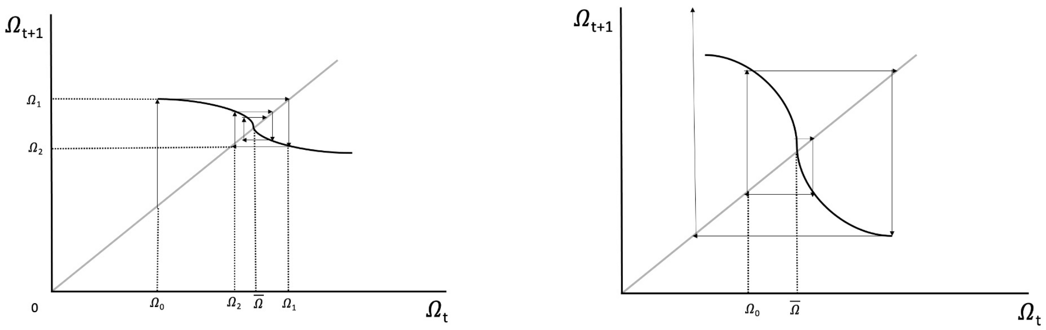
Table and Figure

Table 1: Panel Data Estimation Results

	First Stage:					
	Growth$_t$					
	All		AEs		EDCs	
ΔTA_t	-0.004^{***}	-0.004^{***}	-0.004^{***}	-0.005^{***}	-0.004^{***}	-0.003^{**}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ΔTA_t Volatility$_t$		-0.028^{***}		0.035^{***}		-0.061^{***}
		(0.006)		(0.009)		(0.008)
Growth Volatility$_t$		-0.00001^{***}		0.00001^{**}		-0.00001^{***}
		(0.00000)		(0.00000)		(0.00000)
	Second Stage:					
	ΔTA_t					
	All		AEs		EDCs	
Fitted Growth$_t$	33.142^{***}	25.281^{***}	30.392^{***}	8.237^{***}	34.753^{***}	26.775^{***}
	(8.123)	(3.467)	(10.316)	(2.637)	(11.475)	(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 follow the classification of the International Monetary Fund (IMF).

Figure 1: Model Growth Dynamics



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

A Appendix

Table A1: 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: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.