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Essays on the Political Economy of Growth and the Ecological Transition

Vinícius da Silva Centeno

PhD Program in Economics of
the Tuscan Universities

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Vinícius da Silva Centeno

Supervisor: Riccardo Pariboni

Co-supervisor: Walter Paternesi Meloni

Program Coordinator: Simone D'Alessandro

Universities of Siena, Pisa, and Florence

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Introduction

Economics is inherently political. The separation of classical political economy into distinct disciplines—economics and social sciences—took shape in the late 19th century. Celebrated as revolution, led marginalist economists to claim that it freed economic analysis from extraneous political and social considerations, establishing economics as a supposedly objective and politically neutral discipline. The renaming of the field from political economy to economics reflected an effort to distance the discipline from its explicitly political roots.

However, this shift did not eliminate politics from economics; it merely concealed political interests beneath a technical veneer that presents the status quo as natural and inevitable, making the political dimensions of economic thought more difficult to scrutinize and reinforcing existing power structures. Yet, as Kalecki (1943) pointed out, economic arguments always rest on political assumptions, even when framed in purely technical terms.

Following this premise, this PhD dissertation unfolds essentially within a political economy approach, in which the innate connection between economics and politics permeates the discussion alongside its two main research topics: economic growth and the ecological transition. The core background draws from the Classical-Keynesian perspective to growth theory, which is combined with Comparative Political Economy and Ecological Macroeconomics approaches to build an interdisciplinary framework to address political, social and environmental aspects in the course of the work. Accordingly, the objectives of this dissertation span over multiple research questions.

The discussion begins within the growth models perspective, engaging with an interdisciplinary research agenda that bridges Post-Keynesian Economics and Comparative Political Economy, with a particular focus on export competitiveness. In this approach, growth models or strategies are shaped by specific political and economic relations that influence macroeconomic policy and patterns of growth. These strategies are rooted in the institutional and political configuration of the economy, which, in turn, determines the prominence of different growth drivers. While this research agenda has gained increasing attention, there remains a lack of consensus on how growth models should be operationalized and classified. In this dissertation, it is argued that demand-led growth accounting identifies which expenditures are most prominent in stimulating economic production, while growth driver analysis examines what motivates this spending. Together, these approaches provide a solid framework for analyzing the political economy of growth and its determinants.

The urgency of the ecological transition, alongside the conflictual perspective around economic growth's environmental implications in the ecological macroeconomics literature, leads this dissertation to a further step: integrating economic growth with ecological macroeconomics. From an ecological perspective, continuous growth is incompatible with the environmental boundaries. From a political economy perspective, the absence of economic growth entails serious socio-economic issues considering structural and sizable unemployment in capitalist economies, being particularly critical for developing countries that have not yet attained a certain level of material well-being. Hence, the shift towards environmental concerns is gradual, although not fortuitous. In this context, it is fundamental to integrate ecological aspects into the macroeconomic modeling framework.

Rather than engaging in the normative debate on whether growth is desirable, this dissertation acknowledges that growth is inherent to capitalist economies and argues that growth models should be adapted to embody environmental relations and address the ecological transition. Expanding renewable energy supply is crucial to unlocking this transition, highlighting the need to integrate energy production into growth models. To this end, an analytical framework is developed by incorporating the energy sector within a demand-led growth model. While economic growth remains demand-driven, the feasibility of the green transition is ultimately constrained by the availability of renewable energy, underscoring the interplay between demand-led growth dynamics and energy supply constraints. In the theoretical model, green public expenditures are assumed as a key mechanism to expand renewable energy capacity and, consequently, unlocking the energy transition.

Therefore, the relationship derived from the analytical model paves the way for an empirical investigation into the effectiveness of different policies on renewable energy diffusion. In this context, how public investment in energy R&D affects renewable energy deployment remains largely unexplored in the empirical dimension. In addition to public direct investment in energy R&D, the analysis considers conventional policies such as emissions taxes (price incentives) and regulatory measures.

Accordingly, facing the challenge of a rapid decarbonization of the economy as a concrete problem requires substantial investments in infrastructure and innovation. These investments demand large volumes of resources and entail high risks and uncertain returns, which often discourage private investment. In this context, public direct investment emerges as an instrument capable of playing a key role in mitigating these risks, mobilizing private resources, and generating positive spillovers to expand renewable energy capacity and shape the broader energy transition. Beyond contributing to the empirical literature on environmental policy effectiveness, this discussion extends to the political economy of the ecological transition, as disputes over how much to spend and where to allocate public resources highlight that these are inherently political decisions.

Ultimately, just as growth strategies are shaped by coalitions of actors with conflicting policy preferences, so too are climate actions. Likewise, the institutional and political configurations that sustain a given growth strategy also influence how countries respond to climate change. Therefore, while this dissertation transitions from analyzing growth determinants to incorporating environmental concerns, the political economy approach provides the overarching framework throughout. The dissertation is structured as follows.

The first essay proposes a comprehensive theoretical framework for operationalizing growth models within comparative political economy. It argues that demand-led growth accounting, inspired by the Sraffian supermultiplier model, and the growth driver investigation approach are complementary, together providing a robust framework within the growth models perspective. The empirical investigation consists of two steps. First, demand-led growth accounting is used to examine the economic performance of a sample of emerging economies before and after the 2008–2009 global economic crisis. Exports were the primary source of growth for all these economies before the crisis. The overall decline in exports following the crisis was accompanied by lower average growth rates, underscoring the importance of understanding export competitiveness factors to explain growth dynamics in these economies. Thus, in the second step, panel data estimations analyze export drivers.

The second essay develops an analytical model that examines the transition to a low-carbon economy by integrating demand-led growth dynamics with energy supply constraints. While energy production in the ecological macroeconomics literature has typically been modeled within supply-driven growth frameworks, the novelty of this article lies in incorporating the energy sector into a demand-led growth framework. Specifically, the model builds on a Sraffian supermultiplier structure with two autonomous demand components: business-as-usual and green government expenditures. Investment and capital stock consist of both green and conventional components, and growth and energy dynamics are linked through a green investment equation, which introduces a constraint on green capital stock accumulation based on the availability of renewable energy. Consequently, while economic growth remains demand-driven, the feasibility of the ecological transition is supply-constrained. The transitional behavior and long-run dynamics of the model are explored through numerical simulations.

The third essay investigates the impact of different policy approaches on renewable energy generation, the share of renewables in primary energy, and climate change mitigation, categorizing them into three forms of state intervention: conventional emissions taxes (price incentives), regulatory measures, and public direct investment in energy R&D—an underexplored aspect in the empirical literature. Using data from 22 OECD economies (1995–2023), the empirical analysis applies panel cointegration techniques through an autoregressive distributed lag model (panel-ARDL) to assess policy effectiveness. This study contributes to the empirical literature on environmental policy effectiveness and the determinants of renewable energy diffusion by examining the role of public investment in energy R&D. At the same time, it fosters a broader discussion on the political economy of the ecological transition, particularly the role of the state and the threat posed by fiscal austerity premises.

Chapter 1

Tipping the scales in emerging economies

The role of export and its drivers within the growth model perspective

Abstract

The article contributes to the discussion around export competitiveness in the context of the growth models perspective within the interdisciplinary research agenda of post-Keynesian economics and comparative political economy. It claims that the Sraffian supermultiplier growth decomposition and the growth driver approach are complementary, assembling a solid framework for analyzing the political economy of growth and its determinants. The empirical investigation consists of two steps. First, demand-led growth accounting is employed to investigate the economic performance of a sample of emerging economies before and after the 2008–2009 global economic crisis. Exports were categorized as the primary source of growth for all these economies before the crisis. The overall decrease in exports following the crisis was accompanied by lower average growth rates, which highlights the importance of understanding export competitiveness factors to elucidate the growth dynamics in these economies. Thus, in the second step, panel data estimations examine export drivers. The results indicate that foreign demand, real effective exchange rate depreciation, and participation in global value chains positively impact export growth. Although these results emphasize the importance of price-competitiveness factors, additional estimates show that as economies reach higher levels of complexity, they transition away from relying on low relative prices, with non-price factors playing an increasingly important role in fostering exports.

1.1 Introduction

The Growth Models Perspective (GMP), introduced in the seminal work of Baccaro and Pontusson (2016), established a burgeoning research agenda that brings together interdisciplinary ingredients to investigate a range of topics relevant to the political economy of growth and distribution in contemporary capitalism. This perspective investigates growth strategies and demand regimes that are bound to particular political and economic relations that shape macroeconomic policy and patterns of growth and stagnation in advanced and emerging economies.

Although the research agenda has received increasing attention, there is still a lack of agreement when it comes to how growth models should be operationalized and classified. On one hand, the literature uses distinct growth accounting techniques that are intended to decompose growth and identify the primary elements of aggregate demand, which contribute to economic growth. On the other hand, the growth driver approach (Kohler and Stockhammer, 2021) argues that the institutional and political configuration that supports a particular growth strategy may not hold during periods of instability; hence, factors that effectively impact the growth of demand components should be emphasized more. Although the approaches provide singular insights, the growth decomposition exercise, on its own, may not precisely determine the factors that drive economic growth. Simultaneously, the growth driver analysis cannot quantify the contributions of these factors to growth. Hence, this paper proposes that the Sraffian supermultiplier (SSM) growth decomposition (Morlin et al., 2022) and the growth driver investigation are complementary approaches that provide a robust framework to analyze the aggregate demand formation and the proximate determinants of growth.

In the aftermath of the 2008–2009 crisis, several advanced economies have experienced a trend of growing net exports and current account surpluses. Among different explanations proposed, Hein et al. (2021) suggested a shift to export-led strategies in developed countries. However, the parallel effect in developing countries is less studied. With the aim to contribute to this debate, this article examines the growth performance of nine emerging economies where exports had the largest contribution to growth. Although constituting a heterogeneous group of emerging economies, what the selected countries have in common is a drop in the contribution of exports to economic growth in the period after the Great Recession. Despite continuing to be the primary component for most of these nations, this abrupt export decrease was accompanied by lower average growth rates. Thus, it is important to carry out thorough investigation of the factors that impact the competitiveness of exports in international markets, in order to fully understand the critical role of the factors that tip the scales for these economies under consideration. Similarly, studying factors that contribute to a country's ability to export goods and services successfully has become a focus of growing interest in Comparative Political Economy (CPE) and the literature on growth models (Kohler and Stockhammer, 2021; Pariboni and Meloni, 2024). Hence, this paper contributes to this interdisciplinary research agenda that embodies Post-Keynesian Economics (PKE) and CPE and, particularly, to the discussion on export competitiveness under the GMP.

In view of that, the empirical investigation is intended as a two-step exercise in which the demand formation appraisal motivated by the supermultiplier growth decomposition paves the way to the potential export growth driver investigation. Therefore, the growth accounting answers which expenditures are more prominent to stimulate economic production, whereas the growth driver analysis investigates what motivates the spending. Thus, the demand-led growth accounting method developed by Freitas and Dweck (2013) is first employed to carry out a descriptive analysis of the growth performance of the countries. The period from 2000 to 2008, which precedes the Great Recession, is compared with the period from 2010 to 2019. Since the decomposition analysis underscores the key role of exports in both periods, delving further into the factors influencing its competitiveness aids in the understanding of the dynamics of growth in these economies. Secondly, different panel data estimations are employed to investigate potential drivers of exports. The results reveal that foreign demand, the real effective exchange rate (REER) depreciation and participation in global value chains (GVCs) are significant factors in explaining export growth. Although these findings emphasize the relevance of price-competitiveness, additional estimations show that as the economy reaches higher levels of complexity, non-price factors such as product quality and uniqueness gain relevance in fostering exports. The findings present mixed results regarding the price versus non-price competitiveness dichotomy, suggesting that price factors are more important for low-complexity exporters but lose relative importance as the economy moves toward higher export complexity. Furthermore, including participation in GVCs as an explanatory variable represents a novelty in the literature of export drivers within comparative political economy. Although the variable may exhibit characteristics related to either price or non-price factors depending on the context, participation in GVCs is primarily associated with industrial policy and offers valuable insights into the development of the productive structure of emerging economies.

The article is structured as follows. Section 1.2 briefly recaps the road taken by comparative political economy from the varieties of capitalism (VoC) to the emergence of the growth model perspective and examines the literature on growth model classification from the seminal work of Baccaro and Pontusson (2016). Section 1.3 presents a cross-country study of developing economies. Through the growth decomposition exercise, the analysis of the autonomous and induced components of aggregate demand provides insights in order to compare the growth performance of the countries in the two periods of study. In Section 1.4, using panel data estimation, potential export drivers are investigated. Final remarks close this article.

1.2 CPE meets PKE: the Growth Models Perspective

The field of comparative political economy developed a conceptual framework to identify institutional similarities and differences across nations and examine how this diversity reflects in the aggregate economic performance (Hall and Soskice, 2001, 2009). In the 1960s, the first generation of CPE scholars studied the national economies adjustments in a period of economic modernization by focusing on the character of the state intervention and the role of organized labor (Hall and Soskice, 2009; Baccaro and Pontusson, 2016). Afterward, the VoC approach to comparative political economy, introduced by Hall and Soskice (2001), shifted the focus to diverse institutional equilibria across countries and emphasized the role of the firms in attaining them.

Thereof, two coordination modes were characterized when focusing on cross-national institutional diversity. First, market coordination is characterized when firms coordinate with institutional forms mainly by competitive markets, which classifies the economy under Liberal Market Economies (LME). Second, strategic coordination is pictured when firms generally interact with institutions and other actors strategically, which typifies the economy as a Coordinated Market Economy (CME).[1] Different modes of coordination indicate that national economies can be classified and clustered to the extent that firms engage in market or strategic behavior to achieve one type of institutional equilibrium.

The classification presents theoretical and empirical limitations to the extent of which more criteria are taken into account, as the dimension of the capitalist economies, the welfare provision, and the linkages with the rest of the world[2]. Disregarding the complexity of the institutional setting across countries entails that economies with distinct institutional forms happen to be classified under the same

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[1] The United States and Germany are the canonical examples for LME and CME, respectively.

[2] Bruff (2011) and Leszczyński (2015) critically review the VoC traditional classification.

generic label.[3] As pointed out by Amable (2003, p.92), the interconnection between the major institutional forms - such as corporate governance, labor-market institutions, financial intermediation, and education - delineates the coherence of varieties of capitalism that go beyond the two original classifications. Apart from the labels employed, there is no claim of a supposed best institutional framework, meaning that varied ways of achieving institutional equilibria can deliver economic success (Hall and Soskice, 2009).

A remarkable feature of the VoC literature is the limited place assigned to macroeconomics, which has been the subject of criticism (Baccaro and Pontusson, 2016; Blyth and Matthijs, 2017). The strong emphasis on institutional equilibria and the extensive engagement with supply side features reflects the influence of the anti-Keynesianism tide that followed the crisis of national Keynesian demand management systems.

Although macroeconomics has not been extensively examined in the VoC literature, it has not been entirely disregarded. The predominant approach has been typically drawn from the mainstream perspective and, more recently, from the Neo-Keynesian framework and its three-equation model (Soskice, 2007; Hope and Soskice, 2016)[4]. In this sense, Baccaro and Pontusson (2016) pointed out the absence of an independent role for aggregate demand components and income distribution analysis. Blyth and Matthijs (2017) referred to the necessity of analyzing macro-regimes as an institutional configuration shaped by policy targets. By this means, concerns regarding demand management, unemployment rate, and increasing inequality were less prioritized. Furthermore, a critical understanding of banking and financial instability and its effects in the context of financialization is missing (Karwowski, 2022).

Therefore, seeking to bring demand regimes and distributive features to the fore, the introduction of the GMP by Baccaro and Pontusson (2016) merged neo-Kaleckian ingredients into a long tradition of political economy research within the field of CPE. Cross-national diversity was not left aside, but differently from the original VoC literature, the focus is shifted away from institutional equilibria.[5] Instead, the authors' contribution was to address macroeconomics by drawing on the

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[3] Further influential classifications are offered by Amable (2003) and Coates (2014) Regarding the emerging economies, Karwowski (2022) employs five distinct classifications identified in the VoC literature.

[4] The three-equation model consists in a demand equation for goods market, a Phillips Curve, and a Taylor rule (Hope and Soskice, 2016). For a critical review of the Neo-Keynesian approach in CPE, see Stockhammer (2022), and Baccaro et al. (2022).

[5] For a summarized comparison of the key differences between the VoC and GM approaches, see Baccaro et al. (2022, p.36).

interaction of income distribution and the relative importance of different components of aggregate demand.

The GMP opened the venue to a multidisciplinary research agenda embodying the "distant cousins" Post-Keynesian Economics (PKE) and CPE (Stockhammer and Kohler, 2022).[6] Despite the growing interest in theoretical, empirical and descriptive approaches within this perspective,[7] there is still no consensus regarding the definition of growth models and a methodology for operationalizing and classifying them (Baccaro and Hadziabdic, 2024).

Hence, the following subsection discusses the main contributions in the literature on growth model classification, taking the original Baccaro and Pontusson (2016) contribution as the starting point. Following Baccaro and Pontusson's operationalization,[8] the empirical research on the growth models was briskly diffused. Despite sharing theoretical concerns over Baccaro and Pontusson (2016), Hein et al. (2021) and Morlin et al. (2022) propose different empirical alternatives, based respectively on insights from sectoral financial balances and the Sraffian supermultiplier model. Instead, Kohler and Stockhammer (2021) claim that more attention should be given to growth drivers instead of relative contributions to growth. Hence, this article advocates that, in the face of instability of growth models under financialization, the combination of the Sraffian Supermultiplier's (SSM) growth decomposition (Freitas and Dweck, 2013) and the growth drivers perspective (Kohler and Stockhammer, 2021) offers a comprehensive framework to scrutinize the political economy of growth and its determinants.

Baccaro and Pontusson's (2016) The methodology of growth model classification introduced by Baccaro and Pontusson (2016) methodology of growth model classification is purely descriptive, in which the aggregate demand component of greater contribution to growth in the period of analysis determines the growth model. The contributions to growth express the relative importance of different aggregate demand components as their growth rate is weighted by using their participation in

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[6] Stockhammer and Kohler (2022) show that the roots of both heterodox economics and comparative political economy refer to the 19^{th} Century Political Economy. The bifurcation of the research in political economy separated the disciplines of economics and social sciences, from which PKE and CPE, respectively, emerged as subfields. Therefore, the Growth Models Perspective lies in the intersection of "distant cousins".

[7] The increasing popularity in the subject was materialized in the book "*Diminishing Returns - The new politics of growth and stagnation*" (Blyth et al., 2022), where the Growth Models Perspective is disposed among theoretical perspectives, case studies, and politics and policy implications.

[8] Covering a wide range of topics, the descriptive exercise of GDP growth decomposition to classify GMs was employed for economies in scale (Cárdenas and Arribas, 2021; Hassel and Palier, 2021; Mertens et al., 2022), single-country study cases (Baccaro and Höpner, 2022; Baccaro and Bulfone, 2022), and for specific demand component analysis(Ban and Adăscăliței, 2022; Baccaro and Neimanns, 2022).

GDP (Eq. 1.1).

$$g_{Y_t} = \left(\frac{C_{t-1}}{Y_{t-1}}\right) g_{C_t} + \left(\frac{G_{t-1}}{Y_{t-1}}\right) g_{G_t} + \left(\frac{I_{t-1}}{Y_{t-1}}\right) g_{I_t} + \left(\frac{E_{t-1}}{Y_{t-1}}\right) g_{E_t} + \left(\frac{NX_{t-1}}{Y_{t-1}}\right) g_{NX_t} \quad (1.1)$$

Where g denotes the growth rate, Y is the output, C is the household consumption, G is the government expenditure, I is the invesment, E is change in inventories, and NX corresponds to net exports. As a result, the decomposition indicates the contribution as a proportion. Aiming to identify the different alternatives that countries found to grow since the erosion of the “wage driver” in the post-Fordist era, the authors highlighted the prominence of household consumption and exports to characterize (debt-financed) consumption-led growth and export-led growth, respectively.

Although the seminal work of Baccaro and Pontusson is a remarkable contribution, theoretical and empirical limitations remain. At the theoretical level, Hein et al. (2021) argued that there is an unclear distinction between demand regimes, as the neo-Kaleckian wage- and profit-led (Bhaduri and Marglin, 1990),[9] and the orientation of distributional policies, that could be pro-labor or pro-capital (Lavoie and Stockhammer, 2013). Accordingly, Morlin et al. (2022) emphasized that the apparent extension of the Bhaduri and Marglin demand regimes dichotomy to export- and consumption-led growth strategies lacks theoretical clarity. The demand regimes are related to structural features of the economy, such as the effect in the aggregate demand components that follow from a distributional change. Therefore, a wage-led (profit-led) regime is defined by a positive (negative) net effect in aggregate demand in response to an increase in the wage share.[10] Hence, the structural demand regime does not determine the source of economic growth or its determinants, which are instead given by different growth drivers that arise from a coherent combination of demand and policy regimes (Lavoie and Stockhammer, 2013). Baccaro and Hadziabdic (2024)recognized that this was an essential clarification to distinguish the concepts of demand regimes and growth models employed in the post-Keynesian literature and by comparative political economists, respectively.

At the empirical level, Hein et al. (2021) suggested that relative contribution to the growth of demand components should be considered as a first step to identifying

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[9] Although the authors contribution originally focused in the impact on economic growth, the dichotomy is usually referred to address the level of aggregate demand.

[10] Baccaro and Pontusson refer to "wage-led growth" as the period that followed the World War 2, characterized by labor-oriented policies, regardless whether the demand regime being wage-led or profit-led.

growth regimes.[11] Building on a post-Keynesian approach to the macroeconomics of finance-dominated capitalism, the perspective of the sectoral balances leans on Hein (2012) to combine the relative growth contributions with financial balances of the main macroeconomic sectors (private household, financial, non-financial corporate, government, and external sectors). From there, the traditional export- and consumption-led regimes are extended to four different typologies[12]: (i) export-led mercantilist (ELM) has current account surpluses and positive growth contributions of net exports; (ii) weakly export-led (WEL) has current account surpluses or positive growth contributions of net exports; (iii) domestic demand-led (DDL) is when growth is almost exclusively driven by private demand and households are net lenders; and (iv) debt-led private demand boom (DLPD) shows significant growth contributions of domestic demand and current account deficits.

In addition to the labeling criteria, what stands out is that, under financialization, the possible growth models lie between the export-led (ELM and WEL) and the debt-led (government deficit in the DDL and private sector deficit in the DLPD), as referred to by Stockhammer (2022) as "neoliberal growth models." Thus, Morlin et al. (2022) pointed out that regardless the methodology employed, the main contributions to growth identified in the literature concern autonomous expenditures, which supports the argument that these are the most significant in pushing economic growth. From the empirical analysis based on the sectoral balances approach,[13] the main results hold that after the economic and financial crisis of 2008–2009 (global financial crisis, GFC), there was a shift in the demand and growth regimes of developed economies toward export orientation.

Nevertheless, the classification based on greater net exports and current account surpluses may lead to misinterpretations considering that it can be derived either from increased exports or lower imports. The latter is likely the case for developed economies facing government spending austerity and household deleverage after the GFC (Kohler and Stockhammer, 2021). As expected, a drop in domestic expenditures reduces the demand for imports, which will be reflected in improved positions for both net exports and the current account, leading to an inappropriate export-led growth classification. In view of this and taking into account the modicum economic growth of the OECD countries for the decade between the Great Recession and the

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[11] Although not employed to initially classify growth models, which is explicitly the matter of the criticism, the contributions to growth and net exports were already present in Baccaro and Pontusson (2016). Nonetheless, apart from the construction, both Baccaro and Pontusson (2016) and Hein et al. (2021) calculations of the contributions to growth have the same interpretation.

[12] The detailed classification criteria are presented in Dünhaupt and Hein (2019, p.458).

[13] Hein et al. (2021) examined a set of 30 OECD countries, Dünhaupt and Hein (2019) analyzed three Baltic countries, and Akcay et al. (2022) considered eight large emerging capitalist economies.

