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Full Length Article

Oil consumption and growth: Is there a threshold effect of greenhouse gases emissions☆

Sarah Nandnaba [a], Abebe Hailemariam [b], Rangan Gupta [c,*], Xin Sheng [d]

[a] Department of Economics, École Normale Supérieure (ENS) Paris-Saclay, 91190 Gif-sur-Yvette, France
[b] Bankwest Curtin Economics Centre, Faculty of Business and Law, Curtin University Perth, 6102, Australia
[c] Department of Economics, University of Pretoria, Pretoria, 0002, South Africa
[d] Lord Ashcroft International Business School, Anglia Ruskin University, Chelmsford, United Kingdom

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ABSTRACT

The paper empirically examines the threshold effect of GHG(s) emissions on the oil consumption-growth nexus. Using a nonlinear local projection approach and an extended historical dataset from 1890 to 2022, we find that the impact of oil consumption on economic growth is conditional on the level of GHG(s) emissions. More specifically, we find that economies in high-emission regimes face a slowdown in growth while those in low-emission regimes benefit from a positive shock in oil. The results have important policy implications for sustainable growth.

1. Introduction

When implementing climate change mitigation measures, a concern arises regarding the potential reduction in economic growth. This concern stems from the fact that energy usage, a crucial production input, also generates Greenhouse Gas (GHG(s)) emissions, thus impacting environmental quality. In this context, policymakers promote energy conservation to protect the environment, which may reduce economic growth. GHG(s) emissions adversely affect growth, suggesting that improved energy management could enhance growth rather than hinder it. Given this, our study aims to evaluate the extent to which oil consumption affects growth, conditional on the level of GHG(s) emissions. By directly measuring the negative impact of higher GHG(s) emissions from energy consumption on growth, the study seeks to provide evidence supporting policies for better energy management and reduction of GHG(s) emissions.

The underlying hypothesis is that GHG(s) emissions can positively and negatively affect growth. GHG(s) emissions arising from energy combustion contribute to environmental degradation while being positively associated with growth. On the one hand, GHG(s) emissions are one of the main factors in climate change, as highlighted in Baethgen (2010). The increase in GHG(s) emissions has a detrimental effect on climate, negatively affecting economic growth. Several studies using growth accounting equations show that climate change harms growth. Using a neoclassical stochastic function, Alagidede et al. (2016) shows that climate risk dampens per capita economic growth beyond a certain threshold of temperature and precipitation. GHG(s) emissions can downgrade the environmental quality index and negatively affect economic growth. However, the effect is still indirect and measured through the environment rather than on growth itself. This methodology might be subject to bias since the negative effect can change alongside the environmental quality index chosen and environmental quality's weights on economic growth.

On the other hand, GHG(s) emissions are positively associated with growth. Using a total factor produce-tivity (TFP) index, Kalaitzidakis et al. (2018), examine the relationship between TFP growth and emissions. They found a positive relationship between GHG(s) emissions and economic development. Their model in-cludes an energy input, which is the driving force of GHG(s) emissions. GHG(s) emissions stem from energy consumption and are a by-product of the production process.

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* Corresponding author.
E-mail addresses: sarah.nandnaba@ens-paris-saclay.fr (S. Nandnaba), abebe.hailemariam@curtin.edu.au (A. Hailemariam), rangan.gupta@up.ac.za (R. Gupta), xin.sheng@anglia.ac.uk (X. Sheng).

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Consequently, the increase in energy use, which positively contributes to growth, creates GHG(s) emis-sions. While they contribute to climate change, those emissions are still positively related to growth. From those insights, nonlinear effects of GHG(s) emissions on growth arise. Environmental degradation due to GHG(s) emissions is detrimental to growth, while GHG(s) emissions stemming from energy consumption increase with economic activity.