COVID-19 pandemic (2.07% on average from 2010 to 2019), instead of a shift of growth strategy toward exports, the results obtained by Hein et al. (2021) are, to a great extent, due to the cooling down of the world's economic activity in terms of fiscal consolidation in the post-crisis period and are reinforced by the slowdown of developing economies exports, which are presented in the succeeding sections.

Additionally, Hein et al. (2021) depicted a tendency toward stagnation, which is indicative of the inherent contradictions present in both the debt- and export-led models. The first is characterized by the cyclical dynamics of finance on private demands and its contractionary effect resulting from deleveraging in the financial bust. The second requires increasing the current account deficits of trade partners (Kohler and Stockhammer, 2021). Concerning the latter, regardless of the source of the greater net exports observed in developed countries, the resulting increase in current account surpluses necessitate greater deficits in emerging capitalist economies as a counterpart, which implies a potential balance of payments bottleneck (Akcay et al., 2022).

Furthermore, considering the weak aggregate demand generation, the growth instability turns out to be central in the analysis. The cyclical nature of growth contributions in periods of instability is not necessarily easy to reconcile with the growth model framework, considering that it presupposes a stable political and institutional environment that supports a growth strategy based on specific aggregate demand components. Therefore, the taxonomy derived from the growth contributions might no longer be precise in classifying growth models in periods of instability, when economic growth is not necessarily coherent with a particular institutional and political configuration. In this context, greater relevance should be given to analyzing potential growth drivers. Kohler and Stockhammer (2021) defined growth drivers as distinct factors that are not part of aggregate demand but influence the growth of its components. In the context of weak aggregate demand, determining functional growth drivers and befitting policies that foster them appears to be more appealing than classifying countries into models. Recent contributions have been examining drivers that are potentially attached to debt-financed consumption, government spending, and exports, that are, respectively, house prices, discretionary fiscal policy and price/non-price competitiveness (Kohler and Stockhammer, 2021; Stockhammer and Novas Otero, 2023; Pariboni and Meloni, 2024).

Therefore, it is argued that the supermultiplier growth decomposition (Morlin et al., 2022) and the growth driver investigation (Kohler and Stockhammer, 2021) are complementary approaches that provide a more robust framework to analyze the political economy of growth and its determinants. Considering the growth of net exports and current account surpluses in developed countries after the 2008–2009 crisis Hein et al. (2021), this study aims to analyze the corresponding effects in a group of emerging economies where exports were the main component of aggregate demand before the crisis. In the subsequent period, these economies experienced a decline in export growth, accompanied by lower average growth rates. Particularly, studying factors contributing to a country's ability to export goods and services successfully has become a focus of growing interest in comparative political economy and the literature on growth models. The relevance of this topic is in the fact that different drivers are attached to alternative strategies for enhancing exports. Hence, the empirical investigation in the following sections is designed as a two-step exercise in which the demand formation appraisal inspired by the supermultiplier growth decomposition paves the way for the investigation of exports' determinants.

The literature generally distinguishes between price and non-price factors contributing to a country's export competitiveness. Price competitiveness is typically measured by the REER, which is the value of a country's currency in comparison to a weighted average of other currencies, adjusted by a price deflator or index of costs. By contrast, non-price competitiveness is primarily related to a product's quality and sophistication. The measure most commonly used to assess non-price competitiveness is the economic complexity index (ECI) (Hidalgo and Hausmann, 2009). The ECI measure is published by the Harvard Dataverse The Growth Lab (2019). The index is determined using the diversity, ubiquity, and complexity of the products exported. The concept behind complexity is that a country's exports will receive a more significant stimulus when its goods are more diversified and unique, regardless of price.

Ahmed Hannan et al. (2015) investigated a sample of 46 countries between 1996 and 2012 and suggested that the elasticity of manufacturing export volumes to the REER has decreased over time. Above all, price factors are important if the country's exports exhibit high price elasticity. Within the CPE meets PKE literature, Kohler and Stockhammer (2021) estimated a regression in which gross national income is the dependent variable and potential economic drivers are among the independent variables, including the REER and the ECI. The results propose that only non-price competitiveness is significant for the developed economies analyzed.

Conversely, Pariboni and Meloni (2024) tested price and non-price factors by estimating an autoregressive distributed lags model with export variation as the dependent variable. The estimation suggests that both REER and ECI are significant drivers of exports for a large sample of OECD countries. When contrasting the two main growth models as export-led and domestic-demand-led for developed economies, Baccaro and Pontusson (2016) suggested that a strategy to boost exports via price factors is employed by controlling wage inflation. Therefore, the potential appreciation of the real exchange rate is avoided by constraining domestic demand.[14] However, for financially subordinated emerging economies, on top of domestic inflation, exchange rate fluctuation and its determinants also have a prominent role (Arize et al., 2008).

Arize et al. (2008) performed a cointegration analysis to examine the export performance of a sample of developing countries between 1973 and 1996, finding evidence that exchange rate volatility harms export flows. Accordingly, the GMM panel data estimated by Vieira and MacDonald (2016) suggest an adverse impact of a REER appreciation on exports for developing countries. More recently, Caglayan and Demir (2019) found that medium-skill, low-skill, and resource-intensive manufactured goods are more sensitive to exchange rate volatility, with more pronounced effects for exports from the Global South, especially in South-North trade flows. Although the literature indicates that the relevance of price-competitiveness factors is diminishing in developed countries, expectedly, labor costs and exchange rate volatility will continue to exert a significant impact on export growth in emerging economies.

Hence, in accordance with the purposes of this article, the supermultiplier growth decomposition answers which expenditures are more prominent to stimulate economic production, whereas the growth driver analysis—applied here to the determinants of exports—explores what motivates the spending. It is claimed that although the autonomous expenditures are exogenously determined in the supermultiplier model, this does not prevent an investigation of their determinants. By connecting the SSM with the growth driver analysis, it contributes to the analysis of the determinants of the autonomous component growth, the investigation of which is not properly explored in the supermultiplier literature yet. The framework proposed overcomes issues related to traditional contributions to growth, such as the misguiding use of net exports[15] and the blurred relation between demand expenditures and

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[14] Refer to Pariboni and Meloni (2024) for a more extensive review of the latest price and non-price competitiveness findings for advanced economies.

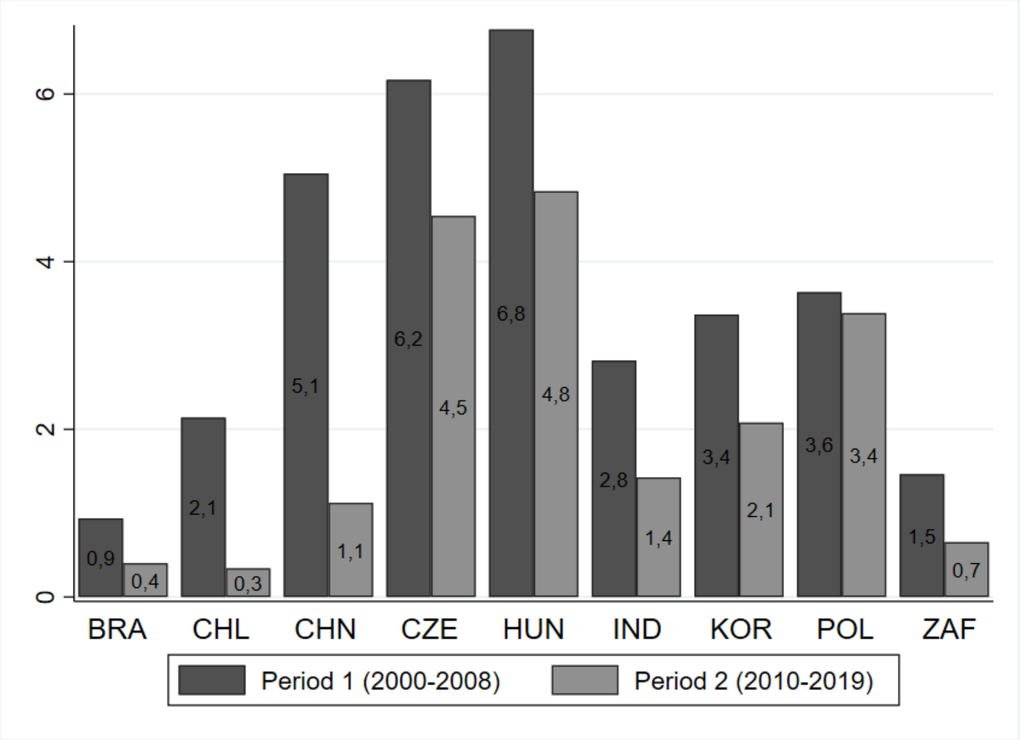
[15] Seeking to deal with the net exports issue, Baccaro and Hadziabdic (2024) employed an import-adjusted calculation to determine the relative contribution to growth of the components of aggregate demand. Nonetheless, given that imports follow the generation of income, netting imports out of every demand component can be problematic as well (see footnote 12).

ex-post financial flows of the sectoral balance analysis.[16]

1.3 A cross-country study for developing economies

The first step of the empirical investigation employs the growth decomposition method inspired by the Sraffian Supermultiplier model (Freitas and Dweck, 2013) to conduct a descriptive analysis of the growth performance of a group of emerging economies. The period from 2000 to 2008, which precedes the Great Recession, is compared with the period from 2010 to 2019. The pool of countries comprises Brazil (BRA), Chile (CHL), China (CHN), Czech Republic (CZE), India (IND), Hungary (HUN), South Korea (KOR), Poland (POL), and South Africa (ZAF). Despite constituting a heterogeneous group of emerging economies, the selected countries have in common a drop in the contribution of exports to economic growth in the period following the Great Recession, as shown in Figure 1.1.[17]

Figure 1.1: Exports contribution to growth - (%)



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[16] Concerning economic growth, the primacy is of demand. Accordingly, the income flows generated by demand expenditures also have a primacy over the result of ex-post accounted financial flows (see Cesaratto (2015). In other words, a deficit (surplus) in the sectoral balance not always can be interpreted as a demand injection (leakage) into the economy. For instance, as demonstrated by Haavelmo's (Haavelmo) theorem, a balanced budget expansion of public spending has a multiplier effect on aggregate demand and output. The same applies for exports.

[17] The contribution was calculated as in Baccaro and Pontusson (2016) and Hein et al. (2021), the so-called traditional method.

In emerging economies, financial subordination can be expressed in different ways, which include through volatile exchange rates and dependence on foreign capital inflows (Alami et al., 2022). When a country's currency is positioned lower in the global currency hierarchy, these effects become more pronounced (De Paula et al., 2017). Therefore, the selection of countries considered economies whose national currencies are in inferior positions in the global currency hierarchy.

1.3.1 The supermultiplier-inspired growth decomposition method

The growth decomposition is an accounting technique based on a mathematical identity, where distinct decomposition methods can be employed depending on the theoretical framework assumed (Alves-Passoni and Neria, 2023). Within a demand-side perspective of growth, as in the supermultiplier-inspired technique, this identity corresponds to the final demand components of GDP. The complete formal version of the Sraffian supermultiplier model is presented in Freitas and Serrano (2015a). For the purposes of this article, it suffices to point out that the output is given by $Y = \alpha Z$, where Z is the autonomous demand and α is the supermultiplier. The autonomous components of demand are defined as the expenditures that are not financed by income and are not capable of creating productive capacity (Serrano, 1995, p.71), comprising government spending, exports, residential investment and debt-financed consumption. Next, the supermultiplier components encompass the induced expenditures on growth, namely the propensities to consume, invest, and import.

Morlin et al. (2022) hold that the supermultiplier-inspired analysis of growth models provides insights on the proximate causes of GDP growth, whereas the ultimate causes of growth are exogenous to the model, being explained by the social and political determinants of autonomous demand components.[18] In this regard, Baccaro and Pontusson argue that growth strategy rests on growth coalitions based in key sectors (export manufacturing, construction, finance), meaning that sectoral actors have conflicting preferences about economics policies. In most times, the growth coalition prevails to determine the key policy planks according to their requirements, while the government plays the role of recalibration of the growth model in periods of crisis (Baccaro and Pontusson, 2022).[19] By this means, the supermultiplier perspective is appropriate to address the political economy ingredients emphasized by

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[18] Besides Morlin et al. (2022), Passos and Morlin (2022) and Labat and Summa (2022) apply the supermultiplier growth decomposition to analyze growth models in Latin America and for the Spanish economy, respectively.

[19] A framework for understanding the political foundations of growth models is elaborated in Baccaro and Pontusson (2022).

Baccaro and Pontusson (2016) at the intersection between CPE and PKE. Furthermore, by distinguishing the autonomous and the induced components of aggregate demand, the SSM attributes the direct and indirect effects of expenditures and the role of the income distribution, supplementing accurate insights concerning the growth performance. The investigation carried out in Morlin et al. (2022) suggests that government expenditures, exports, and private spending financed out of debt are the main autonomous demand components for the developed economies analyzed (US, Japan, Sweden and Germany).[20] Moreover, the interpretation of the propensity to consume suggests that distributional changes have relevant but temporary effects on growth.

The demand-led growth accounting inspired by the SSM model was developed by Freitas and Dweck (2013). Nevertheless, the aggregate demand composition must be built based on available data.[21] The starting point is the equilibrium between real aggregate supply and demand.

$$Y + M = C + G + I + X + E \tag{1.2}$$

The domestic product (Y) plus imports (M) are the aggregate supply, whereas the aggregate demand is composed of household consumption (C), government expenditures G, investment (I), exports (X), and changes in inventories (E).[22] The imported content in aggregate demand is accounted for by introducing the parameter μ, which is the share of the product's domestic content.

$$M = (1 - \mu)(C + G + I + X) \tag{1.3}$$

The term $(1 - \mu)$ gives the share of imported content and corresponds to the propensity to import. Furthermore, consumption (C) and private investment (I) are assumed to be expenditures induced by income generation, where c and h are respectively the propensities to consume and invest.

$$C = cY \tag{1.4}$$

$$I = hY \tag{1.5}$$

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[20] Growth models are not labeled in Morlin et al. (2022). For a growth model classification criteria inspired by the supermultiplier growth decomposition, see Passos and Morlin (2022).

[21] In Freitas and Dweck (2013), consumption is differentiated among household durable and non-durable goods and government consumption, whereas investment is distinguished among state-owned and private enterprises, government, and household investments.

[22] Although not an aggregate demand component, the changes in inventories (E) is the adjustment variable to obtain equilibrium.

Regarding c, one major determinant is the wage share, which is exogenous to the SSM model, considering political and social factors determine income distribution. Conversely, h is endogenously explained by the deviations between the actual capacity utilization and the normal capacity utilization rate.[23] It is stated by the capital stock adjustment principle that if the capacity utilization is greater than the target rate, capitalist competition induces an increase of h and perform the investment to adjust the productive capacity to match the aggregate demand. After simple algebraic manipulation, the real GDP equilibrium level (Y^*) is explicitly attained in terms of the autonomous demand ($Z = RI + G + X$) and the supermultiplier (α) components.

$$Y^* = \left[\frac{\mu}{1 - \mu(c+h)}\right] Z = \alpha Z \tag{1.6}$$

Where $\alpha = \mu/[1 - \mu\,(c+h)]$. In brief, an increase of an autonomous expenditure naturally impacts the aggregate demand but also generates a flow of income that induces directly consumption and imports and indirectly capacity creating investment. This is a remarkable feature of the supermultiplier growth decomposition developed in Freitas and Dweck (2013), which is able to assign whether greater consumption or imports are derived from the income flow generated by higher autonomous spending or due to changes in the respective propensities. Straightforwardly, if the supermultiplier propensities remained unchanged, the growth of the induced components is passive, which stems from the income flow generated by autonomous expenditures. Additionally, the effects captured by the supermultiplier components provide insights into the relationship between growth and distribution.

The idea of autonomous demand is to designate the components that are independent of production income. Effectively, the domestic autonomous expenditures are those that can be financed out of credit and debt, whereas the exports are externally driven.

Where RI is household (residential) investment, G is the sum of government's consumption and investment, and X is exports. After simple algebraic manipulation, the real GDP equilibrium level (Y^*) is explicitly obtained in terms of the autonomous demand (Z) and the supermultiplier (α) components.[24] Accordingly, the

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[23] The evolution over time of the propensity to invest is described by $\dot{h} = h_t \gamma(u_t - \mu)$, where u_t is the actual degree of capacity utilization, μ is the normal rate of capacity utilization and $\gamma > 0$ is a parameter that measures the speed of adjustment. See Freitas and Serrano (2015a).

[24] Despite that private investment is also likely to be financed out of credit rather than firms' savings, there exists a necessary relationship that runs from production to investment by means of the capital stock adjustment principle introduced previously. Therefore, investment will be driven by production requirements to expand productive capacity to accommodate the effective aggregate demand.

expression "semi-autonomous" is also employed in neo-Kaleckian approaches to refer to non-capacity generation expenditures that can be financed out of debt (Fiebiger, 2018). Pariboni (2016) and Fiebiger and Lavoie (2019) emphasized the role of a non-wage source of household consumption and investment in aggregate demand based on credit and mortgage.[25] Furthermore, the autonomous or semi-autonomous character of government spending is adopted in Allain (2015), Hein (2018), and Morlin (2022), whereas some Kaldorian literature assumes exports growth as autonomous (McCombie and Thirlwall, 1994).[26]

Regardless of the terminology (autonomous or semi-autonomous), it is considered that some components of aggregate demand tend to follow income generation, such as the induced components, whereas the autonomous components drive injections in the income inflow. It does not imply that the supply side does not play a role for the latter, but rather that there is no functional nor mechanical relation from Y to Z, which means that previous income generation is not a necessary condition for these expenditures' fulfillment. Therefore, albeit autonomous by definition, the actual determinants of these expenditures can still be investigated, as this article precisely intends to do in the case of exports.

Back to the growth decomposition methodology, the equilibrium level of output is obtained by substituting the terms of Equations 1.4 and 1.5 in Equations 1.1 and 1.2.

$$Y = \mu c Y + \mu h Y + \mu(Z + E) \tag{1.7}$$

Following the steps established Freitas and Dweck (2013), in the next step, by calculating the differences between $t = 1$ and $t = 0$ of the variables in Equation 1.7, economic growth $\Delta Y = gY(0)$ is obtained in the left-hand side.

$$\begin{aligned} Y(1) - Y(0) = \mu(1)c(1)Y(1) - \mu(0)c(0)Y(0) + \mu(1)h(1)Y(1) \\ - \mu(0)h(0)Y(0) + \mu(1)Z(1) - \mu(0)Z(0) \end{aligned} \tag{1.8}$$

From here forward, calculations must be done to isolate the demand components' individual contributions. Afterward, Equation 1.9 provides the final demand-led

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[25] Pérez-Montiel and Pariboni (2022) found evidence for a causal relationship running from household residential investment to output.

[26] As an empirical test of the Sraffian supermultiplier model, Girardi and Pariboni (2016) employed cointegration techniques to examine the relationship between autonomous demand and output. The authors provided evidence to suggest that the long-run causality runs from autonomous expenditures to output growth and indicated that it is the GDP that adjusts to Z when in disequilibrium (Girardi and Pariboni, 2016, p.535).

growth accounting.

$$
\begin{aligned}
g = \alpha(1)\left[\frac{C(0)}{Y(0)}\right] g_c + \alpha(1)\left[\frac{I(0)}{Y(0)}\right] g_h + \frac{\alpha(1)}{\mu(1)} g_\mu + \alpha(1)\left[\frac{G(0)}{Y(0)}\right] g_G \\
+ \alpha(1)\left[\frac{RI(0)}{Y(0)}\right] g_{RI} + \alpha(1)\left[\frac{X(0)}{Y(0)}\right] g_X + \alpha(1)\left[\frac{E(0)}{Y(0)}\right] g_E \quad (1.9)
\end{aligned}
$$

Thus, Equation 1.9 expresses the real growth rate of the variables. The first two terms on the right-hand side are the contributions of the induced components. The third term is the contribution of the domestic content growth in the GDP and the propensity to import (μ).[27] Afterward, the contribution of the different autonomous demand components is distinguished, and the change in inventories concludes the equation.

1.3.2 Growth decomposition results

Using data from the OECD National Accounts database, the growth decomposition was calculated. For China and India, the gross fixed capital formation series for government and household sectors were obtained from the National Bureau of Statistics of China and the Ministry of Statistics of India, respectively. The results for Period 1 (2000–2008) and Period 2 (2010–2019) are displayed in Table 1.1.

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[27] For sake of simplicity, hereafter we will refer to the domestic content contribution as the imported content contribution. Straightforwardly, a negative contribution of the domestic content means an increase in the share of the imported content.

Table 1.1: Decomposition of Growth (%)

Period 1 (2000-08)	**BRA**	**CHL**	**CHN**	**CZE**	**HUN**	**IND**	**KOR**	**POL**	**ZAF**
Consumption	-0.3	0.2	-3.1	-0.5	-0.1	-0.5	-0.8	-0.4	0.5
Private inv.	0.6	1.4	1.9	0.0	-0.1	1.0	0.4	-0.6	1.0
Imported content	-1.1	-2.8	-2.0	-3.6	-5.0	-3.6	-1.8	-2.6	-2.0
Government exp.	1.9	1.1	3.5	1.1	0.9	2.3	1.7	1.8	1.9
Residential inv.	0.0	0.8	1.9	0.3	0.4	2.0	-0.1	0.6	0.4
Exports	2.1	3.7	8.0	6.6	7.3	5.1	5.5	5.2	2.5
Δ in inventories	0.5	0.4	0.6	0.4	0.1	0.4	0.4	0.1	-0.1
GDP growth	**3.7**	**4.8**	**10.7**	**4.3**	**3.5**	**6.7**	**5.4**	**4.1**	**4.2**
Period 2 (2010-19)									
Consumption	1.3	1.6	1.0	-0.2	-0,2	0,3	-0,6	-0,5	0,6
Private inv.	-0.2	0.4	0.1	0.2	0.2	0.1	-0.1	0.1	-0.1
Imported content	-1.6	-0.9	-0.6	-1.9	-2.2	0.8	-0.8	-1.4	-0.9
Government exp.	0.3	1.1	3.2	0.1	0.7	2.0	1.0	0.8	0.8
Residential inv.	0.2	0.2	2.0	0.0	0.0	1.6	0.4	0.1	-0.1
Exports	0.9	0.6	1.9	4.1	4.1	2.3	2.9	4.3	1.1
Δ in inventories	0.1	0.4	0.1	0.2	0.3	0.0	0.5	0.4	0.2
GDP growth	**1.1**	**3.3**	**7.8**	**2.5**	**2.8**	**7.0**	**3.3**	**3.7**	**1.7**

The reduction in the contribution of exports to economic growth in the period following the Great Recession reinforces the idea that subsequent to the world economic slowdown, the enhancement in the current account position and the growth of net exports in developed countries are more linked to a reduction in imports than a transition to an export-oriented economy.

Among the best growth performances in Period 2, the results suggest that China, India, and Poland mitigated the drop in exports by different means. Although government expenditures emerge as the common variable supporting autonomous demand for China and India, Poland's performance appears to be related to a decrease in the negative contribution of imported content.

Although Mertens et al. (2022) classified the Chinese growth model as domestically oriented and investment-driven, our findings indicate that public investment takes center stage in the post-crisis period. Consequently, the formulation of a state-led investment growth model after 2008, as proposed by Tan and Conran (2022), seems to be a more suitable characterization. Additionally, China shifted from a -3.0% of consumption to 1.1% from Period 1 to Period 2. Explanations for changes in the propensity to consume are exogenous to the model, and distributional changes arise as strong candidates. This is likely to be the case in China, as from 1980 to 2013, the poverty measured by headcount ratio decreased by 86%, whereas the bottom 10% share experienced an income rise of 63% in the same period (Jain-Chandra et al., 2018).

Although exports dropped in Period 2 for all countries in the sample, Poland, the Czech Republic, and Hungary remained competitive. Besides exports continuing to be the main engine of growth in Period 2, the imported content dropped significantly for the EE countries. Overall, exports play a principal role in shaping the economic growth in EE for both periods analyzed. Thus, the study conducted by Hagemejer and Mućk (2019) has found evidence that participating in Global Value Chains (GVC) was one of the primary drivers of export growth in the EE region. In Section 1.4, the potential drivers will be discussed in greater detail.

Chile underwent a notable decrease in exports, which was partially offset by a substantial decrease in imported content and relatively consistent government expenditures. Among the Asian economies examined, South Korea's growth performance was the weakest, although it benefited from increased residential investment and reduced imported content. In general, a fall in exports primarily led to lower average growth in Period 2 when compared to that in Period 1. On the one hand, the drop in exports of large emerging economies suggests that developed countries have enhanced their current account positions by lowering imports. At the same time, the economies under study partially offset the decline in exports by importing less. Taken together, both trends reflect a global tendency toward stagnation.

Besides having the worst growth performance in Period 2, Brazil, the Czech Republic, and South Africa experienced the sharpest decline in government expenditures. In view of a lower tax revenue expectation due to the downward trend of growth, the adoption of austerity policies aims to balance the public budget and stabilize the government's debt. However, harming a source of demand as a response to a decline of another aggregate demand component (exports, in this case) makes the situation even more critical since it assumes a pro-cyclical character. In this context, the more aggregate demand shrinks, more spending cuts will be required, perpetuating a vicious cycle.

In addition to having the worst growth performance in Period 2, Brazil, the Czech Republic, and South Africa experienced the sharpest decrease in government expenditures. In view of a lower tax revenue expectation due to the downward trend of growth, the adoption of austerity policies aims to balance the public budget and stabilize the government's debt. Nevertheless, harming a source of demand as a response to a decrease in another aggregate demand component (exports, in this case) makes the situation even more critical since it assumes a pro-cyclical character. In this context, the more aggregate demand shrinks, the more spending cuts will be required, which perpetuates a vicious cycle. In the Czech Republic (as in the EE economies), austerity arose as a response to the 2009 crisis and led to massive demonstrations in 2012. Despite the president's resignation in 2013, the cuts in public spending persisted (Varga, 2015). As for South Africa, Sibeko and Isaacs (2019) showed that the government has been implementing austerity of public spending since 2014. Accordingly, the contribution to growth of government expenditures is negative from 2014 onward. Likewise, austerity began to be predominant in Brazil in 2014 (Mantoan et al., 2021), with a peak represented by the implementation of the "New Fiscal Regime," in 2016. Known as "spending ceiling" and unprecedented in the world, the New Fiscal Regime imposed that the nominal growth of public spending was limited by the prior year's inflation rate (Arestis et al., 2022).[28]

This observation highlights the crucial role of fiscal policy as a fundamental instrument for mitigating adverse demand shocks, such as the decrease in exports, and as a counter-cyclical mechanism for stabilizing autonomous demand creation and stimulating induced expenditures. In this context, China, India, and Hungary were the only countries that held government expenditure contributions at similar levels. However, the case of Hungary is slightly different. The country exhibited the lowest government expenditures contribution across the sample in Period 1, in which growth was essentially led by exports. Thus, despite maintaining the government expenditures contribution similar to the level observed in Period 1, it was still barely relevant to Hungarian growth in Period 2. China and India, conversely, presented a mixed growth composition in both periods. By sustaining government expenditures and residential investment contributions, in combination with reducing imported content, the Asian economies managed to achieve high growth rates also in Period 2. Notably, India was also the only economy analyzed to experience higher economic growth in Period 2 than in Period 1.

Moreover, during Period 2, the decomposition analysis indicates an increase in the contribution of consumption to economic growth in Brazil. Figure 1.A2 (appendix 1.A) reveals that household consumption exhibited higher growth rates in contrast to GDP. Nonetheless, unlike the situation in China, this surge is associated with an increase in household indebtedness, a notable aspect of Brazil's process of financialization as highlighted by (Lavinas et al., 2019) rather than a reduction in income inequality. Additionally, autonomous consumption was not distinguished

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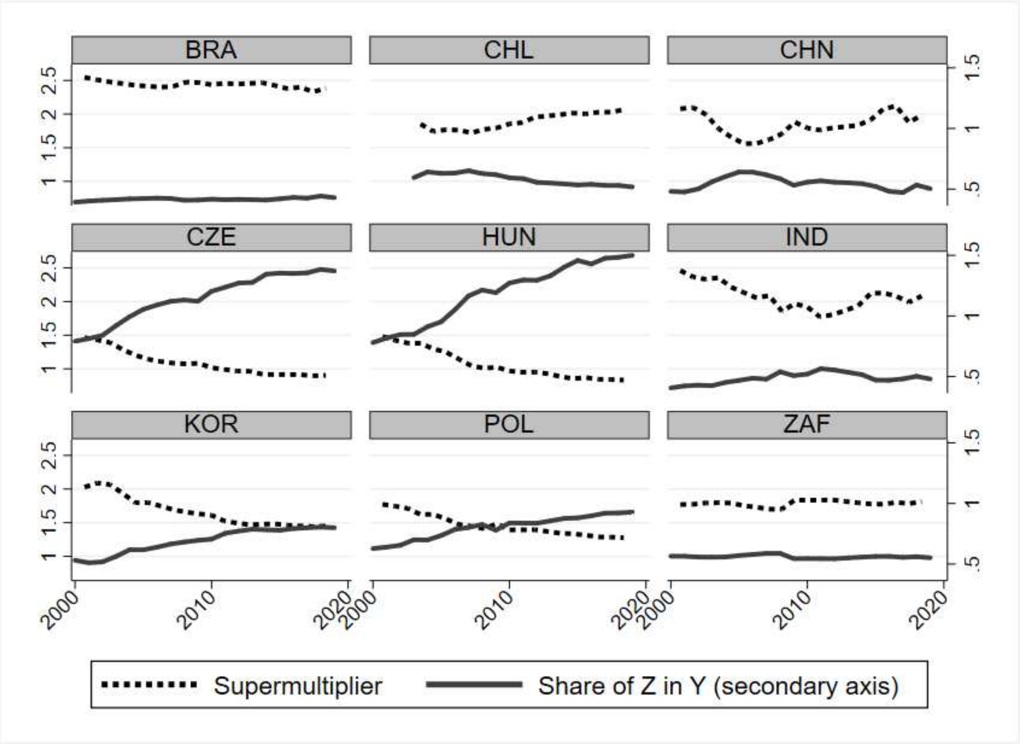
[28] In 2023, the spending ceiling was substituted by a more flexible fiscal rule.

from induced consumption due to data availability. Thus, the decomposition method used captures changes in the propensity to consume, which may underestimate the contribution of consumption. In Brazil's case, however, the observed results are more likely due to a higher level of autonomous consumption financed through debt (Lavinas, 2017).

It is worth noticing the nearly insignificant contribution of private investment in Period 2. An endogenous explanation suggested by the SSM model is that the behavior of the propensity to invest reflects the slowdown in the economic activity represented by the weaker autonomous demand formation (see Girardi and Pariboni (2020)). According to the model, a lower growth of autonomous demand Z leads to a higher share of Z in Y and vice versa through a reduction of the investment share via accelerator effect. The accelerator posits that faster growth of Z leads to an even faster - for a while - growth in induced investment, with the result that the propensity to invest eventually is higher and Z/Y is lower (Freitas and Serrano, 2015a). Figure 1.2 illustrates the evolution of the supermultiplier α and the share of autonomous demand in total output (Z/Y).

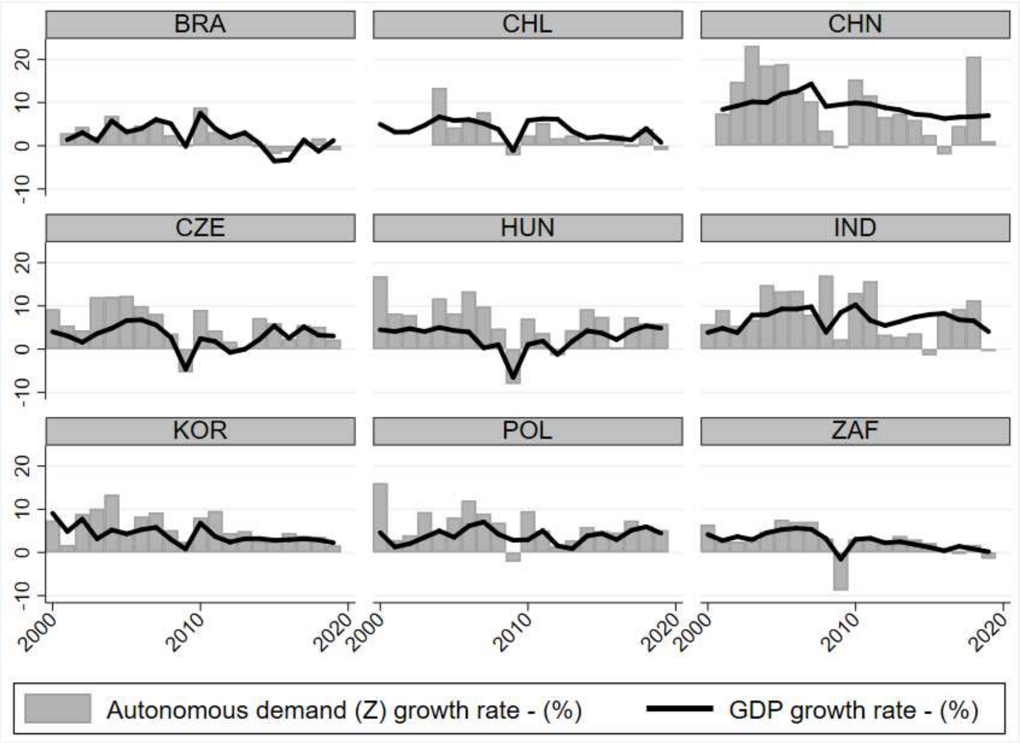
Figure 1.2: Supermultiplier and autonomous demand share in output



A downward trend in the supermultiplier is observed in South Korea and EE countries, the economies with the largest exports contribution to growth in the set. This is potentially because of a decrease in the propensity to invest (h). Nonetheless, this is not what happened for the countries concerned, which rather exhibited a flat and stable pattern for this variable (see Figure 1.A1 in the appendix). Conversely, as shown in Figure 1.A3 (appendix), an upward trend in the imported content appears to be the main explanatory factor for the decrease in the value of the supermultiplier. Moreover, a descending slope of the propensity to consume over the years is observed, although to a lower extent.[29] For these countries, it can be expected that as their productive sector becomes more export-oriented, imports will grow to both fulfill domestic consumption demand and supply inputs for the export sector. Accordingly, the growth decomposition in Period 2 indicates that exports in the EE countries are the primary contributor to the growth and the sole one.

The findings corroborate the role played by autonomous expenditures on economic growth, which reinforces the results found through various approaches in the literature, as in Baccaro and Pontusson (2016), Dünhaupt and Hein (2019), and Morlin et al. (2022). Figure 1.3 displays autonomous expenditures (Z) and GDP growth rates over time.

Figure 1.3: Autonomous demand and GDP - growth rates (%)



The figure suggests that the two variables are closely related, apart from China and India. As revealed by the decomposition analysis, exports were the main growth

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[29] Different from the accelerator effect in h, explanations related to μ and c are exogenous to the model. Potential causes for greater propensities to import and consume are, respectively, increasing globalization and income inequality.

component before the crisis. Similarly, in the period after the crisis, this autonomous spending is responsible for the larger contribution to growth in six out of nine countries in the sample. Although government expenditures also play an essential role, especially in sustaining aggregate demand in China and India, generally, the export performance tips the scales for higher growth rates in Period 1 and their decrease in Period 2. Hence, the following section delves into the export drivers in this group of emerging economies.

1.4 Testing drivers of export competitiveness: a panel-data estimation

The overall slowdown of economic growth in Period 2 is largely due to the decrease in the contribution of exports. Thus, this section goes deeper into the analysis of potential export drivers. Understanding the driving forces behind the competitiveness of exports in developing economies where this component is a primary contributor to growth aids us in understanding the dynamics of growth in these economies as presented in the decomposition exercise. Hence, the second step of the empirical investigation applies panel data estimations to explore potential export drivers, engaging with the debate regarding export competitiveness under the growth models perspective.

Following the existing literature on export competitiveness (refer to section 1.2), the real effective exchange rate (REER) and economic complexity index (ECI) are the variables adopted to analyze price and non-price competitiveness factors of exports, respectively.[30] Additionally, foreign demand (FY) is incorporated as an explanatory variable since it is a primary driver of exports. The growth decomposition analysis reveals that the decline in exports and GDP growth in emerging economies is more closely related to an overall slowdown in economic activity (i.e., lack of foreign demand) rather than a shift of advanced economies towards export orientation. The crucial role played by income elasticity of exports demand is highlighted in Thirlwall's growth model tradition (McCombie, 1985; Thirlwall, 1979), where exports are considered the source of autonomous demand in the long run (Thirlwall,

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[30] The variable selection in this article primarily follows the standard specifications in the export competitiveness literature, which is crucial for comparability. However, as noted by a referee, some potential risk of simultaneity-induced endogeneity persists. Additionally, the inclusion of FY and GVC is theoretically justified. Naturally, the selection of explanatory variables does not encompass all possible determinants of export growth.

1997).[31] Moreover, although foreign income is not considered a competitiveness factor of a country's exports since the country has no influence over it, this variable captures global macroeconomic fluctuations, which allows for the assessment of the prominence of price and non-price competitiveness factors regardless of the evolution of foreign demand. The GDP of the top 5 export destinations for each country in the sample was used to measure FY. The variable was built by summing the GDP in real terms (levels in 2015 US$) of the top 5 partners. Because of this, changing a partner may imply an abrupt change in the level, so the groups of trade partners do not change within the period of analysis.

Finally, participation in GVCs is included as an explanatory variable in the panel data estimation. The inclusion of GVC broadens the picture from the traditional REER versus ECI dichotomy and features a key ingredient of analysis given the increasing integration of international markets. To the best of our knowledge, the inclusion of GVC participation in the analysis is a novelty for the literature on export drivers within comparative political economy. The role played by GVC is related to both price and non-price-competitiveness factors, which will be discussed more thoroughly later. Above all, participation in GVCs is primarily associated with industrial and trade policies and may provide hints about the development of the productive structure of emerging economies.

Lee et al. (2018) pointed out that participation in GVCs is desirable in the initial stages of development as it increases the domestic value added by learning from outside. In this sense, lower labor costs imply cheaper manufactured goods than those produced domestically in developed economies. This means that these economies would boost exports when joining a global chain, even in low value-added rings. Moreover, it may attract foreign direct investment, for instance, a multinational company establishing a factory in these countries to take advantage of lower production costs. However, Lee et al. (2020) added that achieving further stages of industrial upgrading is not spontaneous, considering that from a certain level, it will require independence from existing chains (creating new ones) and enhancing innovation capabilities. Thus, in later development stages, increasing the domestic value added of exports is more related to the uniqueness of the goods and is no longer bound exclusively to cost factors. For the analysis, the GVC variable is measured using the domestic value added embodied in foreign exports as a share

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[31] While the traditional Thirlwall model interprets cross-country differences in income elasticity of demand for exports as a proxy for non-price characteristics of the goods (Thirlwall, 1997), the emergence of direct measures like the Economic Complexity Index (ECI) (Hidalgo and Hausmann, 2009) has reduced the reliance on such indirect assessments. Although ECI is used here to capture non-price competitiveness, income elasticity may still reflect some quality factors alongside its primary role in capturing global demand fluctuations.

of gross exports, commonly referred to as the "pure forward GVC".[32] Table 1.2 presents the summary of selected variables.

Table 1.2: Summary of selected variables

Code	Name	Format	Source
X	Exports	Levels in 2015 US$	OECD National Accounts
FY	Foreign demand	Levels in 2015 US$	OECD National Accounts
REER	Real Effective Exchange Rate	Index, 2010=100	World Bank
ECI	Economic Complexity Index	Index	Atlas of Economic Complexity
GVC	Global Value Chain	Share	OECD Trade in Value Added
D1	Dummy (2009)	Dummy	

1.4.1 The model

The regression models for the panel data consist of nine cross-sectional units and span the period from 1995 to 2018.[33] The dependent variable is exports, while the independent variables include FY, REER, ECI, and GVC. The standard unit root tests[34] indicate that all the variables are non-stationary in level. To address the non-stationarity, the variables of exports and foreign demand are expressed in log differences, whereas the remaining variables are in first differences. Both X and FY are represented in log differences so the coefficient associated with foreign demand can be interpreted as an elasticity. Moreover, the values of REER, ECI, and GVC have been normalized to facilitate comparisons of the coefficients. Lastly, a dummy variable has been included to account for the outlier year 2009.

$$\Delta \ln(X_{i,t}) = \beta + \boldsymbol{\beta'}\mathbf{Z}_{i,t} + \omega D_{t=2009} + \upsilon_{i,t} \tag{1.10}$$

Where $\mathbf{Z}_{i,t}$ is the vector of independent variables, $\boldsymbol{\beta'}$ is the coefficient vector, $\omega D_{t=2009}$ is the dummy variable for the year 2009, and $\upsilon_{i,t}$ is the error term. After conducting the cross-sectional dependence test (Pesaran, 2004) and the heteroskedasticity-robust tests for serial correlation (Born and Breitung, 2016), the existence of cross-sectional correlation and serial correlation (autocorrelation) was identified in the data. These findings indicate violations of the underlying assumptions of linear panel models, which can compromise the validity of statistical inference. To address these issues and generate reliable estimates, the standard errors of the Ordinary

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[32] Therefore, these linkages primarily regard to the country's involvement in earlier stages of the production process.

[33] Starting from 2019, complete data for all variables is not available for every country in the sample. Therefore, the analysis period extends only up to 2018 to maintain panel balance

[34] The unit root tests performed were: Augmented Dickey-Fuller, Phillips-Perron, and Im, Pesaran and Shin.

Least Square (OLS) estimator must be adjusted to account for the panel structure of the data. Hence, two regression models were tested incorporating robust standard errors.

Model (1) is a fixed effects regression with Driscoll–Kraay standard errors (Driscoll and Kraay, 1998), in which the disturbances are assumed to be heteroskedastic, autocorrelated up to some lag and possibly correlated between panels (Hoechle, 2007). Finally, Model (2) is estimated using a panel-corrected standard errors (PCSE), which assumes that disturbances are, by default, heteroscedastic and contemporaneously correlated across panels. Furthermore, to account for serial correlation, the autocorrelation structure is specified to be panel-specific and estimated by time series methods. The difference between (1) and (2) is that the former denotes autocorrelation of the moving average type with lag length q, whereas the latter assumes autocorrelation as a first-order autoregression ($AR(1)$). Table 1.3 shows the regressions results.

Table 1.3: Regression models on panel data (1995-2018), different specifications

Variables	(1) Δln(X)	(2) Δln(X)
Δln(FY)	2.932***	1.402***
	(0.424)	(0.431)
ΔREER	-0.132***	-0.0867**
	(0.0573)	(0.0351)
ΔGVC	0.101**	0.174**
	(0.0855)	(0.0772)
ΔECI	0.109	0.163
	(0.143)	(0.105)
$D_{t=2009}$	-0.0146	-0.0868***
	(0.0167)	(0.0326)
Constant	-0.00929	0.0404***
	(0.0118)	(0.0129)
Observations	207	207
R-squared		0.469
Fixed effects	Yes	No
Countries	9	9

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Expectedly, the estimation of the elasticity of export growth to foreign demand presented strong results. The large and significant coefficients highlight the crucial role of foreign demand not only in exports but also in the overall growth rate of these economies. This finding reinforces the idea that the slowdown in global economic activity after the 2008-2009 crisis is central to explaining the decline in the contribution of exports to growth and the lower growth rates in export-oriented emerging economies. Therefore, the FY coefficient captures the effects of fluctuations in foreign demand, allowing the assessment of competitiveness factors regardless of changes in foreign demand patterns.

Then, REER has a negative and significant coefficient in both specifications, although at different significance levels. Since the values of REER are normalized, the coefficients suggest that a one standard deviation increase in the real effective exchange rate negatively impacts the export growth rate by approximately -8.7% to -13.2%. This means that an exchange rate appreciation is negatively related to export growth, stressing the price-competitiveness character of emerging economies' exports. Conversely, for any of the specifications, ECI is not significant at any statistically convenient level. As for GVC, the coefficients are positive and statistically significant at 5%, which suggests that increasing the domestic value added in foreign exports is associated with a higher export growth rate.

Moreover, model (2) shows the constant term and the dummy variable for the year 2009 as statistically significant at the 1% level. The constant value of 4% is reasonable considering that the export growth has an average rate of 7% in the sample. The dummy coefficient of approximately 8.7% also corresponds to the sharp drop in export growth rates in 2009. Ultimately, the PCSE model (2) produces the lowest standard errors and the most significant coefficients; hence, it is considered the most suitable for the data used. However, a real exchange rate depreciation indicates distributional effects that are potentially harmful to domestic consumption and may mitigate, to some extent, the export contribution to growth. Although the growth decomposition provides valuable insights in this regard, as suggested by the relatively low contribution of consumption to growth, it does not explicitly address the determinants and effects of changes in income distribution. Sequentially, the relation between growth models and distribution is an aspect that finds its explanation within the realm of political economy dimensions.

The prevailing feature for enhancing price competitiveness may vary depending on the composition of the export basket. If exports consist mainly of commodities with globally standardized prices, the country becomes a price taker in international markets. Nonetheless, the exchange rate is still a relevant variable for export performance. First, political pressure from the natural goods export sector to keep the exchange rate over-depreciated must be taken into account. Due to the price-taker condition, an appreciation in the exchange rate squeezes the exporting firms' profits.

Moreover, exchange rate volatility, rather than the level, can affect profitability. A depreciation shock in the exchange rate increases the profitability of exporting goods rather than selling them domestically. Therefore, even if these economies are not primarily competing on price and costs, a depreciation in the exchange rate is expected to boost exports. By contrast, if the export basket comprises mainly manufactured goods and services, the lower labor costs compared to developed economies enable competition on price.

The relevance of GVC participation rather than ECI adds new ingredients to the price versus non-price-competitiveness debate. As briefly discussed, joining GVCs in the early stages of development is likely to be related to lower production costs and tends to boost the domestic value added of exports. Lee et al. (2020) pointed out that participation in GVC does not necessarily mean industrial upgrading, as several emerging economies get stuck in positions of suppliers of goods with low-value-added and low technological intensity. Lee et al. (2018) developed the "in–out–in" hypothesis for GVC participation and functional industrial upgrading. In the initial stages of economic development for a country that catches up with more advanced economies, engaging in the GVC to obtain foreign knowledge and production skills is vital. As the country progresses to a middle-income level, industrial upgrading involves striving for autonomy and minimizing dependence on existing GVCs predominantly controlled by foreign economies. Finally, in the third stage, the latecomer economies may eventually need to reintegrate into the GVC after establishing their own local value chains. Following the reasoning of Lee et al. (2018), GVC participation may lead to technological catch-up if adequate industrial policies are implemented to enhance innovation and knowledge capabilities and support infant industry development. As pure forward linkages primarily denote a country's involvement in earlier stages of the production process, they are likely related to lower production costs. Consequently, although increased GVC participation tends to improve the domestic value added in exports, the estimated coefficient for GVC further highlights the significance of price-competitiveness factors in stimulating export growth.

Conversely, the non-price competitiveness of exports in emerging economies necessitates careful consideration. Although the first results do not suggest that fluctuations in complexity are associated with export growth rates in the short-run dynamics, its importance should not be relegated to a secondary plane. Contrarily, to catch up with advanced economies in terms of productive structure and reduce dependence on them, particularly for capital goods and cutting-edge technologies, increasing economic complexity is essential. Drawing inspiration from the structuralist approach, an economy's initial stages of development are closely linked to shifting from importing to producing the goods locally for the domestic market. This might explain the nonsignificant effect of changes in the ECI to boost exports in a sample of emerging economies. For example, increasing complexity, up to a certain level of sophistication, is expected to be more related to import substitution than a quantitative increase in exports. Likewise, economic complexity is anticipated to gain greater relevance once a certain threshold is obtained. Hence, considering the level of complexity rather than its fluctuations may provide further insights when assessing the impact on export growth.