The effect of oil consumption, as well as CO_2 emissions, on economic growth, has been widely assessed in the literature (see, for example, Mardani et al. (2019); Adekoya (2021); Agboola et al. (2021) for detailed reviews). However, no studies have measured the nonlinear effect, emphasizing the need for energy consump-tion control. Assessing the direct effect of GHG(s) emissions on growth would be a way to go one step further in supporting climate mitigation. Indeed, it would support the weak sustainability arguments, stating that continued growth is incompatible with environmental sustainability. By assessing that GHG(s) emissions have a stronger adverse effect on countries that emit more, i.e., those who consume more pollution-emitting energy, one can state that GHG(s) emissions dampen the environment and cause a decline in economic growth after a certain threshold.

To examine the threshold effect of GHG(s) emissions on the nexus between oil consumption and growth, we employ a regime-based nonlinear local projections model proposed by Jordà et al. (2020). This approach allows for estimating the effect of an oil shock on growth while differentiating by level of carbon dioxide (CO_2) emissions to assess whether higher GHG(s) emissions harm growth, potentially leading to a slowdown in economic activity. The study covers a panel of 16 OECD countries between 1890 and 2022. The find-ings reveal that oil consumption nonlinearly impacts growth conditional on the level of GHG(s) emissions. Specifically, we find that the low-emission regime continues to exhibit superior performance while there is an adverse effect on growth at the high-emission regime, suggesting that policies to mitigate CO_2 emission have a win-win effect on growth and the environment.

The remainder of the paper is organized as follows: Section 2 presents the data, while Section 3 presents the methodology involving the nonlinear local projection model in a panel setting. The empirical results are contained in Section 4. Finally, Section 5 concludes the paper.

2. Data

Different datasets are used to assess the slowdown effect of CO_2 emission on Gross Domestic Product per capita. Data on GDP per capita, labor productivity, and capital intensity are obtained from Bergeaud et al. (2016). Capital intensity, i.e., total capital divided by the number of hours worked, and labor productivity, which is gross labor divided by hours worked, are used as control variables in the model. The growth of the CO_2 emissions variable is chosen from the Ritchie et al. (2023) database to account for GHG(s) emissions. Finally, to associate GHG(s) emissions level with the energy consumed, the study relies on the growth of oil consumption per capita, built on the work of Bergeaud and Lepetit (2020). The final dataset constitutes a long historical panel of data that covers 16 Organisation for Economic Co-operation and Development (OECD) countries[1] from 1890 to 2022.

3. Methodology

To measure the potential effect of CO_2 emission on growth, the study measures the effect of an oil shock while differentiating by the level of CO_2 emissions. The nonlinear shock is computed through a nonlinear local projection model, following the methodology of Jordà et al. (2020). In the model, the switching variable is a dummy variable derived from the cross-sectional average of CO_2 emissions. Countries emitting more than the average are classified as high GHG emitters. This approach allows us to gauge the threshold level of GHG(s) emissions beyond which oil consumption contributes to the slowdown of growth.

An endogeneity bias could arise when estimating oil shock-effects alongside the level of CO_2 emissions (Balcilar et al., 2010; Chang et al., 2015). CO_2 emission is a function of energy consumption, and regimes emitting more CO_2 tend to consume more oil, implying that high CO_2 emitters are also high oil consumers. Consequently, when estimating the nonlinear effect of an oil shock on growth, high-emission regimes relying.

Heavily on oil are likely to benefit more from the positive shock. The high correlation between the two variables might affect the estimation and provide biased results.

The estimated residuals from the oil consumption pattern are used to overcome this issue. They represent exogenous shocks from oil, which are less likely to follow the oil consumption pattern.[2]n Rudebusch (1998), the residuals of a regression of the Federal fund's rate on an information set are used to estimate exogenous shocks. Furthermore, the study of Mendoza and Vera (2010) used the adjusted residual of a GARCH model on real oil prices to approximate oil shocks, in the case of Venezuela.