Therefore, three additional regression models were estimated to capture the effects of the heterogeneity of complexity levels within the sample. The countries were divided into two groups based on the average ECI in the period of analysis. Group 1 involves the low-ECI economies, which comprises Brazil, Chile, China, India, and South Africa. Group 2 consists of the high-ECI economies: the Czech Republic, Hungary, Poland, and South Korea.[35] First, a dummy variable was created to differentiate the groups, where $D_{ECI} = 1$ for the group of high-ECI countries. Afterward, regression model (3) employs a PCSE estimation as in model (2) presented before but instead includes ECI as a dummy rather than a continuous variable. The coefficient estimate of D_{ECI} is expected to capture the effect of higher complexity on exports. Then, to compare the effect of the REER for low-ECI (4) and high-ECI (5) countries, a PCSE regression was carried out on each group.[36] Based on the reasoning mentioned earlier, REER is expected to play a more prominent role in countries with lower economic complexity. Table 1.4 presents the output.

As suggested by the estimated coefficient of D_{ECI}, positive and significant at 1%, the results of model (3) indicate that high ECI is associated with more rapid export growth. Furthermore, the output for the additional variables in (3) aligns with the estimations in Table 1.3, where FY, REER, and forward participation in GVCs have statistically significant coefficients. As for the REER effects, the results indicate that the REER coefficient is larger and significant only in the low-ECI group estimation (4). Hence, the findings in Table 4 reinforce two noteworthy interpretations. First, it suggests the idea that the level of complexity, rather than its change over time, is a more relevant factor of export competitiveness. Second, it implies that the impact of REER diminishes as the economic complexity increases.

Additional insights into the findings may be brought out when referring to the

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[35] After rescaling the ECI values from 0 to 1, the average index is 0.24 for Group 1 and 0.69 for Group 2.

[36] Given that we are particularly interested in the REER effect and the substantial reduction in the observations due to the countries split into two groups, only foreign demand and REER were included as explanatory variables.

Table 1.4: Comparing REER effects dummy ECI

	(3)	(4) Group 1 Low-ECI	(5) Group 2 High-ECI
Variables	Δln(X)	Δln(X)	Δln(X)
Δln(FY)	2.282***	2.591***	2.599***
	(0.466)	(0.747)	(0.486)
ΔREER	-0.0920***	-0.0891**	-0.0363
	(0.0343)	(0.0450)	(0.0577)
ΔGVC	0.128*		
	(0.0692)		
D_{ECI}	0.0552***		
	(0.0111)		
$D_{t=2009}$	-0.0539*	-0.0871**	-0.00845
	(0.0325)	(0.0392)	(0.0384)
Constant	-0.0155	-0.0221	0.0342***
	(0.0192)	(0.0301)	(0.0105)
Observations	207	115	92
R-squared	0.519	0.446	0.615
Countries	9	5	4

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

growth decomposition outlined in Section 2. Notably, the high-ECI group comprises the EE economies plus South Korea, the countries in the sample in which GDP growth is driven practically in its totality by exports. In a strict export-oriented growth strategy, increasing the exports basket sophistication might be sufficient to succeed while foreign demand is heated. Nonetheless, even considering the predominance of price-inelastic goods, this strategy relies strongly on foreign demand growth while leaving aside the other autonomous demand components. Thus, when facing a global stagnation trend, the country will be in a hands-tied position to resume economic growth.

Moreover, notably, despite the lower ECI, among the countries in the sample, Brazil, Chile, and South Africa present the highest forward GVC participation.[37] Based on the hypothesis of Lee et al. (2018), one possible interpretation is that these economies got stuck in positions of suppliers specialized in low-valued goods

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[37] In the appendix, figures 1.A4, 1.A5, 1.A6 and 1.A7 show, respectively, the evolution of foreign demand, the real effective exchange rate, economic complexity index, and domestic value-added of foreign exports for the countries in the sample.

for further processing in foreign countries. Conversely, the countries with higher ECI show a lower GVC share. Hence, this position might configure the second stage described by Lee et al. (2018), when the countries are reducing the dependence on existing GVCs dominated by foreign economies. At this stage, a larger share of final goods in their export basket is expected over low-value-added intermediaries to be processed. This interpretation is in line with the relatively lower reliance on price-competitiveness factors of high-ECI countries.

In summary, the overall results are interpreted as mixed, showing that while price-competitiveness factors play a sizable role in boosting exports during the early stages of development (when economic complexity is lower), the REER effect tends to soften as long as the sophistication of the export goods increases and they become more price-inelastic. Thus, to the extent that the economy develops its productive structure and achieves higher complexity levels, non-price factors such as product quality and uniqueness are expected to become more relevant in fostering exports. This study suggested that countries with low ECI have negative and significant REER coefficients (group 1), whereas it is not significant for countries with higher ECI levels (group 2). At the same time, the findings suggest that non-price competitiveness also matters, although the level of complexity is more decisive than its fluctuation. As of GVC, increasing the domestic value added in foreign exports represents an alternative to increasing complexity. However, it must be accompanied by a coherent industrial policy to prevent becoming trapped in the position of commodities suppliers.

1.5 Concluding remarks

This article claims that the growth decomposition inspired by the SSM model and the growth driver investigation approaches are complementary and can provide a robust framework within the growth models' perspective. Although the decomposition exercise by itself cannot pinpoint the precise factors propelling economic growth, the growth driver analysis, conversely, cannot measure the contributions of these factors to growth. Hence, growth accounting quantifies the key aggregate demand expenditures that contribute to growth, whereas growth driver analysis delves into the factors driving this spending. Overall, the study contributes to the literature by providing a more comprehensive framework for analyzing the determinants of economic growth and factors that contribute to a country's so-called export competitiveness.

The analysis of economic growth decomposition has been built on the premise of the major role attributed to autonomous components of demand in driving overall economic expansion. In this regard, when considering the contributions to growth among the nine emerging economies under examination, exports emerged as the predominant factor. Nevertheless, it is noteworthy that after the 2008–2009 crisis, the export contribution dropped across all the countries, an impact cushioned in different ways by the countries in the sample. Although slower growth in imported content was a common feature, the countries that maintained a high average growth rate after the 2008–2009 crisis, namely, China and India, relied on government expenditures to support autonomous demand. Despite exports being the primary component for most of these nations, this abrupt export decrease was accompanied by lower average growth rates. Therefore, the study reinforces the idea that the improvement in the current account position and the growth of net exports in developed countries can be mostly explained by a reduction in imports. Thus, instead of a shift to an export orientation, the movement depicts a tendency toward stagnation.

The pivotal role of exports within this set of countries warrants a deeper exploration of the factors influencing their competitiveness in international markets. Similarly, the investigation of potential drivers of exports is of growing interest in comparative political economy and the growth models literature. The panel data estimations indicate large and significant coefficients of the income elasticity of export demand, reinforcing its crucial role not only in exports but also in the overall growth rate of these economies. Furthermore, the findings suggest that greater participation in GVCs and REER depreciation positively impact export growth. Regarding non-price-competitiveness factors, the study suggests that considering the level of complexity rather than its change over time provides further insights to analyze the effect on export growth. Additional estimations revealed that to the extent that the economy achieves higher complexity levels, non-price factors such as product quality and uniqueness gain relevance in fostering exports. Moreover, contrasting the coefficients of REER between low and high-ECI groups indicates that countries characterized by low ECI exhibit negative and statistically significant REER coefficients. In summary, beyond the income elasticity of export demand, the study establishes that price competitiveness is significant in promoting export growth in low-complexity emerging economies, while non-price factors become more important at higher levels of export goods complexity.

Although REER depreciation is accepted as a catalyst for increased exports in the emerging economies in the sample, it also carries distributional consequences, potentially causing a decline in real wages. As revealed by the analysis of growth decomposition, it is noteworthy to highlight that the contribution of consumption to growth is relatively small and even negative for the economies heavily reliant on exports, such as South Korea and EE countries. Accordingly, relatively lower production costs are a feature of economies that supply goods in the initial rungs of GVCs. Hence, the participation in GVCs as a driver of exports is observed, in this context, as strengthening the importance of price-competitiveness factors.

The empirical investigation shows the intricate interplay of political economy features throughout both analysis steps. It is essential to emphasize that while growth decomposition offers valuable insights, it does not explicitly tackle the factors influencing income distribution and their effects. These aspects are instead explained by the social and political determinants within the political economy dimension. It becomes evident that multiple distinct growth models can arise from the contribution of mixed components of aggregate demand. As highlighted, these growth models find their roots in the institutional and political configuration of the economy, which, in turn, sets the stage for the prominence of one growth driver over another.

The political dynamics of growth models typically indicate that they are upheld by growth coalitions centered on key sectors. When a country's economic growth is heavily dependent on a key sector, the growth coalition projects its own interests as national interests, thereby exerting political influence in formulating policies and shaping government guidelines. In emerging economies characterized by structural heterogeneity, there is a fertile ground for establishing a powerful growth coalition due to the clear distinction between high- and low-productivity sectors. For example, a productive structure that specializes in natural resources or low-value-added manufactured goods fosters the emergence of an export-oriented growth model based on price-competitiveness factors. Then, despite the primacy of demand in driving economic growth, the nuances of these growth models, especially within the context of emerging economies, are intrinsically associated with factors that can be considered as belonging to the supply side realm (institutional, political, and productive) and are significantly shaped by the sophisticated social relations within the realm of political economy.

Appendix

1.A Panel variables at country-level

Figure 1.A1: Induced investment (h).

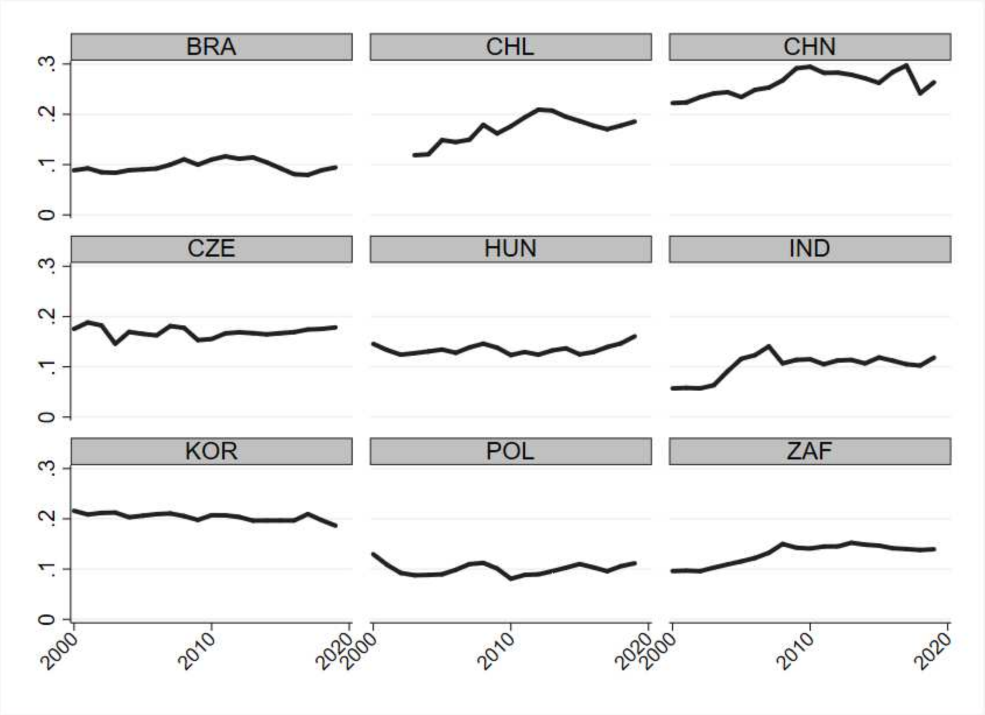


Figure 1.A2: Propensity to consume (c)

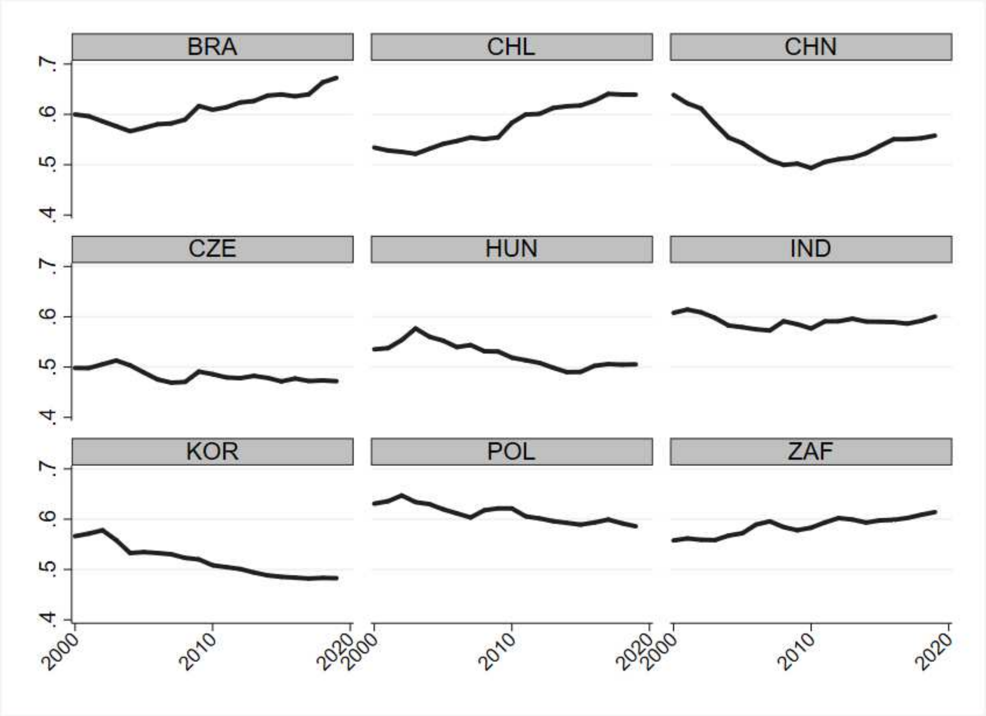


Figure 1.A3: Propensity to import (μ)

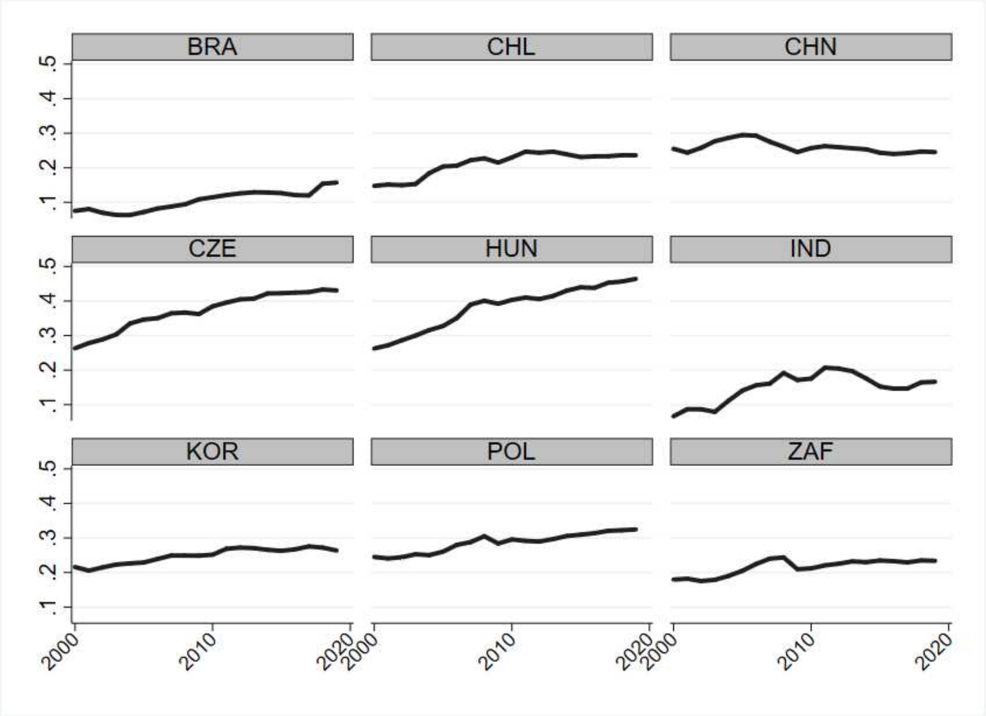


Figure 1.A4: Foreign demand (log). Source: Author's calculation. OECD National Accounts database.

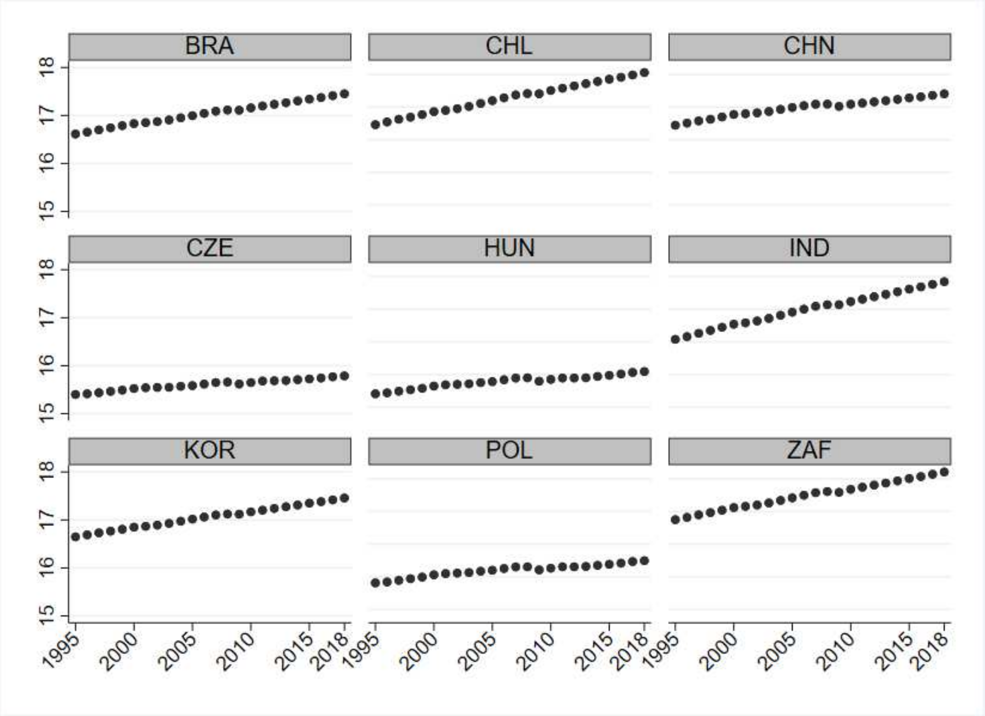


Figure 1.A5: Real Effective Exchange Rate (2010=100). Source: World Bank Data.

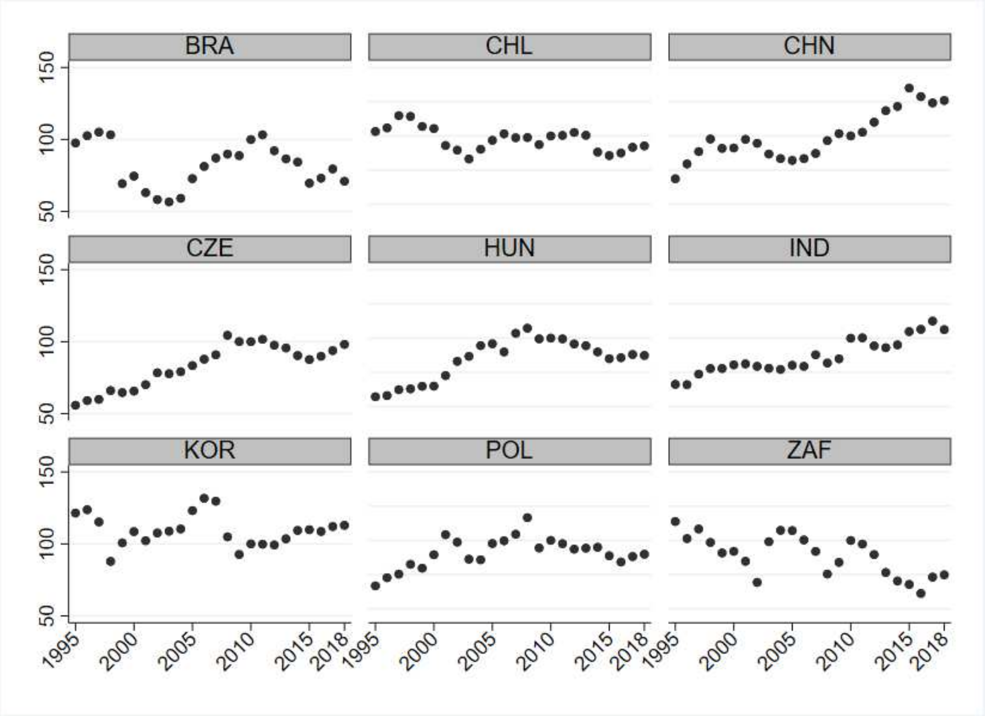


Figure 1.A6: Economic Complexity Index. Source: Atlas of Economic Complexity (2019).

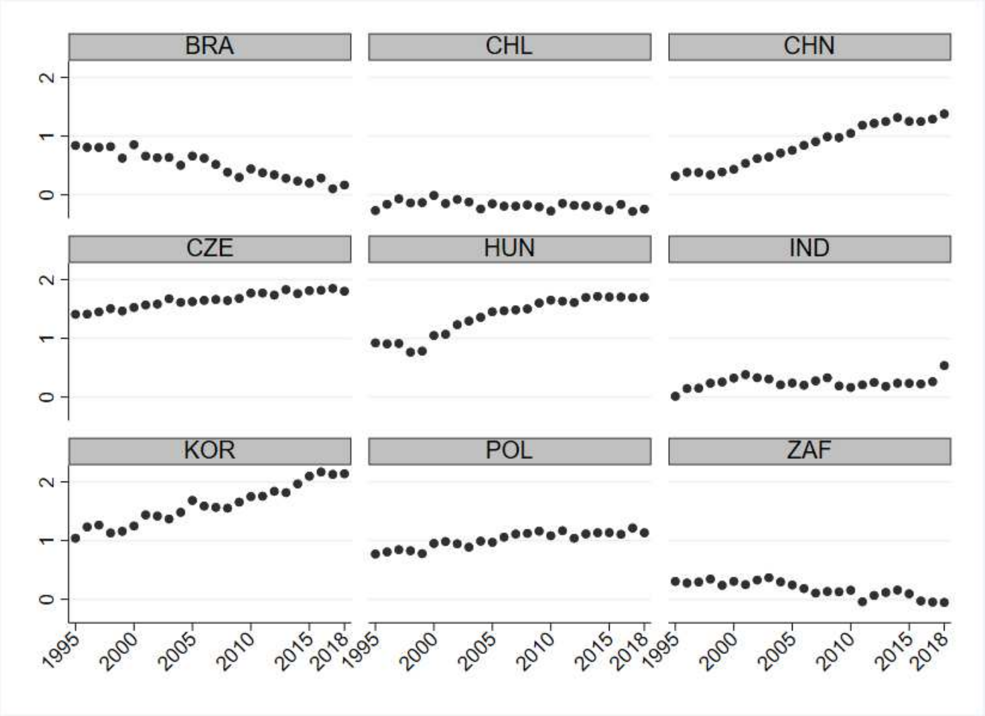
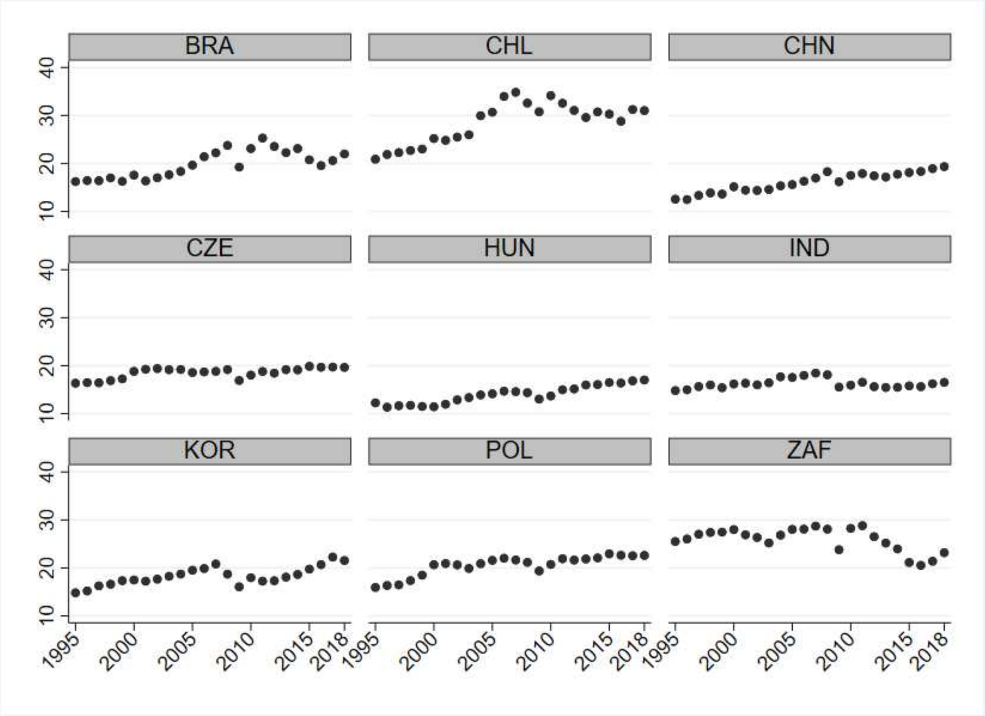


Figure 1.A7: Global Value Chain participation. Source: TiVA OECD.



Chapter 2

Interplaying demand-led growth and energy-supply constraints

a Sraffian Supermultiplier Model with Energy Sector

Abstract

This work aims to develop an analytical model that addresses the transition to a low-carbon economy by interplaying demand-driven dynamics and energy supply constraints. As the modeling of energy production in the ecological macroeconomics literature has been addressed within supply-driven growth models, the novelty of this article lies in integrating the energy sector into a demand-led growth framework. On the growth side, our model follows the Sraffian supermultiplier literature (Serrano, 1995). On the energy side, it draws inspiration from Bernardo and D'Alessandro (2016), explicitly modeling energy production from renewable sources. We assume business-as-usual and green government expenditures are sources of autonomous demand, with investment and capital stock composed of green and conventional components, respectively. The growth and energy sides of the model are connected through a green investment equation, which embodies a constraint on green capital stock accumulation given by the availability of renewable energy. Therefore, the growth dynamics are demand-driven, but the feasibility of the ecological transition is supply-constrained. Numerical simulations demonstrate that scenarios combining green fiscal policy and low growth are more conducive to promoting the energy transition, aligned with post-growth approaches.

2.1 Introduction

Transitioning from fossil fuels to renewable sources is at the forefront of efforts to confront climate change, prevent natural resource depletion, and potentially decouple economic growth from carbon emissions. Enhancing the capacity of renewable energy production is key in this context. Although several macroeconomic modeling tools have been devised to enhance comprehension of the connections between energy consumption and macroeconomic aggregates, the renewable energy production side is often overlooked in the ecological macroeconomics literature.

The post-Keynesian ecological macroeconomics literature has developed and expanded in recent decades to cover a broader range of issues. However, the modeling of energy production is typically addressed within supply-driven growth models (Hardt and O'Neill, 2017). Although there are ecological stock-flow consistent models (eco-SFC) that differentiate between renewable and fossil energy, its production is not specifically addressed (Dafermos et al., 2017; Carnevali et al., 2024; Jacques et al., 2023). In Dafermos et al. (2017) and Carnevali et al. (2024), the share of renewable energy consumed in production increases with the share of green capital stock, while the availability of renewable energy supply is not explicitly considered. In Jacques et al. (2023), the share of renewable energy in the total energy supply is exogenously determined.

Increasing renewable energy supply is essential to unlocking the energy transition, highlighting the importance of incorporating energy production into ecological macroeconomic modeling. Therefore, this work aims to build an analytical model to address the transition to a low-carbon economy based on a framework in which economic growth is demand-driven, but the feasibility of the green transition is supply-constrained by the availability of renewable energy. To do so, a framework integrating the energy sector into a demand-led growth model is developed. On the growth side, the model is based on the Sraffian supermultiplier literature (Serrano, 1995), while on the energy side, it draws inspiration from Bernardo and D'Alessandro (2016).

The World Energy Investment Report revealed that public spending on energy research and development (R&D) rose by 7% globally in 2023, highlighting that governmental efforts to cut emissions while maintaining economic growth are inducing more corporate R&D and fostering the establishment of more innovative energy companies (IEA, 2024a, pp. 150-176). This evidence aligns with the concept of a 'mission-oriented innovation policy of public spending' proposed by Mazzucato (2018), which argues that these spending have positive spillovers resulting from their inter-sectoral character and mobilize a crowd-in of private innovation spending. Building on the mission-oriented innovation approach and drawing from recent literature contributions that developed the Sraffian supermultiplier model with two autonomous demand sources (Freitas and Christianes, 2020; Morlin, 2022; Pedrosa et al., 2023), two kinds of government expenditures as components of autonomous demand are proposed: business as usual expenditures and green innovation expenditures. Moreover, two types of capital and investment—green and conventional—are introduced while preserving the standard capital adjustment principle of the Sraffian supermultiplier model.

In the supply-driven growth models developed by D'Alessandro et al. (2010) and Bernardo and D'Alessandro (2016), the energy sector is modeled by explicitly addressing energy production from renewable sources. Building upon their approach, the energy sector is integrated into the Sraffian supermultiplier growth model by introducing a green investment function in which increasing the stock of green capital is only possible with sufficient renewable energy capacity. Hence, by integrating the energy production side, an endogenously determined constraint is imposed on green capital accumulation, which differs substantially from the 'energy-constrained output' approach commonly proposed in ecological models, where production and output are constrained by an exogenously given finite stock of fossil energy reserves.

The introduction of the green investment function affects the composition of the capital stock, while it does not deal with the determination of total investment and capital stock growth rates in the Sraffian supermultiplier model. Therefore, its applicability is not limited to this class of models but is also compatible with alternative determinations of aggregate investment. Thus, this theoretically simple mechanism can be extended to different demand-led growth models, enabling them to address the energy transition, tackle environmental variables and relationships, and provide insights into pathways to sustainable development.

The article comprises three sections in addition to this introduction and the conclusion. Section 2 discusses the emergence of ecological macroeconomics alongside the 'post-growth' approaches, highlighting its complementarity with the post-Keynesian framework and clarifying the contribution to this literature. Section 3 presents the model, going through its growth side, the energy sector, and the environmental variables and relationships incorporated. Section 4 discusses the results of numerical simulations under distinct scenarios. The results highlight the role of public spending in green innovation and show that the cases with relatively lower economic growth are more conducive to the energy transition. Finally, the conclusion section closes the article.

2.2 The emergence of ecological macroeconomics

In recent decades, concerns over climate change have arisen due to widespread environmental degradation and a rapid increase in greenhouse gas (GHG) emissions in the atmosphere, challenging the economic system's production and consumption patterns. The rising global atmospheric temperatures due to the extensive GHG emissions threaten the ecosystems and current living standards as it could unleash extreme climate events with severe impacts if the threshold of 1.5°C above pre-industrial levels is crossed (on Climate Change), 2018). The primary goal of the Paris Agreement, the main international treaty on climate change, is to keep the global average temperature rise this century well below the critical limit of 2°C and as close as possible to 1.5°C. To achieve this goal, the treaty stipulates that GHG emissions must peak before 2025 and decline by 43 percent by 2030 with respect to 2015 levels.

Fossil fuels are the primary source of carbon emissions, accounting for around 76 percent of total GHG emissions (IEA, 2020). As the time horizon to stay within the limits imposed by the Paris Agreement narrows, the urgency of a low-carbon transition as the pathway to reduce emissions is stressed. The low-carbon transition is the process aimed at shifting the energy resources and technologies that society relies upon, currently heavily dependent on fossil fuels, towards a state where zero or low-carbon emissions are required to sustain the socioeconomic system (Nieto et al., 2020).

Based on the idea of scarcity of natural resources, the concept of 'green growth' arose in the early 2010s. Its policy agenda is intrinsically related to neoclassical economics foundations and aims to optimize resource allocation through market incentives – green subsidies and carbon taxes to correct market externalities, i.e., to enhance productivity through more efficient use of natural resources, waste reduction and lower energy consumption. The idea is that the harmful impacts on economic performance due to environmental degradation could be mapped, and the efforts to mitigate such effects represent an opportunity to improve economic growth (Reilly, 2012).

So far, the set of policies put forward on the green growth agenda failed to achieve relevant outcomes in terms of environmental sustainability (Jackson and Victor, 2019). Moreover, this approach also presents an inherent logical problem. Even if the production optimizes its efficiency, i.e., if the economy produces the same output at the highest productivity level possible and, consequently, without wasting resources, a unit of additional production would require new resources (Crist, 2019). Therefore, although optimizing the use of scarce resources is the fundamental problem in this framework, there is no optimal allocation capable of solving the scarcity issue in a growing economy. This logical problem has a second layer: the primary threat is not resource scarcity but global warming, as highlighted by the Paris Agreement's goal to limit rising atmospheric temperatures. Although both are related, in this context, it is more likely that the depletion of natural resources is a consequence of global warming rather than the immediate risk to humanity's living standards. Therefore, improving resource allocation alone cannot be a plausible solution to fight climate change.

From a theoretical point of view, several ecological economists have been arguing that the neoclassical approach ignores the principles of thermodynamics, such as the principle of mass balance and the entropy law (Georgescu-Roegen, 1971).[1] Moreover, underlying assumptions of orthodox models such as the rational maximization behavior in markets and the optimal equilibrium growth path are considered flawed in addressing environment-economy interactions and "inconsistent with some of the basic premises about systems function derived from ecology" (Spash and Ryan, 2012, p. 8). In addition, Rezai et al. (2013) point out that the rationality of agents and the perfect foresight are incompatible with the fundamental social change necessary to avoid environmental collapse.

Considering the significant coupling between resource use and economic activity (Wiedmann et al., 2015), the continuous pursuit of growth is contested with the emergence of 'post-growth' approaches, which developed a conception of an environmentally sustainable and prosperous economy that does not rely on economic growth. The post-growth approaches are not homogeneous,[2] but converge to a common claim that continuous growth is incompatible with the finite nature of resources, advocating for reducing or stabilizing material and energy use within ecological limits (Hardt and O'Neill, 2017).

Although an overall economic decline is not a direct claim, the post-growth guidelines might imply slowing down, stabilizing, or even reducing GDP. Hence, post-growth approaches must deal with potential negative socioeconomic impacts. In this respect, the absence of economic growth is particularly critical for developing countries that have not yet attained a certain level of material well-being. This conflictual perspective around economic growth has been referred to in the ecological macroeconomics literature as a 'double-edged sword' (Fontana and Sawyer, 2016)

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[1] The former states that the mass of the outputs must be equal to the mass of inputs, suggesting non-substitutability between material and non-material inputs. The latter implies that production is irreversible, rejecting the neoclassical assumption of malleable capital and highlighting the importance of path dependence (Kronenberg, 2010).

[2] See Kallis et al. (2012) for a differentiation among the strains of post-growth literature.

and 'the twin problem of global dependencies' Gräbner-Radkowitsch and Strunk (2023), the latter explicitly addressing degrowth and the Global South.

This challenge faced by post-growth approaches highlighted the need for a macroeconomic framework to evaluate the aggregate socioeconomic effects of their proposals, paving the way for the emergence of ecological macroeconomics literature. Ecological macroeconomics aims to create robust analytical and empirical simulation frameworks to analyze the conflict between the social imperative of growth and biophysical constraints, understand the interactions between the economy and the environment on a macro level, and provide strategies for transitioning to a sustainable economy (Rezai et al., 2013; Hardt and O'Neill, 2017).

Hence, rejecting the existing mainstream approaches to integrate macroeconomic and environmental processes, the ecological macroeconomics literature emerges as a synthesis of ecological economics and post-Keynesian approaches (Hardt and O'Neill, 2017). Despite being accused by ecological economists of historically neglecting environmental issues (Daly, 2007), the post-Keynesian compatibility with the thermodynamic principles – due to the path-dependency and non-substitutability between production inputs – and the assumptions of fundamental uncertainty, the rejection of the notion of rational agents, the endogenous money creation, and the existence of involuntary unemployment, make the framework well-suited to complement – and be complemented by – ecological economics to address socio-economic-environmental relations (Fontana and Sawyer, 2016; Victor and Jackson, 2020).[3]

Reflecting the field's interdisciplinarity and pluralism, the ecological macroeconomics literature models are eclectic (Hardt and O'Neill, 2017; Jacques et al., 2023). As an attempt to define the scope of ecological macroeconomics, Hardt and O'Neill (2017, p. 208) identify one strain in the literature that focuses more on integrating ecological aspects into an existing macroeconomic framework without necessarily redefining the goals of the macroeconomy (Taylor et al., 2016). Meanwhile, a broader approach to ecological macroeconomics involves developing an extensive framework to comprehensively tackle the social, economic, and ecological dimensions (Jackson et al., 2014). Consequently, the visions of economic growth are not homogeneous, and not all works in the field adhere integrally to the post-growth principles.

Rather than delving into the normative debate about whether growth is desirable, this work engages with the positive side of the discussion, precisely acknowledging that growth is ultimately inherent in capitalist economies. Consequently, growth models remain relevant in the literature and should be adapted to embody envi-

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[3] See Saes and Romeiro (2019) for an extensive methodological review of the foundations of the ecological macroeconomics framework.

ronmental relations and address aspects of the ecological transition. Recognizing the contentious aspects of economic growth, a more nuanced approach is adopted towards the notion – initially proposed by ecological economists (Kronenberg, 2010) and reflected in post-growth theories – that growth no longer enhances welfare globally. This stance does not promote 'growth-mania' (Fontana and Sawyer, 2016) but recognizes that the relevance of economic growth cannot be neglected, particularly for low-income countries facing high unemployment. Therefore, this work aims to build an analytical model to address the transition to a low-carbon economy by integrating the energy sector into a demand-led growth framework, interplaying demand-driven dynamics and energetic supply constraints.[4]

Given the high uncertainty surrounding the investments needed to decarbonize the economy and the urgency of the climate crisis, the State emerges as a potential agent for planning and coordinating efforts to mobilize the economy toward a low-carbon transition (Feijo et al., 2023). The green transition that requires a large volume of investments with high risk and uncertain return, which discourage private investments and call attention to the limitations of relying majorly on market-based mechanisms. Therefore, on the growth side, we build on the mission-oriented innovation approach (Mazzucato, 2018; Deleidi and Mazzucato, 2021) and propose a Sraffian supermultiplier model with two autonomous demand sources, namely business as usual and green innovation government expenditures.

Among the twenty-two ecological macroeconomics articles surveyed in Hardt and O'Neill (2017), there are only two where the energy sector is modeled, precisely in the supply-driven growth models developed in D'Alessandro et al. (2010) and Bernardo and D'Alessandro (2016). Since then, a few eco-SFC models considered the energy transition from fossil fuel to renewable energy (Dafermos et al., 2017; Carnevali et al., 2024), although the energy production sector was overlooked (see Jacques et al. (2023)). Usually, the models within the ecological macroeconomics literature that integrate the environment do so by including energy, resources, or waste as proportional to the total output of the economy given some exogenous intensity parameter (Hardt and O'Neill, 2017).[5]

Building on the energy sector modeled in Bernardo and D'Alessandro (2016), a step forward is taken by embodying renewable energy production in the growth model, allowing the changes in the composition of total energy from renewable and

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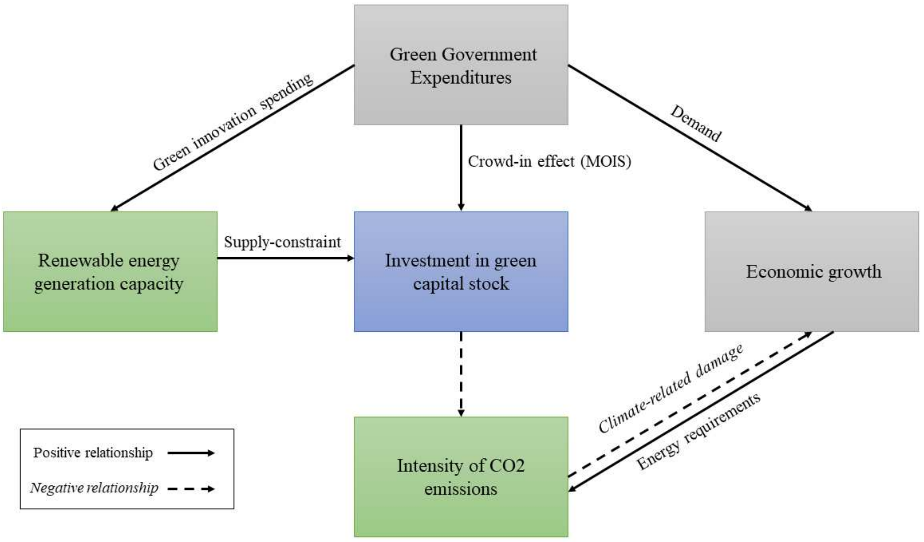
[4] The necessity of interplaying demand-led and supply-constrained in ecological macroeconomics analytically solvable models is stressed in Hardt and O'Neill (2017, p. 134).

[5] Here, it refers specifically to analytical models. Integrated Assessment Models (IAM) such as MEDEAS (Capellán-Pérez et al., 2020), E3ME (Econometrics, 2022), and the EUROGREEN (D'Alessandro et al., 2020), are simulation models that rely on a different approach (see Nieto et al. (2020, p. 2).

fossil sources to be determined endogenously. Simultaneously, renewable energy availability is integrated into the green investment function, representing a supply constraint to green capital stock accumulation. Therefore, the growth dynamics are demand-driven, but the feasibility of the ecological transition is supply-constrained. Moreover, it is noteworthy that two post-growth policy themes are integrated as elements of the model.[6] First, we relate the economic side of the model with the ecosystem and interact it with environmental limits. Second, by disaggregating the energy sector production between renewable and fossil fuel sources, we incorporate the ability of industries to produce goods with different environmental impacts. Figure 2.1 presents a simplified diagram that illustrates the model's primary relationships.

Figure 2.1: Simplified model diagram



As the next section demonstrates, a valuable feature of the green investment function introduced in this article is its ability to allow changes in the composition of the capital stock while preserving aggregate investment determination. For this reason, the mechanism is not limited to the Sraffian supermultiplier model, and it is also compatible with alternative demand-led growth models, enabling them to address the energy transition, incorporate environmental variables and relationships, and provide insights into pathways for sustainable development.

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[6] See Table 2 in Hardt and O'Neill (2017, p. 202) for a summary of post-growth policy themes potentially incorporated into models within the ecological macroeconomics literature.

2.3 The model

Consider a closed two-sector economy that produces, with a given technology,[7] one single final good and energy as an intermediary good. We employ a Leontief production function with capital (K) and energy (E) as inputs, which, by definition, assumes no substitutability between factors – an approach consistent with the thermodynamic principles discussed in the previous section. We assume that there is no labor scarcity, so it is never a constraint to production. The production function is presented in the Equation 2.1.

$$Y^{(K,E)} = \min\left(\frac{K}{v}, \frac{E}{\varepsilon}\right) \tag{2.1}$$

Where v denotes the capital-output ratio and ε is the energy intensity of output. Both are treated as fixed exogenous parameters, as technical progress is not addressed. Firms can produce either with brown or green capital, which differ based on the source of energy they use, respectively fossil and renewable energy.

2.3.1 Growth side

The structure of the growth dynamics follows a standard Sraffian Supermultiplier model in discrete time. In our model, autonomous demand (Z) is composed of two kinds of non-capacity-creating government expenditures, while the induced components are characterized by their respective propensities. The demand components are described by the equations from 2.2 to 2.8.

$$Y_t = G_t + C_t + I_t + I_t^R + I_t^Q \tag{2.2}$$

$$G_t = G_t^{bau} + G_t^{gr} = Z_t \tag{2.3}$$

$$C_t = c_t Y_t \tag{2.4}$$

$$I_t = h_t Y_t \tag{2.5}$$

$$I_t^R = e_t Y_t \tag{2.6}$$

$$I_t^Q = q Y_t \tag{2.7}$$

$$Y_t = \frac{1}{1 - c_t - h_t - e_t - q} Z_t = \alpha_t Z_t \tag{2.8}$$

Where Eq. 2.2 describes the equilibrium in the goods market, given by the equality between the output Y and aggregate demand; Eq. 2.3 denotes the gov-

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[7] For the sake of simplicity, it is assumed that there is no technical progress.

ernment expenditures (G_t) and, consequently, autonomous demand (Z_t) as the sum of 'business-as-usual' (G_t^{bau}) and 'green' government expenditures ($G_t^g r$); Eq. 2.4 indicate the propensity to consume (c_t); Eq. 2.5 stand for the propensity to invest in the final sector (h_t); given that it is a two-sector model, we account for the investment in the energy sector, where Eq. 2.6 specifies the propensity to invest in the renewable energy (e_t) and Eq. 2.7 the exogenously given propensity to invest in fossil energy (q); finally, Eq. 2.8 expresses output in terms of the supermultiplier (α) and autonomous demand (Z).[8]

The potential output (Y_t^K) (Eq. 2.9) is the level of output at full capacity, depending on the capital stock (K_t) and on the fixed capital-output ratio (v), since there is no substitution between production inputs. So, the current capacity utilization level (u_t) is given by the ratio between Y_t and Y_t^K (Eq. 2.10).

$$Y_t^K = \left(\frac{1}{v}\right) K_t \tag{2.9}$$

$$u_t = \frac{Y_t}{Y_t^K} \tag{2.10}$$

Next, we can introduce the main relations of the Sraffian supermultiplier model, which are described by the equations from 2.11 to 2.13.

$$\hat{h} = \gamma \left(u_{t-1} - u_n\right) \tag{2.11}$$

$$g_t^K = \frac{h_{t-1}}{v} u_{t-1} - \delta \tag{2.12}$$

$$\hat{u} = \frac{g_y^Y - g_t^K}{1 + g_t^K} \tag{2.13}$$

The rate of change of investment $\hat{h}$ follows the flexible accelerator principle, which posits that whenever the current capacity utilization deviates from the normal level desired by firms (u_n), the propensity to investment slowly adjusts to bring the current capacity back to the target. The mechanism is described in Eq. 2.11, where $\gamma > 0$ is a fixed coefficient indicating the speed at which h responds to deviations

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[8] As showed in Freitas and Serrano (2015b), the model is stable as long as the so-called Keynesian stability condition holds, i.e., the expanded marginal propensity to spend is lower than 1. Therefore, stability requires that $(\bar{c} + \bar{h} + \bar{e} + q) < 1$.

in u_t. The growth rate of capital stock (g_t^K) is given by Eq. 2.12,[9] where δ is the fixed depreciation rate. Finally, Eq. 2.13 indicates the rate of change in capacity utilization ($\hat{u}$).[10]

To adapt the model to tackle the ecological transition, we distinguish capital and investment in the final goods sector into green and conventional (brown) components (Equations 2.14-2.16). Regarding capital, this differentiation hinges solely on the energy source employed. Green capital (K^{gr}) operates on renewable energy, whereas conventional capital (K^c) relies on fossil fuel. For the sake of simplicity, considering that v and ε are fixed parameters, it is assumed that green and conventional capital are technically perfect substitutes, having identical productivity and energy efficiency. This means they share the same capital-to-output ratios and require the same amount of energy to produce one output unit.

$$K_t = K_t^c + K_t^{gr} \tag{2.14}$$

$$K_t = \left[K_{t-1}^c(1-\delta) + I_{t-1}^c\right] + \left[K_{t-1}^{gr}(1-\delta) + I_{t-1}^{gr}\right] \tag{2.15}$$

$$I_t = I_t^c + I_t^{gr} \tag{2.16}$$

Enhancing energy efficiency is undeniably an essential aspect of the transition to a low-carbon economy. However, considering the purposes of this article, although an eventual increase in energy efficiency would reduce the energy required per unit of output, this improvement would not alter the model's underlying constraint: that the availability of renewable energy generation capacity limits green capital accumulation. The same reasoning applies if hybrid capital was considered, i.e., capital capable of operating either with fossil or renewable services. Ultimately, the share of capital effectively operating with renewable energy (green capital) would still be constrained by the availability of renewable energy capacity. Therefore, two simplifying assumptions are adopted for analytical tractability: constant energy

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[9] Eq. 2.12 is obtained from the law of motion of capital, given by: $g_t^K = \frac{K_t - K_{t-1}}{K_{t-1}} = \frac{I_{t-1}}{K_{t-1}} - \delta$. We first divide both terms of the fraction by Y_{t-1}^K. Then, we multiply the numerator by Y_{t-1}/Y_{t-1}, which doesn't imply any changes in its value. We obtain the following expression: $\frac{I_{t-1}Y_{t-1}/Y_{t-1}^K Y_{t-1}}{K_{t-1}/Y_{t-1}^K}$. Finally, we can rewrite I_{t-1}/Y_{t-1}, $Y_{t-1}/Y_{t-1}^K/Y_{t-1}^K$, and K_{t-1}/Y_{t-1}^K respectively as h_{t-1}, u_{t-1} and v.