First, we obtain the residuals from the estimation of the fixed effect model of the form:

$$ {}^{O}i,t = {}^{O}i,t{-}1{+}{}^{Y}i,t{+}{}^{\alpha}i{+}{}^{\mu}t{+}{}^{e}i,t \tag{1} $$

$$ \begin{aligned} Y_{i,t+s} = (1-D_t)\left[\alpha_{i,s}^{High} + \beta_s^{High} Y_{i,t} + \lambda E_{oil_{i,t}^{High}} + \gamma_{i,j,s}^{High} X_{i,t}\right] \\ + D_t\left[\alpha_{i,s}^{Low} + \beta_s^{Low} Y_{i,t} + \lambda E_{oil_{i,t}^{Low}} + \gamma_{i,j,s}^{Low} X_{i,t}\right] e_{i,t+s} \end{aligned} \tag{2} $$

$$ D_t = \begin{cases} 1 & if\, \frac{1}{N} \sum_{i=1}^{N} co2_i < \frac{1}{N\,T} \sum_{i=1}^{N} \sum_{t=i}^{T} co2_{it} \\ 0 & if\ else \end{cases} \tag{3} $$

where $O_{i,t}$ is the growth of oil consumption per capita, $O_{i,t-1}$ is the first lag of growth of oil consumption per capita, $Y_{i,t}$ is GDPpc growth, used as controls. α_i and μ_t are country and time fixed effects respectively. $e_{i,t}$ is the residuals, which will be used as the shock variable in the nonlinear local projection model.

The main model of interest, following Jordà et al. (2020) is given by:

$Y_{i,t+s}$ is the growth of GDP per capita (GDPpc) for the country i at time t, and s is the forecast horizon (which we at ten years). D_t is the switching dummy variable based on the average of the time series of the cross-sectional average of CO_2 emissions. It takes the value of 1 for low-regime i.e., countries whose average time series emissions are less than the abovementioned average, and takes 0 otherwise for high-emitters. $\delta_{i,s}$ is the regime-specific cross sectional fixed-effects, with β_s, λ_s, and γ_s correspond to the responses of economic growth one to ten-year-ahead due to values of economic growth, oil shock ($e_{i,t}$) and other control variables ($X_{i,t}$, i.e., capital intensity and labor productivity) at time t, for high- and low-emitters, given by the superfixes "High" and "Low", respectively.[3]

[1] The countries considered are: Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States.

[2] I·

[3] It must be realized that, CO_2 emission is a function of energy consumption, and countries emitting more (less) CO_2 tend to consume more (less) oil. Consequently, when estimating the nonlinear effect of an oil consumption shock on growth, high (low)- emission countries relying more (less) heavily on oil are likely to benefit more (less) from the positive shock. The high correlation between the two variables might affect the estimation and provide biased results, which we avert via the exogenous dummy variable that categorizes the countries into high and low-emitters in our nonlinear set-up, rather than using an interaction variable.

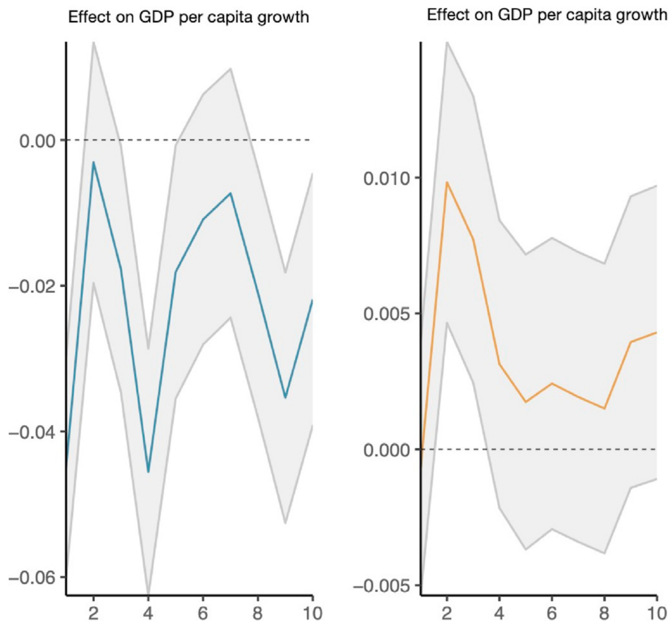

Fig. 1. Impulse responses of per-capita growth from Local Projection model due to oil consumption shocks under high (left-panel)- and low (right-panel) of GHGs emission regimes with shaded area 68 % of confidence intervals (shaded area): 1890–2022.

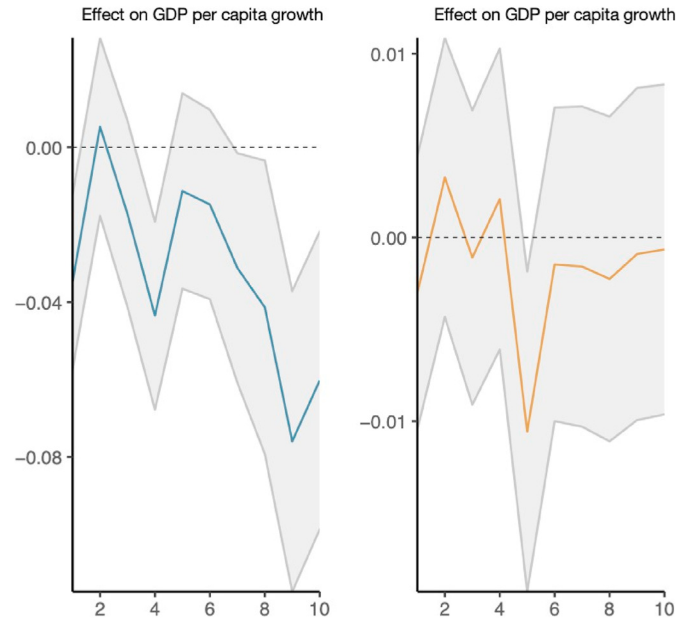

Fig. 2. Impulse responses of per-capita growth from Local Projection model due to oil consumption shocks under high (left-panel)- and low (right-panel) of GHGs emission regimes with shaded area 68 % of confidence intervals (shaded area): 1890–1945.

4. Empirical findings

Fig. 1 represents the impulse response function of GDPpc growth after a positive and exogenous oil shock. The left panel represents the impulse response function for the high CO_2 emissions regime; the right-hand side graph represents the low CO_2 emission regime. Although the impact of the low-emission regime may not be statistically significant after the fourth year, it still outperforms the high-emission group, in the sense that the effect on the growth rate is positive. Although the impact of the low-emission regime may not be statistically significant, it still outperforms the high-emission groups. Ceteris paribus, a low-emission regime that emits less CO_2 emissions, is less affected by the shock in oil consumption than the high-emission regime. Furthermore, the effect remains persistent following the shock, indicating that the oil shock effect does not vanish over time. So, while in line with the extant literature, energy consumption is growth enhancing (Adekoya, 2021; Agboola et al., 2021; Balcilar et al., 2010; Chang et al., 2015; Mardani et al., 2019), but our results qualify this finding in a nuanced manner by showing that this is only the case when oil consumption growth is associated in a scenario with lower emissions. If this is not the case, i.e., we are looking at high-emissions regime, energy consumption can be growth-reducing. These observations, spanning a long sample.

of data covering 133 years of data is the first of its kind. Moreover, the fact that this finding is robust, is confirmed by Fig. 4 included in the Appendix of the paper, when we repeat this analysis without the controls of capital intensity and labor productivity.