[10] To obtain Eq. 2.13 we depart from $\hat{u} = \left(u_t - u_{t-1}\right)/u_{t-1}$. By substituting u as given by Eq. 2.10 and rearranging, we obtain: $\frac{Y_t Y_{t-1}^K}{Y_t^K Y_{t-1}} - 1$. Then, we substitute Y_t/Y_{t-1} and Y_{t-1}^K/Y_t^K respectively by $1 + g_t^Y$ and $1/(1 + g_t^{Y^K})$ and simplify the expression. Finally, since the capital-output ratio v is constant, we replace the growth rate of potential output by the growth rate of capital to obtain Eq. 2.13.

efficiency and the absence of hybrid capital stock. Future versions of the model, however, could incorporate these potential improvements.

Recall that Eq. 2.16 represents the investment in the final sector, while the investment in the energy sector is described in Eq. 2.6 and 2.7. The decomposition of capital and investment does not alter the aggregate behavior of total investment, as defined in Eq. 2.11, or the total capital growth rate, as in Eq. 2.12, but rather allows for changes in its composition shares, which enables the model to consider aspects regarding the ecological transition explicitly. The changes in composition stem from the green investment (I^{gr}) equation, while the conventional investment (I^c) is residual, accounting for the portion of total investment not allocated to green investment. The equations will be introduced in the next section.

Given that we have two sources of autonomous demand, Eq. 2.17 introduces σ as the share of government expenditures in green innovation over total government expenditures. Eq. 2.18 gives the growth rate of autonomous demand, which is precisely the growth rate of government expenditures.[11]

$$\sigma_t = \frac{G_t^{gr}}{G_t} = \frac{G_t^{gr}}{Z_t} \tag{2.17}$$

$$g_t^Z = \sigma_{t-1} g^{G^{gr}} + (1 - \sigma_{t-1}) g^{G^{bau}} \tag{2.18}$$

We assume that public expenditures are financed out of public debt, although the financial side of the economy is not explicitly addressed in this study. However, public debt's growth rate converges with government expenditures' growth rate. Pariboni (2016) presents formal proof for an analogous case in which it is shown that the growth rate of autonomous consumption tends to coincide with the growth rate of consumer debt (Pariboni, 2016, p. 225). In our model, this means that the debt-to-output ratio is stable in equilibrium.[12] In models with a second source of autonomous demand besides government expenditures, the long-run stability of the

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[11] Although in our model the autonomous demand (Z) is represented solely by government expenditures (G), we use the notation Z to follow the pattern in the literature and clarify that the properties discussed apply to autonomous expenditures in general, regardless they consist solely of government expenditures, as in our case, or different sources.

[12] For a very plain exposition, consider that the stock of public debt (B) is described by $B_t = B_{t-1} + G_t$. For simplicity, we proceed with the algebraic steps in discrete time, where the evolution of B is described as $\dot{B} = G$. Dividing both sides by B, we obtain that $\frac{d\hat{B}}{dt} = \hat{B}\left(g^G - \hat{B}\right)$. This equation describes that the growth rate of B changes whenever it is different from the growth rate of government expenditures. If $g^G > \hat{B}$, we have that $\frac{d\hat{B}}{dt} > 0$, meaning that the growth rate of B increases until it converges to g^G. The same holds if $g^G < \hat{B}$, as $\frac{d\hat{B}}{dt} < 0$ and the growth rate of B decreases until it converges to g^G. Therefore, in equilibrium, $g^G = \hat{B}$ and the debt-to-output ratio is stable. The dynamics still holds for more complex debt equations, including taxes and interest rate, for example.

debt-to-output ratio requires that the equilibrium growth rate is higher than the interest rate and that both autonomous expenditures do not grow persistently at different rates (Freitas and Christianes, 2020; Morlin, 2022).

Finally, we outline the energy and ecological-related variables on the growth side of the model by determining the propensities to consume c_t (Eq. 2.19) and to invest in renewable energy sector e_t (Eq. 2.21).

$$c_t = p_c(1 - D_t) \tag{2.19}$$

$$\Delta c_t = p_c(D_{t-1} - D_t) \tag{2.20}$$

$$e_t = e_{t-1} + \Delta e_t \tag{2.21}$$

$$\Delta e_t = e_{t-1}\left(g^{G^{gr}}_{t-1} - g^{Z}_{t-1}\right) \tag{2.22}$$

Where p_c is a fixed propensity to consume which is affected negatively by D_t, a damage coefficient between 0 and 1. As described in Eq. 2.20, the propensity to consume is assumed to be sensitive to climate-related damages which is a function of the atmospheric temperatures. In response to these damages, households may act cautiously, leading to a higher propensity to save (Dafermos et al., 2017). The damage function will be described in the next section. Equations 2.21 and 2.22 show that the propensity to invest in the renewable energy sector increases if the government adopts a more aggressive ecological policy by increasing green expenditures' growth ($g^{G_t^{gr}}$) beyond the growth trend of the economy, represented by g^Z. It signals to the private sector its intention to accelerate the expansion of renewable energy capacity and guide the economy towards greener production. Therefore, aligned with the mission-oriented innovation spending, it generates a crowd-in effect, captured by increasing the private sector's propensity to invest in renewable energy capacity. As shown in the World Energy Investment Report (IEA, 2024a), the rise in government spending to tackle climate change and policies promoting the adoption of low-emission technologies have been inducing corporate spending on energy R&D. Since 2019, this spending has grown by an average of 7% per year, more than three times faster than global GDP (IEA, 2024a, p. 163).

2.3.1.1 The fully adjusted position

Before outlining the model's convergence to the fully adjusted position, we emphasize that the dynamics of the variables outside of equilibrium reveal more about the underlying processes of the ecological transition, beyond just the long-run equilibrium values. Accordingly, in Section 4, we conduct a numerical simulation to explore these transitional behaviors. Nonetheless, the convergence to the fully adjusted position ensures the stability of the framework, allowing the transitional dynamics to be meaningfully analyzed.

In the standard Sraffian supermultiplier model, the fully adjusted position is achieved when the capacity utilization converges to the normal rate desired by firms ($u_t = u_n$), stabilizing the propensity to invest ($\Delta h = 0$) and consequently the level of capacity utilization itself ($\Delta u = 0$). Since, in equilibrium, the output growth is the autonomous demand growth, a persistently stable growth of autonomous demand is required to obtain the fully adjusted position of the model (Freitas and Serrano, 2015b). In a version with two sources of autonomous demand, this condition requires that both expenditures grow at the same rate (see Morlin (2022)). If the growth rates of two sources of autonomous demand differ persistently, σ will tend toward 0 or 1. Therefore, the fully adjusted position requires a constant ratio between the autonomous expenditures ($\Delta\sigma = 0$).

Since we are dealing with two types of government expenditures, it is reasonable to assume that neither will disappear. The divergence in growth rates for each type of expenditure is significant for the analysis, as they lead to different long-run equilibrium paths. However, we consider this variation as a temporary policy measure, assuming that the government sets a single long-run growth rate for its spending, ensuring that both G^{bau} and G^{gr} will ultimately grow at the same pace and σ stabilizes.

Moreover, recalling Eq. 2.8, the output growth will converge to the autonomous demand growth only when the propensities that compose the supermultiplier α are constant.[13] Besides h that was already discussed, we have two additional endogenous variables c and e. In sum, the convergence to the fully adjusted position requires that $\Delta u = \Delta h = \Delta\sigma = \Delta c = \Delta e = 0$.

Regarding e, Eq. 2.22 shows that $\Delta e = 0$ when $g^{G^{gr}} = g^{Z}$, which is precisely the condition that stabilizes σ. In this case, the private investment in renewable energy sector simply follows the output and the propensity e remains constant. Finally, as of c, Eq. 2.20 shows that the propensity to consume is stable when the damage coefficient D is constant. The conditions to meet this requirement will be discussed

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[13] See Appendix B for the derivation of output growth.

in the environment subsection.

2.3.2 Energy sector

We build upon the work of Bernardo and D'Alessandro (2016) to model the energy sector with a specific focus on renewable energy production capacity. Their macroeconomic framework analyzes the impacts on employment and inequality of various strategies for reducing carbon emissions, including the expansion of renewable energy capacity.

Equation 2.23 represents the equilibrium in the final energy sector. On the supply side, the total energy flow available (E_t) consists of the fossil energy flow (X_t) and the renewable energy flow (L_t). On the demand side, total energy required for production is the product of output (Y) and energy intensity coefficient, denoted by the fixed parameter ε. The energy intensity measures the energy needed to produce one unit of output and is typically expressed in kilowatt-hours per dollar.

$$E_t = X_t + L_t = Y_t \varepsilon \tag{2.23}$$

In our model, we assume that the economy's intermediary sector, precisely the energy production sector, produces its own energy requirements. In this sense, the capital in the intermediary sector consumes part of the energy it produces. The relation between the net energy output and energy input throughout the energy production process is evaluated by the concept of energy-return-to-investment (EROI). The EROI is a ratio between the net energy produced and the energy invested directly and indirectly in the process (Eq. 2.24).

$$EROI = \frac{\text{net energy output}}{\text{energy input}} \tag{2.24}$$

Recent estimations suggest that the final stage EROI of fossil fuels and renewables ranges within overlapping intervals (Brockway et al., 2019). So, for simplicity, we assume they are equal. Considering that the net energy output of fossil and renewable energies is given respectively by X and L, we define the energy consumed in the intermediary sector in equations 2.25 and 2.26.

$$X^{int} = \frac{X}{EROI} \tag{2.25}$$

$$E^{int} = \frac{E}{EROI} \tag{2.26}$$

Therefore, E can be understood as a net energy production, which is also the energy available for the final sector. Still, the energy consumed in the intermediary sector will be taken into account to address pollutant emissions.[14]

Since the shares of fossil and renewable energy within total energy are determined by the capital composition, we first have to define the amount of energy required by the operating capital stock. By playing with equations 2.10, 2.9 and 2.23, we can express both the capital stock (K) and energy (E) in terms of output (Y). Starting with Eq. 2.10, we isolate Y_t to arrive at $Y_t = u_t Y_t^K$. Substituting Y_t^K with its expression from Eq. 2.9 results in $Y_t = \frac{u_t K_t}{v}$. Similarly, isolating Y_t in Eq. 2.23 gives $Y_t = \varepsilon E_t$. Since both equations are expressed in terms of Y_t, equating them leads to $\frac{E_t}{\varepsilon} = \frac{u_t K_t}{v}$. Finally, by isolating E_t, we obtain Eq. 2.27, which represents the total energy demanded by the capital stock, considering the level of capacity utilization.

$$E_t = \frac{u_t \varepsilon}{v} K_t \tag{2.27}$$

Since green and conventional capital are technically perfect substitutes,[15] Kt can be decomposed into green and conventional capital components (as expressed in Eq. 2.15). This allows us to explicitly calculate the renewable and fossil energy required for production, given by equations 2.28 and 2.29, respectively.

$$L_t = \frac{u_t \varepsilon}{v} K_t^{gr} \tag{2.28}$$

$$X_t = \frac{u_t \varepsilon}{v} K_t^{c} \tag{2.29}$$

The fossil energy flow is treated as a residual variable in the model, so it adjusts to meet the technical efficiency of production ($X_t = Y_t \varepsilon - L_t$). In sum, the composition of investment alters the share of green and conventional capital, thereby determining the composition of energy consumed. The flows of renewable and fossil energy are limited to R_t and Q_t, their respective production capacities during the period, as shown in Eq. 2.30 and Eq. 2.31.

$$L_t = l R_t \tag{2.30}$$

$$X_t = x Q_t \tag{2.31}$$

Where l and x are coefficients ranging between 0 and 1. Since fossil fuel energy is treated as a residual variable, we assume that Q_t will consistently meet the demand

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[14] Following Brockway et al. (2019), we assume a final stage EROI of 6:1.

[15] We assume that the target capacity utilization is identical for both types of capital. For simplicity, we also consider their current capacity utilization rates to be equal.

for fossil energy. While we acknowledge the finite nature of fossil fuel reserves, our model does not address this aspect as we do not intend to analyze pathways for resource-constrained growth; rather, our focus is on pathways for a transition constrained by the availability renewable energy.

Hence, the underlying principle of the model is that the structural shift from conventional to green capital and, consequently, the ecological transition is limited by the availability of renewable energy. Since in our model firms demand renewable energy (L) to fuel their green capital stock, the accumulation of the latter is constrained by the renewable energy capacity generation (R), whose accumulation function is adapted from Bernardo and D'Alessandro (2016) and described as follows.

$$R_t = R_{t-1} + \left[\left(I^R_{t-1} + rG^{gr}_{t-1}\right) f(R_t)\right] - \delta^R(R_{t-1}) \tag{2.32}$$

$$f(R_t) = \rho_0 + \frac{\rho_1}{1 + e^{-\rho_2(\rho_3 R_{t-1} - \rho_4)}} \tag{2.33}$$

Where r is a parameter between 0 and 1 that determines the share of green government expenditures specifically oriented to innovations to expand the renewable energy capacity. Following the concept of the mission-oriented innovation, the government expenditures in green innovation have a direct effect in expanding the renewable energy capacity, as depicted by the parameter r, and also indirect by generating a crowd in effect in green private investment (recall Eq. 23). Next, δ^R is the depreciation rate of the capacity; and $f(R_t)$ is a logistic function that captures the diffusion of knowledge to the extent that R increases (Eq. 2.33). In sum, it is the ability of investment to actually increase R (Bernardo and D'Alessandro, 2016).

Therefore, increasing the stock of green capital is only possible with sufficient renewable energy capacity, as any incremental unit of green capital beyond the energy generation capacity would be necessarily idle. Thus, this constraint must be embodied in our green investment function. Recalling Eq. 2.30, the flow of renewable energy L is limited by the renewable energy capacity generation R. When $L = R$, it signifies that the flow of renewable energy consumed during the period reaches its maximum potential given the capacity. Then, R represents the maximum supply of renewable energy in the period. Therefore, considering a scenario where $L = R$, substituting L by R in Eq. 2.28 leads to $\frac{u_t \varepsilon}{v} K^{gr}_t = R_t$. Then, by isolating K^{gr}, we obtain the maximum amount of green capital that the renewable energy capacity can accommodate, which we denote as K^{gr}_{max} in Eq. 2.34. In sum, K^{gr}_{max} represents the stock of green capital that would fully utilize the renewable energy capacity, implying that $L = R$.

$$K^{gr}_{max,t} = \frac{R_t v}{u_t \varepsilon} \tag{2.34}$$

The renewable energy supply constraint requires that $\left(\frac{\varepsilon K^{gr}}{uv}\right) \leq R$, ensuring that $0 \leq l \leq 1$.[16] This condition applies when $K^{gr} \leq K^{gr}_{max}$. If, eventually, $K^{gr} > K^{gr}_{max}$, the excess of green capital would be idle due to the lack of availability of renewable energy. Therefore, this constraint (Eq. 2.34) underpins the foundation of the green investment function, which is defined in Eq. 2.35. Since total investment in the final sector (I) is determined following the flexible accelerator principle (recall Eq. 2.11), the investment in conventional capital (I^c) is treated as a residual variable, representing the remainder of total investment not allocated to green investment (Eq. 2.36).

$$I^{gr}_t = \left(K^{gr}_{max,t-1} - K^{gr}_{t-1}\right)\lambda + K^{gr}_{t-1}\delta^{gr} \tag{2.35}$$

$$I^c_t = I_t - I^{gr}_t \tag{2.36}$$

The green investment function (Eq. 2.35) incorporates the spare capacity of renewable energy as both a trigger and a supply-constraint of green investment. The $K^{gr}_{max,t-1}$ is the maximum green capital held by the renewable energy capacity in the previous period, representing the renewable energy supply-constraint. If $K^{gr}_{max,t-1} = K^{gr}_{t-1}$, it means that there was no spare renewable energy capacity in the previous period. Thus, the terms cancel out and the share of green investment will simply be the one that compensates the green capital depreciation $\left(K^{gr}_{t-1}\delta^{gr}\right)$. On the other hand, if the renewable energy capacity was not fully used in the previous period $\left(K^{gr}_{max,t-1} > K^{gr}_{t-1}\right)$, the available margin to expand the stock of green capital increases the green investment. The speed of this adjustment is given by λ, an exogenous coefficient between 0 and 1.

The spare renewable energy encouraging investment in green capital and the treatment of conventional investment as residual embody the assumption that firms have incentives to prefer green capital over conventional capital. In the model, this assumption aligns with the fact that climate change negatively affects consumption through a damage function, implicitly favoring green capital since it is not a pollu-

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[16] If the demand is lower than the capacity $\left(R > \frac{\varepsilon K^{gr}}{uv}\right)$, then $l < 1$. If the demand for renewable energy is equal to the capacity $\left(\frac{\varepsilon K^{gr}}{uv} = R\right)$, then $l = 1$ Finally, if the demand for renewable energy exceeds the capacity, we would have idle green capital. However, it is not the case since the green capital accumulation is constrained by K^{gr}_{max} (see Eq. 2.35).

tant and does not impact the damage. Also, although energy storage is not explicitly addressed, it is taken into account that renewable energy is difficult to store. Hence, any unused capacity is essentially lost, wasting both the energy and the resources invested in expanding renewable energy capacity, represented by I^R in the model (see Eq. 2.6). Additionally, this assumption is supported by real-world legislation aligned with ecological transition objectives. For example, the European Union (EU) Renewable Energy Directive 2023/2413 prioritizes using renewable energy over fossil fuels.

2.3.2.1 The fully adjusted position

As previously emphasized, the decomposition of capital and investment into conventional and green categories does not alter the aggregate behavior of total investment and the capital accumulation rate. Similarly, including the energy sector does not alter the equilibrium and stability conditions of the model, as the energy variables converge to the exogenous growth rate set by the autonomous demand growth rate.

Regarding the renewable energy capacity R, once $f(R)$ reaches its maximum value and becomes constant, the rate of accumulation of R depends solely on the growth rate of both public and private investment in renewable energy capacity, expenditures whose growth rate converge to the autonomous demand growth rate (see section 2.3.1.1). In sum, when the rate of accumulation of R stabilizes, the entire energy side of the model converges to equilibrium.

Since the growth rate of K^{gr}_{max} depends on R, it also converges to the autonomous demand growth rate. Recalling Eq. 2.35, the green investment I^{gr} depends on K^{gr}_{max} and K^{gr}. However, since we have two K^{gr} terms with opposite signs, $-\lambda K^{gr}$ and $\delta^R K^{gr}$, the contributions to growth cancel out, resulting in $g^{I^{gr}} = g^{K^{gr}_{max}} = g^Z$. Consequently, since in the long run $\Delta h = 0$ and total investment is fully induced, we have that $g^{I^{gr}} = g^I$ and the share of green investment stabilizes.

Finally, this implies that the accumulation rate of green capital K^{gr} and, subsequently, the growth rate of renewable energy consumption L, also converge to g^Z. Thus, the share of green capital and, consequently, the share of renewable energy consumption out of total energy stabilize.

2.3.3 Environment

Once the energy sector was integrated to the growth model, we can address the ecological relations by introducing the environmental variables. We define pollution as function of carbon emissions (Eq. 2.37).

$$P_t = \phi \left(X_t + X_t^{int} \right) \tag{2.37}$$

Where ϕ is an exogenous parameter indicating the carbon emission by unit of fossil energy used in production. Recall that X_t is the fossil energy flow consumed in the final sector and X_t^{int} is the energy consumption in the intermediary sector Eq. 2.25, as the capital in the intermediary sector consumes part of the energy it produces. The consumption of renewable energy, L, is naturally non-polluting as it produces no waste or harmful emissions. Moreover, since the intermediary sector generates its own energy requirements, the renewable energy production is assumed as non-polluting in the model.

Pollutant emissions are the main driver of climate change, which, in our model, affects negatively the economic output through a harmful effect in household consumption. The effect was introduced in Eq. (20), where the determination of the propensity to consume was described as $c_t = p_c(1 - D_t)$. The propensity to consume is assumed to be sensitive to climate-related damages due to the increase in natural disasters, which can cause job losses, property destruction, and health issues driven by climate change. In response to these damages, households may act cautiously, leading to a higher propensity to save (Dafermos et al., 2017).[17] The magnitude of the effect is determined by a damage coefficient D, described in Eq. 2.38.

$$D_t = 1 - \frac{1}{1 + \eta_1 T_t + \eta_2 T_t^2 + \eta_3 T_t^{6.754}} \tag{2.38}$$

As proposed in Weitzman (2012) the function links the damage to the atmospheric temperature over pre-industrial levels (T). The coefficient D ranges between 0 and 1, and the parameters η were calibrated for $D = 0.5$ for an atmospheric temperature of 6º C above pre-industrial levels (Weitzman, 2012). The atmospheric temperature raises due to a higher concentration of CO2 in the atmosphere, so we determine T as a logistic function of pollution (Eq. 2.39).

$$T_t = \frac{\tau_1}{1 + e^{-\tau_2 (P_t \tau_3 - \tau_4)}} \tag{2.39}$$

According to the report *Climate Change 2021* released by the Intergovernmental Panel on Climate Change, the worst-case scenario estimates suggest an annual mean atmospheric temperature between 4°C and 4.8ºC above pre-industrial levels for the year 2100 (Lee et al., 2021, p. 572), which is incompatible with the ecological system. Therefore, the parameter τ_1 assumes the maximum value of T considering

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[17] Besides affecting the propensity to consume, the damage coefficient may also be related to investment decisions and capital depreciation (see Dafermos et al. (2017); Carnevali et al. (2024)).

a worst-case scenario, and τ_2, τ_3, and τ_4 are calibrated to stem an initial value of 1^{o} C, roughly the current level of atmospheric temperatures relative to pre-industrial period.

2.3.3.1 The fully adjusted position

As previously mentioned, the convergence to equilibrium requires a stable propensity to consume, which is achieved under a constant damage coefficient ($\Delta D_t = 0$). According to Eq. 2.38, this condition requires a stable atmospheric temperature (T), which can be achieved either by stabilizing the level of carbon emissions ($\Delta P_t = 0$), or when the atmospheric temperature achieves its maximum value. Therefore, unless the flow of fossil fuel energy stops rising, reaching the atmospheric temperature tipping point of 4.8°C can only be delayed, akin to buying time. Since the pollution is determined by the fossil energy consumed, which instead is function of the conventional capital used in production, the emissions-to-output ratio converge to an equilibrium value since the growth rate of conventional capital tends to coincide with the autonomous demand rate of growth.

2.4 Simulation scenarios and results

The main properties and relationships of the model can be analyzed through numerical simulations. In this study, our primary interest lies in the relative differences among distinct scenarios rather than the absolute values of the variables. Since the model does not rely on real-world data, the absolute values generated are not intended to represent any specific real-world quantities. Instead, these values serve as a means to explore the convergence dynamics and interactions within the model under different conditions. The model's equilibrium robustness is assessed through sensitivity analysis within the dynamic system, using Monte Carlo simulations to introduce random shocks to selected variables, with the results presented in Appendix C. At the same time, we argue that observing the behavior of the variables out of the fully-adjusted position provides more interesting insights than assessing the long-run equilibrium values.

All scenarios depart from a steady-state position, allowing us to isolate the effects of parameter changes in different scenarios.[18] Otherwise, it would be unclear whether variable behaviors result from exogenous shocks or the model's intrinsic convergence

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[18] We temporarily set the atmospheric temperature as fixed to depart from a steady-state position, implying a constant damage coefficient. Since the damage coefficient depends on pollution, and pollution grows at an exogenous rate in equilibrium, the damage coefficient would naturally increase, causing a variation in the propensity to consume and a deviation from the steady-state position.

dynamics. Then, we create different scenarios by imposing shocks in the period t. The different scenarios are described in Table 2.1.

Table 2.1: Simulation scenarios

	Case 1	**Case 2**	**Case 3**	**Case 4**
Name	Baseline	Green G	Green G + low g^*	Case 3 + temporary shock
g^*	0.03	0.03	0.01	0.01
σ_t	-	0.1	0.1	0.1
Temporary shock	-	-	-	$gG^{gr}_{t:t+25} = 0.03$

We denote g^* as the equilibrium growth rate, which is determined by long-term growth rate of autonomous sources of demand, represented in our model by government expenditures. In the baselin/e scenario, we 'activate' the atmospheric temperature function, allowing the damage coefficient to be endogenously determined. Furthermore, we assume the absence of green policy ($\sigma = G^{gr}/G = 0$), characterized by a single business-as-usual government expenditure component. Hence, in the baseline scenario, any short-term deviations from equilibrium are specifically due to the impact of the increasing damage coefficient on consumption.

Based this on the pollution emissions in the baseline scenario, the atmospheric temperature function (Eq. 2.39) was calibrated to achieve 4°C above pre-industrial levels in t+80 periods, accordingly to the worst-case scenario forecasted by the IPCC Lee et al. (2021, p. 572). In our model, since the rate of change of pollutant emissions is greater than zero under all simulated scenarios, slowing down emissions only delays the rise in atmospheric temperature. Eventually, the temperature reaches its maximum value of 4.8°C. Consequently, the lower the rate of change in emissions, the longer it takes for the model to stabilize and converge to its fully adjusted position.

Case 2 introduces G^{gr} with an initial value set at 10 p.p. of total government expenditures ($\sigma_t = 0.1$), which applies to the subsequent scenarios. Case 3 simulates a 'low growth' scenario. The simulation reveals a relatively faster energy transition simply by reducing growth, which is coherent to post-growth approaches and will be discussed in further detail next.

In case 4, we implement a low growth scenario alongside an aggressive green fiscal policy. This involves temporarily accelerating the growth rate of G^{gr} relative to G^{bau}, which remains constant and equal to the economy's long-term trend g^*. The policy spans 25 periods,[19] such that $g^{G^{gr}} > g^{G^{bau}}$ from t to $t + 25$, after which both rates equalize to g^*, ensuring the model converges to the long-run equilibrium. The resulting output growth rates for the different scenarios are depicted in Figure

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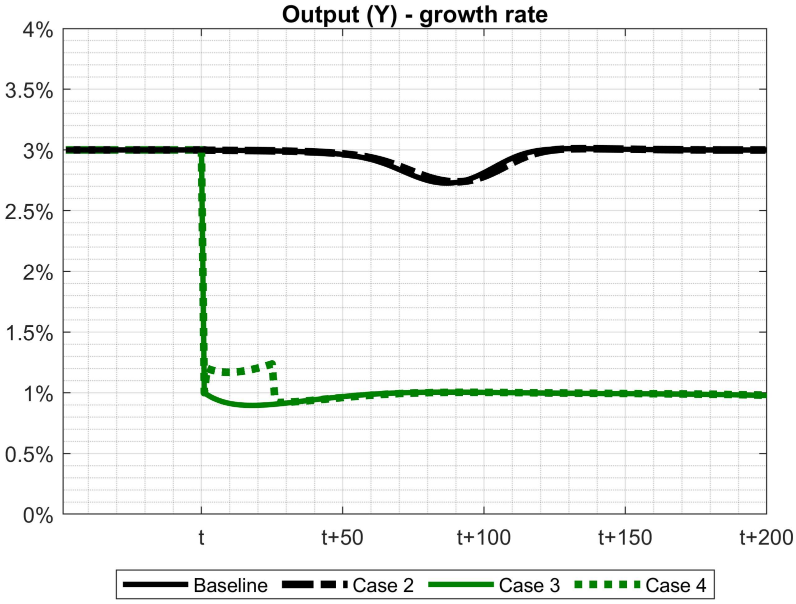
[19] Considering the periods as years, 25-years is the time-horizon for the long-term strategy of the EU Climate Action, which aims to be climate-neutral by 2050.

2.2.

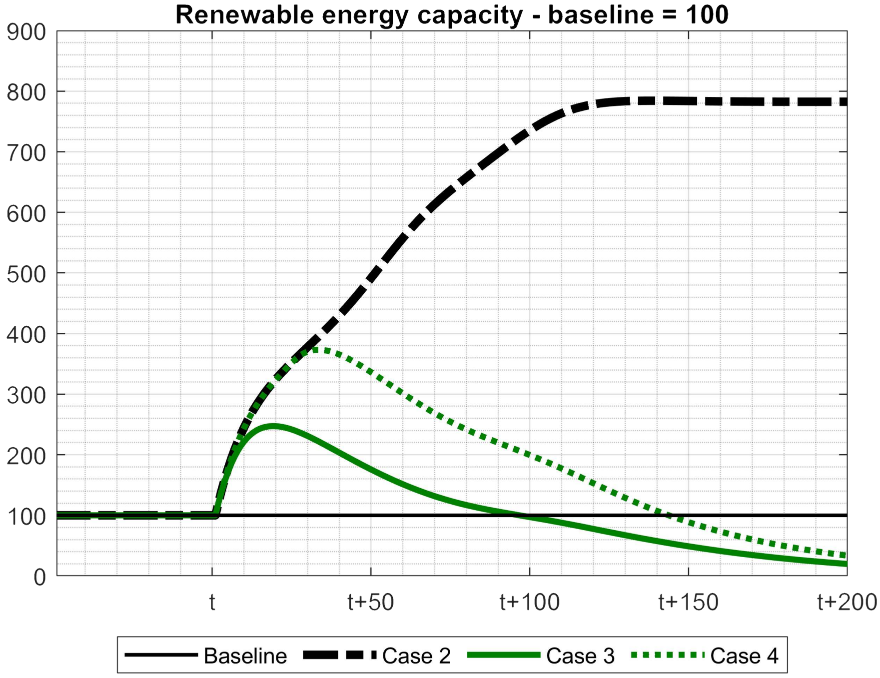
Figure 2.2: Output (Y) - growth rate %



In the real world, there is a significant coupling between resource use and economic activity (Wiedmann et al., 2015). As discussed in Section 2, post-growth approaches emphasize the incompatibility of continuous economic growth with the finite nature of natural resources, advocating for reducing and stabilizing material and energy use within ecological limits. This perspective may entail lowering or stabilizing GDP or, in some cases, allowing it to decline. By simulating ‘high’ and ‘low’ growth scenarios, our model captures the effects of different growth rate levels on the energy transition and resource use.

Recall that, in our model, the transition towards greener production relies fundamentally on the availability of renewable energy, which represents the supply constraint to green capital accumulation. In turn, renewable energy capacity accumulation is a function of public and private investments, implying that the cases with higher output growth rates present also a higher renewable energy capacity accumulation rate, as shown in Figure 2.3.

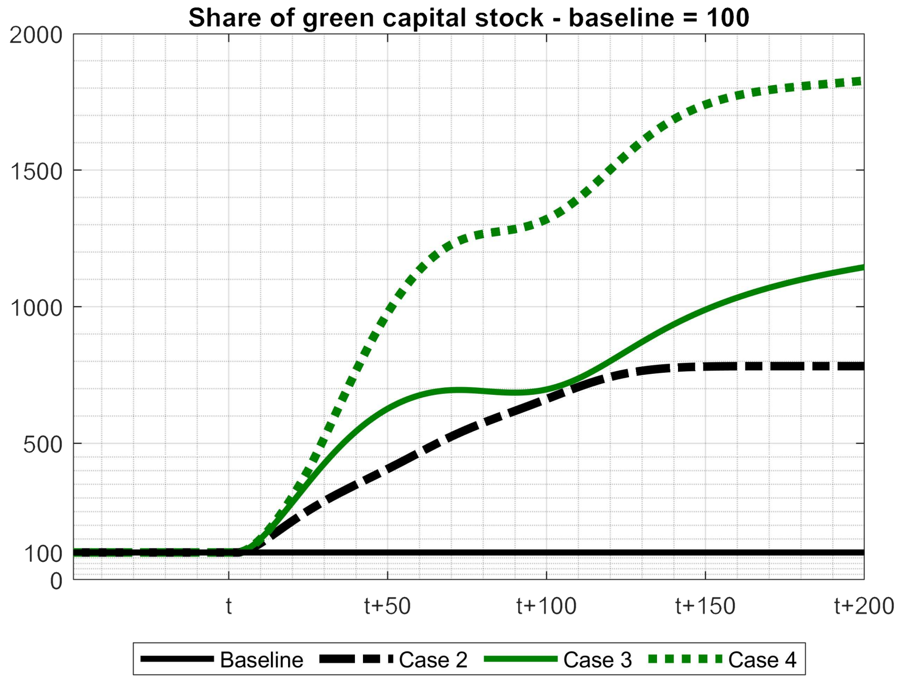
Figure 2.3: Renewable energy capacity generation (R)



We observe the shock in R caused by introducing green government expenditures for cases 2, 3, and 4 in period t. Even without G^{gr}, due to the higher g^*, the accumulation of R stemming from private expenditures I^R (recall Eq. 2.32) in the baseline scenario surpasses both low g^* cases after nearly 150 periods.

However, despite a greater renewable energy capacity in case 2, the simulations indicate that the ecological transition is less feasible in high growth scenarios. As shown in Figure 2.4, cases 3 and 4, characterized by lower growth rates, attain a higher share of green capital stock out of total capital and consequently a higher share of renewable energy consumption.

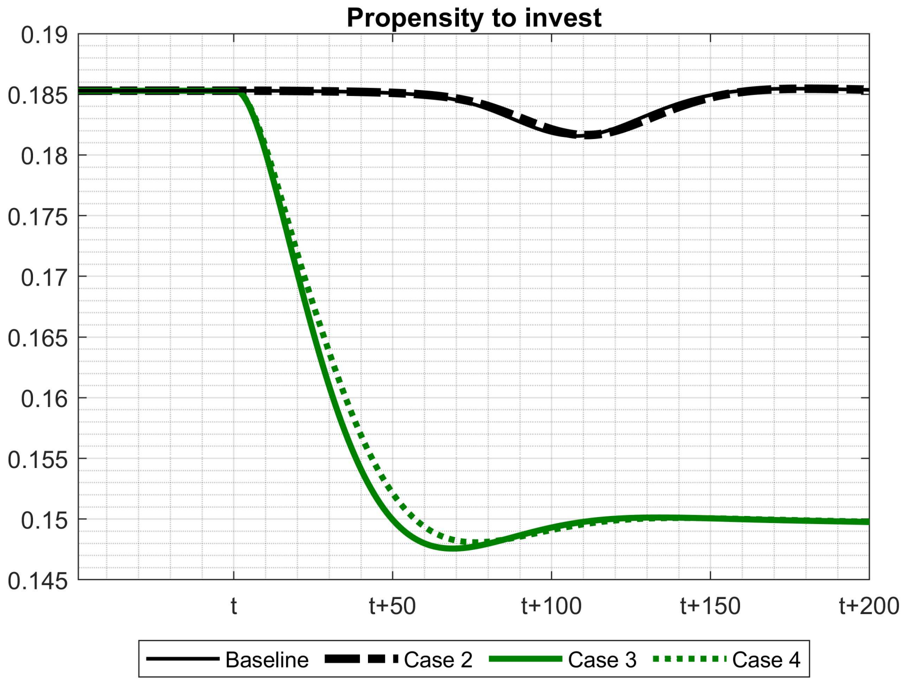
Figure 2.4: Share of green capital stock



This property of the model arises from the renewable energy capacity constraint to green investment. In the simulation, once we introduce G^{gr} in cases 2, 3, and 4, there is a positive shock in the availability of renewable energy capacity, creating room to increase the green capital stock. However, for a given availability of renewable energy capacity, there is a maximum amount of new green capital stock that can be accommodated, setting a limit on green investment (recall Eq. 2.35). Consequently, the higher the total investment, the greater the stock of conventional capital required to complement green investment. Therefore, for a given availability of renewable energy, the share of green investment will be higher the lower the total investment is.

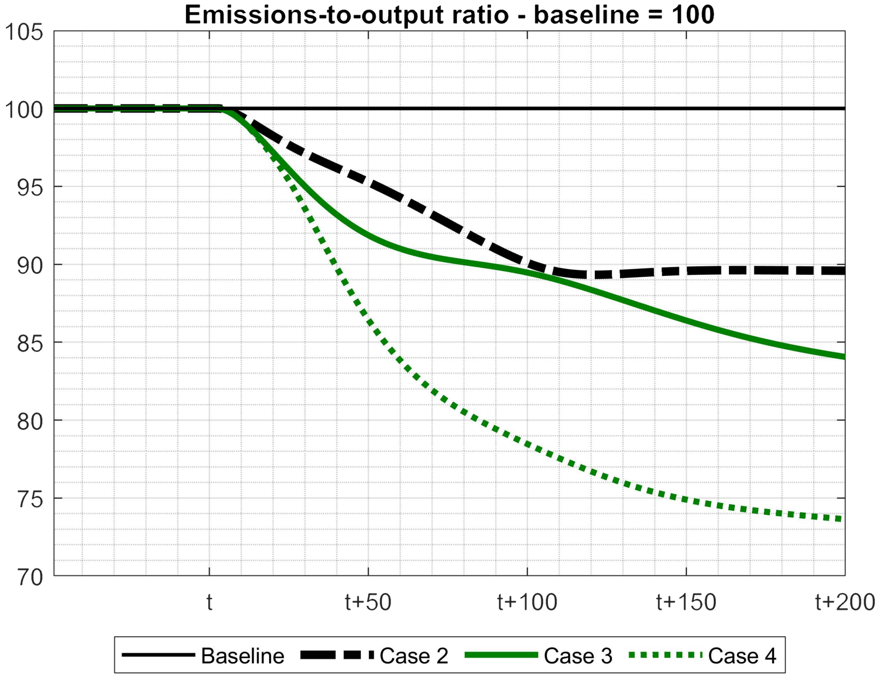
The difference observed between cases 3 and 4 stems from the aggressive green fiscal policy imposed in the latter. Since the growth of G^{gr} exceeds g^* for 25 periods, the renewable energy capacity grows faster than total investment during the policy period, resulting in greater spare renewable capacity in case 4 compared to case 3. Additionally, in cases 3 and 4, the shock from lowering g^* reduces the capacity utilization rate u and, consequently, the propensity to invest h. This is an important outcome of the Sraffian Supermultiplier model, which was empirically validated by Girardi and Pariboni (2020). Figure 2.5 illustrates the evolution of h for the different scenarios.

Figure 2.5: Propensity to invest (h)



The model's intuition is straightforward, as slowing down economic growth effectively buys time to execute the energy transition. The energy transition takes time since the accumulation of renewable energy capacity is not an immediate process. Meanwhile, higher economic growth demands more fossil fuel energy to meet production requirements. This results in a lower share of renewable energy in the energy mix, but ultimately a higher absolute level of fossil energy consumption and consequently higher pollutant emissions. In the model, this aspect is also captured by the emissions-to-output ratio, as depicted in Figure 2.6.

Figure 2.6: Emissions-to-output ratio



In case 4, the relatively higher capacity for transitioning from fossil fuels to renewable energy is also reflected in a lower emissions-to-output ratio compared to the other cases. The scenario simulated in case 4 combines two fundamental aspects for the feasibility of the ecological transition. First, following the concept of the mission-oriented innovation policy of public spending (Mazzucato, 2018), the government expenditures in green innovation play a key role in expanding the renewable energy capacity and generating a crowd in effect in green private investment. Second, the economic growth is slowed down, increasing the feasibility of the energy transition and, consequently, the decoupling between economic growth and emissions.

Therefore, it is important to emphasize that continuous economic growth has negative implications that can hinder or delay the effectiveness of the energy transition in reducing CO2 emissions, aligning with post-growth principles. Since output growth induces also investment in the fossil energy sector, ongoing economic growth sustains investments in fossil fuels. Additionally, it implies that energy demand will continue to rise. Recalling the discussion in Section 2, while improvements in energy efficiency can soften increasing energy needs, efficiency gains cannot increase indefinitely. Even at maximum energy efficiency, any increase in output would still rise energy demand. Consequently, continuous economic growth inevitably expands energy requirements. Given that achieving near-zero CO2 emissions necessitates phasing out fossil fuel consumption, a necessary condition is that renewable energy generation capacity grows faster than overall energy demand. Therefore, the lower the economic growth rate and the faster the increase in renewable energy capacity generation, the more feasible is a rapid transition toward a low-carbon economy.

2.5 Concluding remarks

In recent decades, the ecological macroeconomics literature has expanded to address a broader range of issues. We contribute to this literature by developing an analytical model that integrates the energy sector – and the constraints it imposes on the ecological transition – within a demand-led growth framework. The growth model is connected to the energy sector through a green investment equation, which incorporates a constraint given by the availability of renewable energy and affects investment and capital stock composition. Thus, we developed a framework capable of interplaying demand-driven dynamics and energetic supply constraints. By doing that, we also provide a simple and manageable analytical strategy that can be adapted for other demand-led growth models to address the energy sector constraints, environment-related variables, and the feasibility of the ecological transition.

The simulation results demonstrate that scenarios combining green government expenditures with lower output growth rates achieve a higher share of renewable energy consumption and lower emissions-to-output ratios. Despite scenarios with higher economic growth accumulating greater renewable capacity, the energy transition is hindered. This property of the model arises from the renewable energy capacity constraint to green investment. It implies that for a given availability of renewable energy, the share of green investment will be higher the lower the total investment is. At the same time, continuous economic growth implies a corresponding continuous increase in energy demand. Hence, expanding the renewable energy generation in a low-growth scenario is more conducive to promoting the energy transition. This characteristic is consistent with post-growth perspectives, where slowing economic growth effectively extends the timeframe available for executing the energy transition.

From a political economy perspective, the absence of economic growth is particularly critical for developing countries that have not yet attained a certain level of material well-being. As discussed in Section 2, this conflictual perspective around economic growth has been referred to in the ecological macroeconomics literature as a 'double-edged sword' (Fontana and Sawyer, 2016) and 'the twin problem of global dependencies' (Gräbner-Radkowitsch and Strunk, 2023), the latter specifically addressing degrowth and the Global South.

Moreover, engaging in the ecological transition implies that governments must confront the interests of large and economically significant industries that are heavily carbon-intensive. These industries include those directly related to fossil fuels, such as oil and gas exploration, intensive agriculture and land use, fashion, and transportation. Furthermore, the potentially harmful social impacts of shutting down carbon-intensive industries or simply degrowing the economy in general, such as rising unemployment, must be taken into account.

Appendices

2.A Simulation parameters and initial values

Table 2.A1: Model Parameters and Their Descriptions

Symbol	**Description**	**Value**	**Remarks**
u_n	Normal capacity utilization rate	0.85	Standard in the SSM literature.
pc	Propensity to consume	0.5	Model's baseline scenario.
q	Propensity to invest (fossil energy sector)	0.007	Based on IEA (2024).
γ	Speed of adjustment of investment to changes in the capacity utilization	0.05	Standard in the SSM literature.
v	Capital-output ratio	1.5	Standard in the SSM literature.
δ	Capital depreciation rate	0.075	Standard in the SSM literature.
ϵ	Energy intensity	8	As in Bernardo and D'Alessandro (2016).
r	Share of G^{gr} destined to investments in renewable energy sector	0.5	Model's baseline scenario.
λ	Speed of adjustment of green investment to spare renewable energy capacity	0.05	Assumed as equal to γ.
ϕ	Carbon intensity	1.28	As in Bernardo and D'Alessandro (2016).
EROI	Energy return to investment	6	Adapted from Brockway et al. (2019).
ρ_0	Parameter of $f(R)$	1	Adapted from Bernardo and D'Alessandro (2016).
ρ_1	Parameter of $f(R)$	5	Adapted from Bernardo and D'Alessandro (2016).
ρ_2	Parameter of $f(R)$	0.202	Adapted from Bernardo and D'Alessandro (2016).
ρ_3	Parameter of $f(R)$	$3.56 \cdot 10^{-6}$	Adapted from Bernardo and D'Alessandro (2016).
ρ_4	Parameter of $f(R)$	2.5	Adapted from Bernardo and D'Alessandro (2016).
τ_1	Parameter of atmospheric temperature function	4.8	Maximum value of T^{AT}.
τ_2	Parameter of atmospheric temperature function	0.702	Calibrated for an initial $T^{AT} = 1°C$.
τ_3	Parameter of atmospheric temperature function	$6.08 \cdot 10^{-8}$	Calibrated for an initial $T^{AT} = 1°C$.
τ_4	Parameter of atmospheric temperature function	2.4	Median reference value of T^{AT}.
η_1	Parameter of damage function	0	As in Dafermos et al. (2017).
η_2	Parameter of damage function	0.00284	As in Dafermos et al. (2017).
η_3	Parameter of damage function	0.000005	As in Dafermos et al. (2017).

Table 2.A2: Initial Values

Symbol	**Description**	**Value**	**Remarks**
G	Government expenditures	50,000	Model's baseline scenario
σ	Share of G^{gr}/G	0	For cases 2, 3, and 4, we introduce $\sigma = 0.1$
h	Propensity to invest (final sector)	0.1853	Calibrated for steady state initial value
e	Propensity to invest (renewable energy sector)	0.003	Based in IEA (2024)
u	Capacity utilization	0.85	Calibrated for steady state initial value
K^{gr}/K	Share of K^{gr}	0.01503	Calibrated for steady state initial value
R	Renewable energy capacity	32,828.34	Calibrated for steady state initial value
$f(R)$	Renewable energy capacity logistic function	3.00	Obtained from the given parameters
T^{AT}	Atmospheric temperature above pre-industrial levels	1°C	Obtained from the given parameters
D	Damage coefficient	0.0028	Obtained from the given parameters

2.B Output growth derivation

To derive the output growth equation, we first suppose a simpler version of the Sraffian supermultiplier model for a closed economy Eq. B1. The propensity to consume is fixed, and the only endogenous component in the supermultiplier is the propensity to invest h.

$$Y_t = \frac{1}{1-c-h_t} Z_t \tag{2.B1}$$

To obtain the output growth in a continuous-time system, we compute Eq. B2 by taking the logarithm and derivatives with respect to time t from both sides of Eq. B1:

$$\ln \frac{\partial Y_t}{\partial t} = \ln \frac{\partial Z_t}{\partial t} - \ln \frac{\partial (1-c-h_t)}{\partial t} \tag{2.B2}$$

We know that the log-differences of Y_t and Z_t represent their respective growth rates, g and g^Z. Using the chain rule, we differentiate the term involving h_t as described in Eq. B3.

$$\ln \frac{\partial (1-c-h_t)}{\partial t} = \frac{1}{1-c-h(t)} \left(-\frac{\partial h(t)}{\partial t} \right) \tag{2.B3}$$

Denoting the derivative of h_t with respect to time as $\dot{h}$, we substitute Eq. B3 into Eq. B2 and express the output growth as described in Eq. B4.

$$g = \frac{\dot{h}}{1 - c - h_t} + g^Z \tag{2.B4}$$

Therefore, the output growth (g) is determined by the growth of autonomous demand and changes in the supermultiplier stemming from variations in h.