Given that the only difference between these regimes is their CO_2 emission levels, one plausible explana-tion for this different impact lies in the management of fossil fuel resources and energy consumption. Thus, a regime with lower GHG(s) emissions indicates more efficient oil management, as energy consumption sigsignificantly contributes to GHG(s) emissions. Indeed, the primary emission source is tied to oil and fossil fuel combustion. They are identified as the main factor of environmental degradation, as pointed out by Thompson et al. (2017). In Keçebaş et al. (2011), fossil fuels combustion is considered as the major cause of climate change because of its major CO_2 emissions.[4] Thus, controlling energy consumption is the primary cost-effective way to prevent climate change and control GHG(s) emissions.[5]

Thus, better energy management and reduced oil consumption allow for alleviating the growth slowdown arising from feedback effects from GHG(s) emissions. Indeed, a positive oil shock may increase CO_2 emissions, leading to a feedback loop that negatively impacts economic growth. The negative effect on growth could be realized through the depreciation of capital stock and reduced labor productivity. Those effects are exacerbated by the high CO_2 emission regime since their GHG(s) emission and oil dependence are already strong.[6]

Consumption, it is plausible to assume a higher dependency on oil within this regime than its low-emission counterpart. This heightened dependency may render the high-emission regime more vulnerable to oil price spikes, as entities within it could face challenges in swiftly adapting their production processes or transitioning to alternative energy sources. Secondly, it could arise from capital and labor constraints. Indeed, the potential non-response of economic growth to an increase in oil consumption for the high regime could be attributable to the existing alignment of labor and capital with the customary level of oil consumption. An augmentation in one production input might not alter the production dynamics significantly if the process and utilized inputs are already optimized to match the current stock of capital and labor.

To increase the precision and accuracy of the differentiated effect between high and low CO_2 emission regimes, the sample is divided into pre-war (1890–1945) and post-war (1946–2022) periods. The aim is to

[4] According to the International Energy Agency (IAE), 34.4 % of CO_2 emission are due to oil consumption.

[5] For example, the IAE has drawn a Net Zero Emissions by 2050 Scenario, which is a normative scenario that promotes energy consumption management to achieve net zero CO_2 emissions by 2050.

[6] Other explanation for the difference in effect could be drawn. First, an increased production cost. Indeed, the oil consump-tion shock is a demand shock, which can increase prices, further affecting economic growth by increasing the cost of production input. Given that the high-emission regime is characterized by the most substantial CO_2 emissions, closely linked with oil.

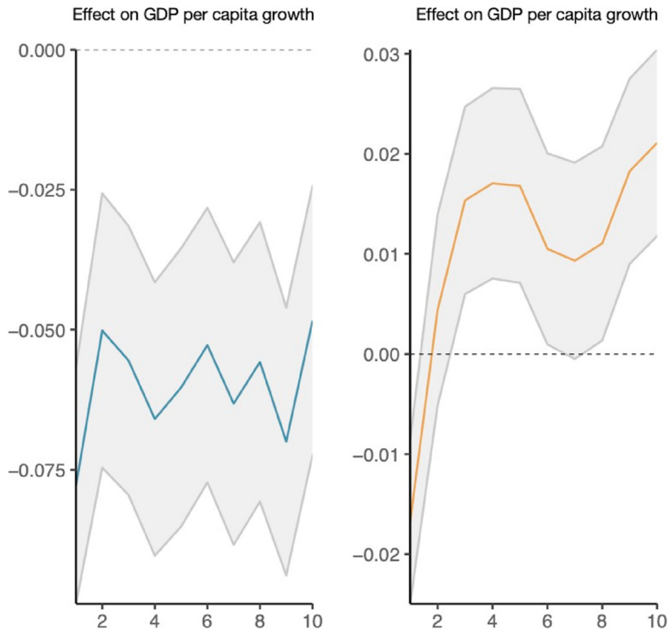

Fig. 3. Impulse responses of per-capita growth from Local Projection model due to oil consumption shocks under high (left-panel)- and low (right-panel) of GHGs emission regimes with shaded area 68 % of confidence intervals (shaded area): 1946–2022.

ensure that the differentiated effect is consistent over a shorter period while identifying the starting point of growth and pollution acceleration. The period after World War II is also a period of increased economic activity and, thus, of higher pollution.

Fig. 2 plots the LP models for the period up to WWII and shows an insignificant effect of the exogenous oil shock on growth per capita for the low-emitters group. Although both groups appear to suffer from the oil shock, the impact is notably more pronounced for the high-emission group, exacerbating the extent of the negative consequences they face. The period between 1890 and 1945 shows no significant proof that GHG(s) emissions have a slowdown effect on growth.

Fig. 3, on the contrary, shows a significant difference between the two regimes. Furthermore, the effect of an exogenous oil shock is negative and significant in all periods for the high-emission group. In contrast, it is positive and mostly significant for the low-emission group. Results are consistent with the previous graph on the full sample and confirm the hypothesis that higher CO_2 emissions have affected growth more strongly in the recent decades.

Note that the findings for the sub-samples is unaffected without the control variables of capital intensity and labor productivity, as depicted in Figs. 5 and 6 portrayed in the Appendix of the paper.

5. Conclusion

To empirically assess the threshold effect of CO_2 emissions on the nexus between oil consumption and the growth rate of real GDP per capita, the study applied a nonlinear local projection method developed by Jordà et al. (2020) to long historical data from OECD countries spanning the period from 1890 to 2022.

The model differentiated regimes based on the CO_2 emissions levels and aimed to determine whether higher. GHG(s) emissions lead to a more pronounced impact on GDP growth in the aftermath of an oil shock.

The results indicate that the high-emission regime, which heavily relies on oil and produces higher pollution, experiences a slowdown in growth and reduced economic activity compared to the low-emission regime. The findings suggest that efficient resource management tends to mitigate CO_2 emissions, supporting the study's initial hypothesis. From these insights, a nonlinearity effect arises, showing that after a certain amount of CO_2 emissions, an exogenous increase in oil consumption has a slowdown effect on growth. Policies should promote the transition to renewable energy sources to prevent this economic activity reduction (Khan et al., 2024). Stringent regulation of energy combustion would also reduce GHG(s) emissions. Identifying the nonlinear relationship between CO_2 emissions and growth allows for a nuanced understanding of GHG(s) emissions: the economy could still flourish if controlled and maintained. From these results, it is obvious that oil consumption can still be growth-enhancing, but would require lower GHGs emissions possibly associated with stringent regulation of energy combustion, but, in general, the transition to clean energy is paramount in the context of the energy-growth relationship.

As part of further research, it would be interesting to extend our analysis to more countries beyond the 16 industrial economies considered here. While this is likely to involve a shorter sample period, but such an exercise would allow us to generalize our findings by considering developing and emerging countries as well, given that some of them are major polluters ((Liu & Lee, 2025; Pan et al., 2024)).

CRediT authorship contribution statement

Sarah Nandnaba: Writing – original draft, Software, Investigation, Data curation. **Abebe Hailemariam:** Writing – review & editing, Validation. **Rangan Gupta:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Xin Sheng:** Writing – review & editing, Software, Methodology.

Declaration of interest

The author declares no conflict of interest.

Appendix

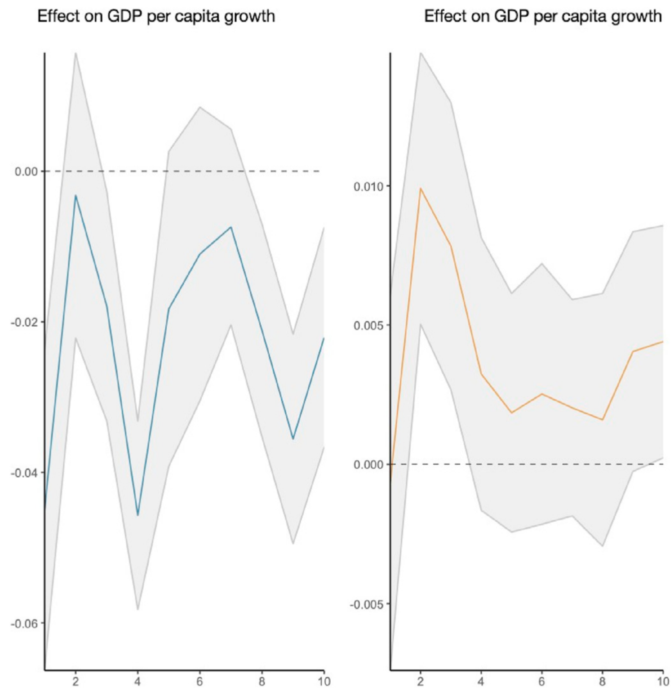

Fig. 4. Impulse responses of per-capita growth from Local Projection model with no controls due to oil consumption shocks under high (left-panel)- and low (right-panel) of GHGs emission regimes with shaded area 68 % of confidence intervals (shaded area): 1890–2022.

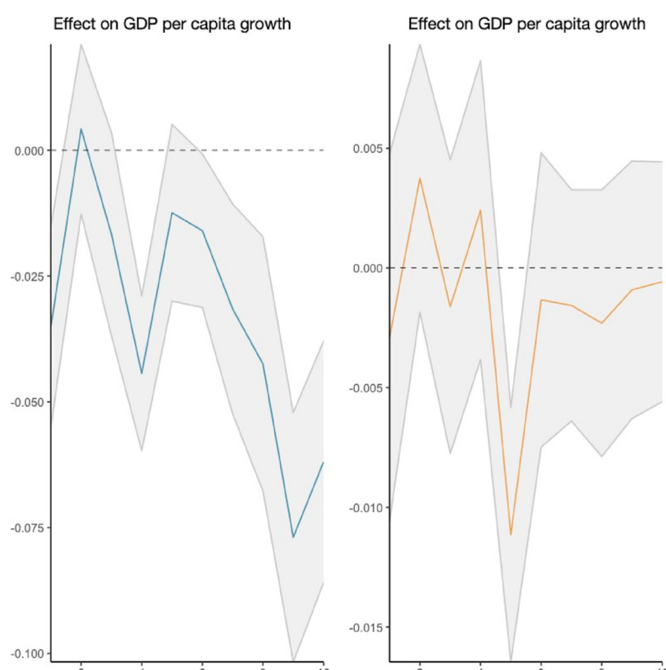

Fig. 5. Impulse responses of per-capita growth from Local Projection model with no controls due to oil consumption shocks under high (left-panel)- and low (right-panel) of GHGs emission regimes with shaded area 68 % of confidence intervals (shaded area): 1890–1945.

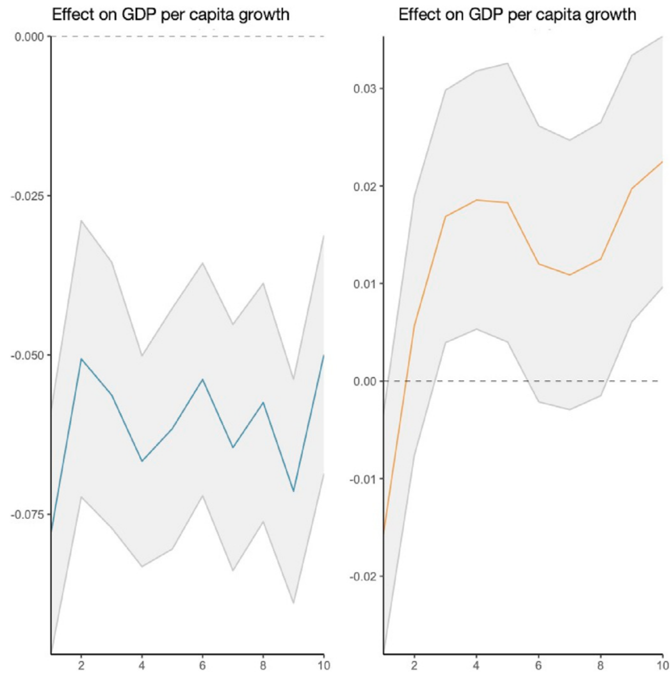

Fig. 6. Impulse responses of per-capita growth from Local Projection model with no controls due to oil consumption shocks under high (left-panel)- and low (right-panel) of GHGs emission regimes with shaded area 68 % of confidence intervals (shaded area): 1946–2022.

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