In discrete time, it is known that if $A_t = B_t C_t$, the growth rate of A_t is determined by the sum of the growth rates of B and C plus the product of their growth rates, such that ($g^A = g^B + g^C + g^B g^C$). We refer to this property as the discrete-time product growth rate rule. Accordingly, the output Y is the product of the autonomous demand Z and the supermultiplier α. Applying this property to calculate the output growth of Y in discrete time, we sum the growth rates of the autonomous and supermultiplier components plus their product. In the next steps, we calculate the growth rate of the supermultiplier component:

$$\hat{\alpha}_t = \frac{\frac{1}{1-c-h_t} - \frac{1}{1-c-h_{t-1}}}{\frac{1}{1-c-h_{t-1}}} \tag{2.B5}$$

The simplified expression of Eq. B5 is shown in Eq. B6.

$$\hat{\alpha}_t = \frac{h_t - h_{t-1}}{1 - c - h_t} \tag{2.B6}$$

To avoid complications stemming from the simultaneous determination between h_t and Y_t, we take advantage of the fact that we know $h_t = \gamma(u_{t-1} - u_n)$ (Eq. 2.11) to rearrange Eq. B6. The numerator can be expressed as $h_t - h_{t-1} = \Delta h_t = h_{t-1}\hat{h}_t$, and h_t in the denominator can be expressed as $h_{t-1}(1 + \hat{h})$. After performing these rearrangements, we obtain Eq. B7:

$$\hat{\alpha}_t = \frac{h_{t-1}\hat{h}_t}{1 - c - h_{t-1}(1 + \hat{h}_t)} \tag{2.B7}$$

Therefore, the growth rate of Y is determined as in Eq. B8:

$$g_t = g^Z + \frac{h_{t-1}\hat{h}_t}{1 - c - h_{t-1}(1 + \hat{h}_t)} + g^Z \left(\frac{h_{t-1}\hat{h}_t}{1 - c - h_{t-1}(1 + \hat{h}_t)} \right) \tag{2.B8}$$

In our model, we instead have three endogenous components in the supermultiplier (recall Eq. 2.8: the propensity to invest in the final sector h, the propensity to consume c, and the propensity to invest in the renewable energy sector e. The derivation of the output growth rate expression, however, follows the same steps. Hence, in continuous time, g_t is determined as in Eq. B9:

$$g_t = g_t^Z + \frac{\dot{h}}{1 - c_t - h_t - e_t - q} + \frac{\dot{c}}{1 - c_t - h_t - e_t - q} + \frac{\dot{e}}{1 - c_t - h_t - e_t - q} \tag{2.B9}$$

Accordingly, in discrete time, we will have a term for each endogenous component in the supermultiplier. Recall that from Eq. 2.19 we know that $\hat{c}_t = \frac{p_c(D_{t-1} - D_t)}{c_{t-1}}$ and from Eq. 2.21 we know that $\hat{e} = g^{G^{gr}_{t-1}} - g^{Z_{t-1}}$. To simplify the notation, we denote $\hat{\alpha}^h$, $\hat{\alpha}^c$, and $\hat{\alpha}^e$ as the respective terms for each component, as described in equations B10, B11, and B12:

$$\hat{\alpha}_t^c = \frac{c_{t-1}\hat{c}_t}{1 - c_{t-1}(1 + \hat{c}_t) - h_{t-1}(1 + \hat{h}_t) - e_{t-1}(1 + \hat{e}) - q} \tag{2.B10}$$

$$\hat{\alpha}_t^h = \frac{h_{t-1}\hat{h}_t}{1 - c_{t-1}(1 + \hat{c}_t) - h_{t-1}(1 + \hat{h}_t) - e_{t-1}(1 + \hat{e}) - q} \tag{2.B11}$$

$$\hat{\alpha}_t^e = \frac{e_{t-1}\hat{e}_t}{1 - c_{t-1}(1 + \hat{c}_t) - h_{t-1}(1 + \hat{h}_t) - e_{t-1}(1 + \hat{e}) - q} \tag{2.B12}$$

Following the discrete-time product growth rate rule, we can calculate the output growth g as the sum of the rates of change of each component plus their cross-products. Finally, g is determined in Eq. B13:

$$\begin{aligned} g_t = g_t^Z + \hat{\alpha}_t^c + \hat{\alpha}_t^h + \hat{\alpha}_t^e + g_t^Z(\hat{\alpha}_t^c + \hat{\alpha}_t^h + \hat{\alpha}_t^e) + \hat{\alpha}_t^c(\hat{\alpha}_t^h + \hat{\alpha}_t^e) + \hat{\alpha}_t^h\hat{\alpha}_t^e \\ + g_t^Z(\hat{\alpha}_t^c\hat{\alpha}_t^h + \hat{\alpha}_t^c\hat{\alpha}_t^e + \hat{\alpha}_t^h\hat{\alpha}_t^e) + \hat{\alpha}_t^c\hat{\alpha}_t^h\hat{\alpha}_t^e + g_t^Z\hat{\alpha}_t^c\hat{\alpha}_t^h\hat{\alpha}_t^e \end{aligned} \tag{2.B13}$$

2.C Sensitivity analysis

To evaluate the robustness of the model's long-run equilibrium, we conduct a sensitivity analysis by randomly varying four key parameters within a range of 50% above and below their baseline values. The parameters are: i) the government expenditures growth rate (g^G); ii) the initial share of green government expenditures out of total government expenditures (σ), iii) the share of green government expenditures oriented to expand renewable energy capacity (r); and iv) the speed of adjustment of green investment to spare renewable energy capacity (λ).

The results indicate that the output growth rate, capacity utilization level, and investment propensity converge to a steady-state long-run equilibrium. On the environment side, the share of green capital and the emission-to-output ratio also converge in the long run, although the different parameter value combinations lead to distinct outcomes with respect to the feasibility of the energy transition. The results of the Monte Carlo simulations are summarized in the figures below.

Figure 2.C1: Sensitivity analysis - Output growth rate

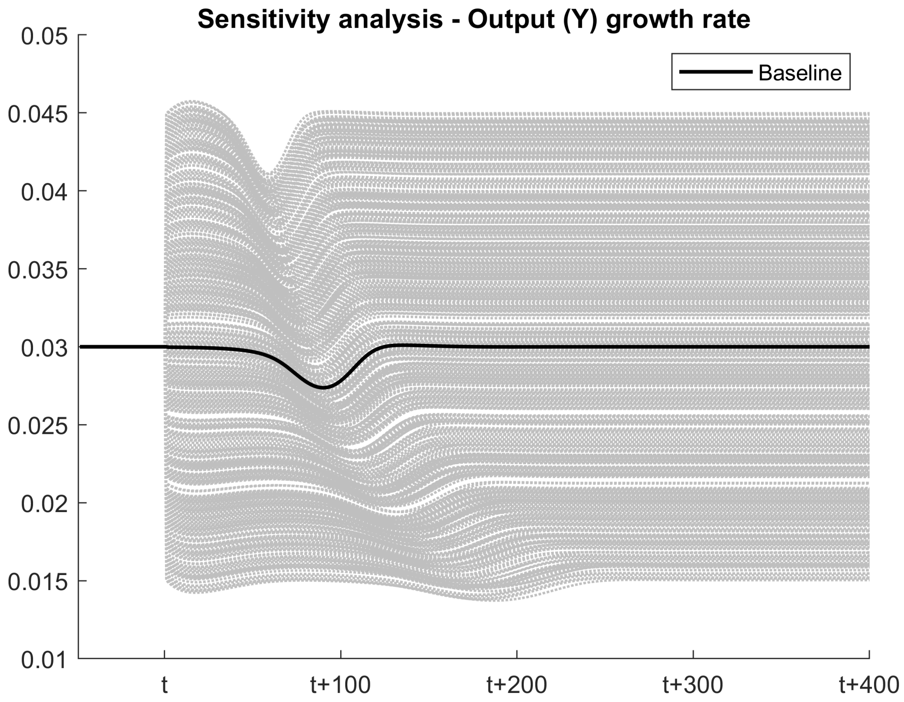


Figure 2.C2: Sensitivity analysis - Capacity utilization

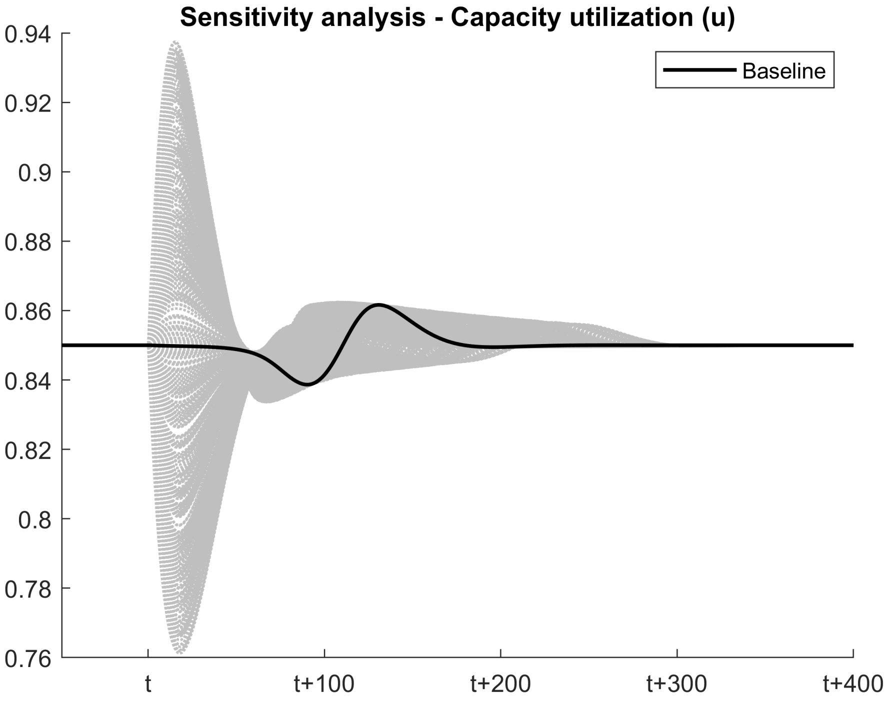


Figure 2.C3: Sensitivity analysis - Propensity to invest

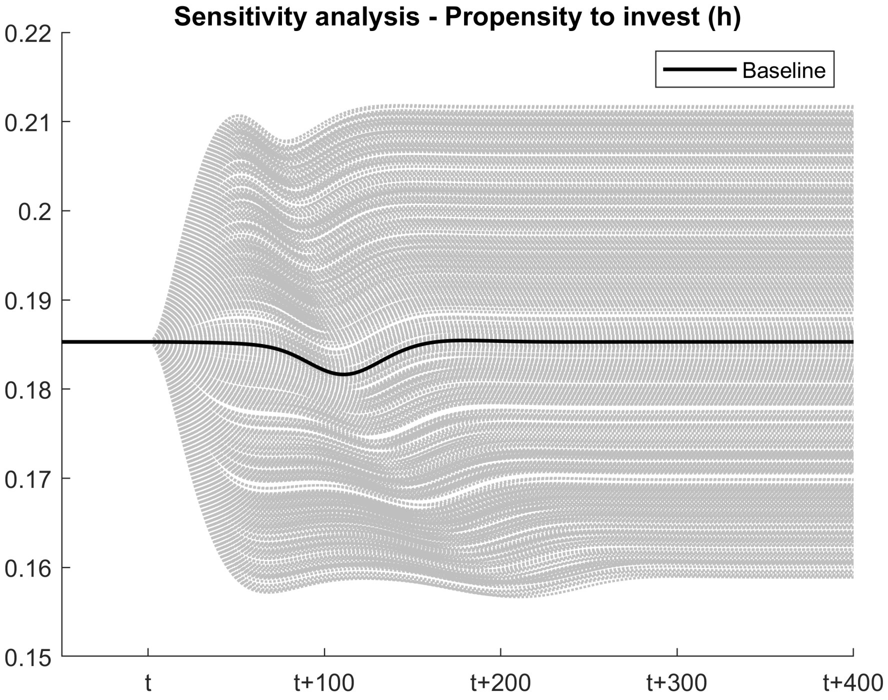


Figure 2.C4: Sensitivity analysis - Share of green capital stock

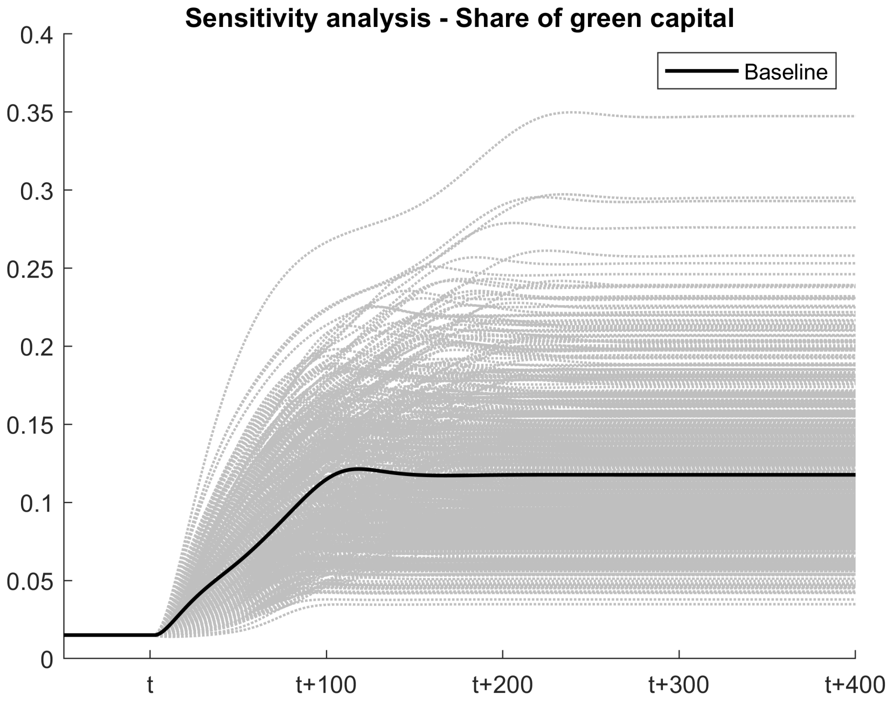
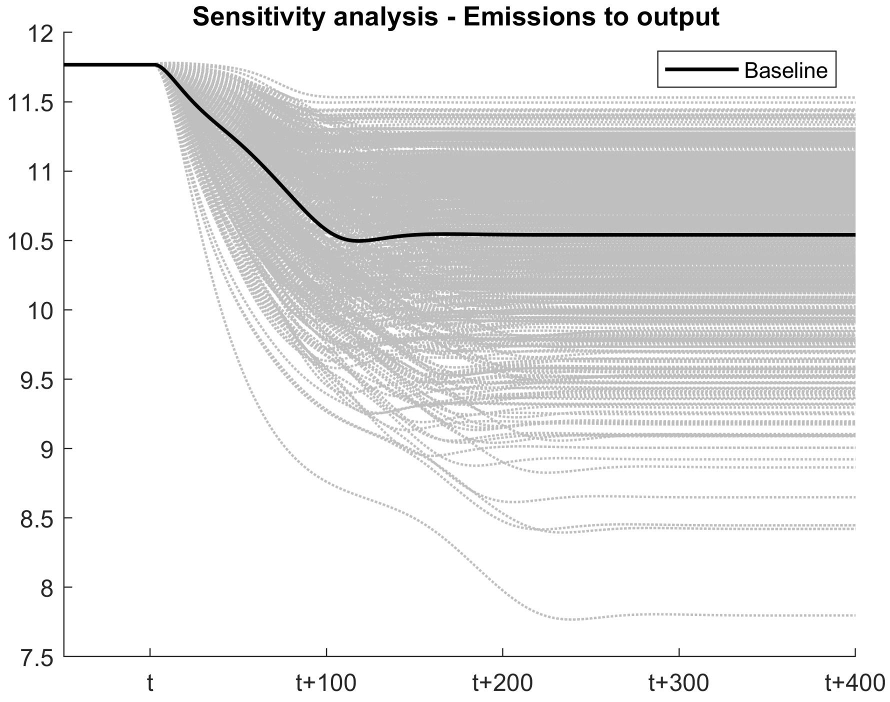


Figure 2.C5: Sensitivity analysis - Emissions to output



Chapter 3

Austerity, an environmentally dangerous idea

The role of public expenditures in energy R&D for the ecological transition

Abstract

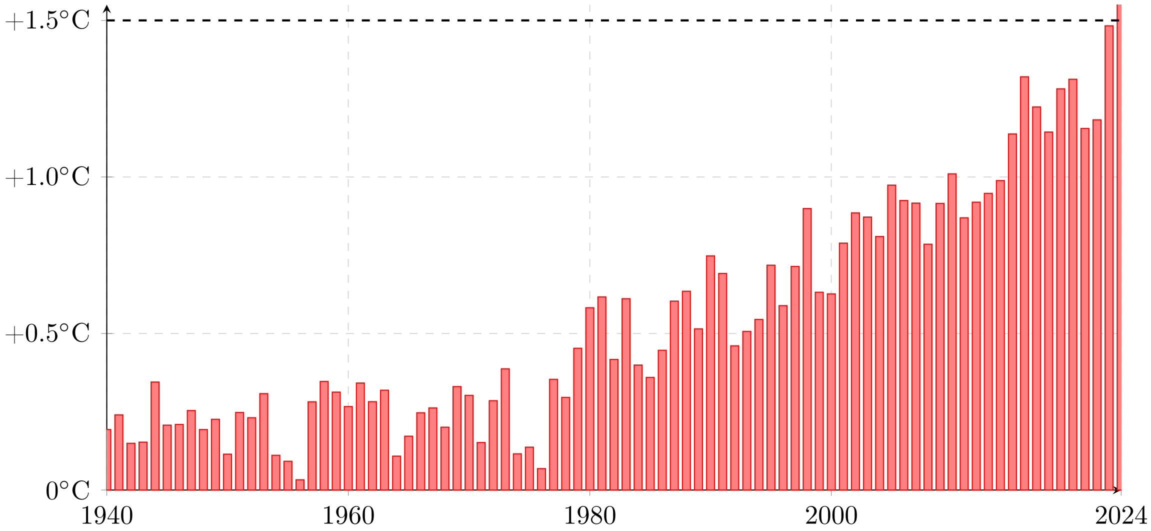
This article investigates the effectiveness of different policies in expanding renewable energy and their broader impact on climate change mitigation performance. While the literature and policy-makers concentrate predominantly on market-based and regulatory instruments, how public investment in energy R&D affects renewable energy deployment remains largely unexplored. Aiming to fill this gap, an empirical analysis based on a Panel-ARDL framework for is proposed, covering 22 OECD economies for the 1995-2023 period. The results of the empirical analysis suggest that public investment in energy R&D is prominent in fostering renewable energy diffusion and increasing renewables share in primary energy and overall climate change mitigation performance. At the same time, regulatory non-market-based policies are revealed as important complementary actions, although their effectiveness tends to be subject to diminishing returns. Finally, price instruments such as fossil taxation ultimately constrain fossil fuel consumption but fail to diffuse renewable generation. Given the urgency to accelerate the energy transition, the gradual return of austerity measures across several advanced economies might curb the room for public direct investment in climate action, reinforcing the predominance of mainstream environmental instruments.

3.1 Introduction

The urgency of the ecological transition has spurred a broad array of policy and regulatory instruments aimed at addressing multifaceted challenges. These actions extend beyond mitigating environmental degradation caused by climate change to include preserving and restoring ecosystems, safeguarding water resources and biodiversity, and managing natural resource depletion. However, a cornerstone of the ecological transition remains achieving substantial reductions in emissions to limit rising atmospheric temperatures and mitigate climate change.

As global greenhouse gas emissions continue to rise, with an expected increase of up to 0.8% in 2024 compared to 2023, fossil fuels account for 91% of the total emissions in 2024 (Friedlingstein et al., 2024), highlighting the critical need for a energy transition to reduce fossil fuel dependency and build energy systems capable of sustaining socioeconomic activity with minimal or zero carbon emissions. Although the share of renewables in total energy supply rose from 8.7% in 2010 to 12.3% in 2022 (International Energy Agency, 2023), this increase remains strikingly insufficient compared to the drastic transformations required. In this context, the atmospheric temperature in 2024 surpassed the critical 1.5ºC threshold above pre-industrial levels, as shown in Figure 3.1., underscoring the limited effectiveness of mainstream environmental policies over recent decades in accelerating this shift towards renewables.

Figure 3.1: Annual global temperature anomalies (°C) relative to 1850–1900



Source: ERA5 Dataset (Copernicus Climate Change Service, 2024).

Emerging in the 1970s, the environmental economics literature conceptualized pollution as a negative externality that could be mitigated through market adjustments, emphasizing cost-efficiency and the role of economic incentives in reducing emissions (Baumol and Oates, 1975). These policies were expected to foster new technologies to spur the adoption of emission-reducing or energy-saving solutions Requate (2005), framing mitigation as a matter of resource allocation, productivity, and energy efficiency. This approach have come to define the core of environmental policy, where the state's role has primarily centered on providing incentives (controlling prices) or enforcing regulations (controlling quantities), while direct public action has remained secondary. However, prioritizing efficiency gains has inherent limitations in driving a substantial shift away from fossil fuels. Hence, given the socioeconomic risks of an abrupt fossil fuel ban, the ecological transition hinges on rapidly expanding renewable energy capacity.

Facing the challenge of a rapid decarbonization of the economy as a concrete problem requires substantial investments in infrastructure and innovation, particularly in R&D expenditures oriented to develop renewable energy technologies, build renewable power plants, grid systems and electricity storage. These investments demand large volumes of resources and entail high risks and uncertain returns, which often discourage private investment. In this context, public direct investment represents an instrument capable of playing a key role in mitigating these risks, mobilizing private resources, and generating positive spillovers to expand renewable energy capacity and shape the broader energy transition. Therefore, understanding which policies can effectively accelerate this transition is crucial.

To date, no research has directly examined the impact of public green R&D investment on renewable energy generation. Hence, this article investigates the impact of different policy approaches on renewable energy generation, renewables share in primary energy, and climate change mitigation, categorizing them into three forms of state intervention: the conventional emissions taxes (price incentives) and regulatory measures, and public direct investment in energy R&D, a novelty in the empirical literature. Using data from 22 OECD economies (1995–2023), the empirical analysis applies panel cointegration techniques through an autoregressive distributed lags model (panel-ARDL) to assess their effectiveness. Although it is considered that a comprehensive strategic plan to launch the low carbon transition requires coordination of policies reflecting distinct forms of state intervention, this analysis' hypothesis holds that public direct investment emerges as a primary instrument to effectively expand renewable energy capacity and tackle climate change, given the urgency of rapidly reducing carbon emissions.

In recent decades, states have taken a more active role in climate action, notably by planning large-scale programs such as the European Green Deal and increasing public finance[1] to the private sector. Although direct public investment in energy R&D has also been part of the policy scenario, it has never been a leading instrument. Accordingly, carbon pricing instruments remain central either in the European Green Deal Claeys et al. (2019) as in the decarbonization pathways proposed by organizations like the IPCC (Lamperti et al., 2024).

Moreover, fiscal austerity and public budget cuts are once again surfacing in policy agendas across several advanced economies, further constraining already incipient public budgets for energy R&D. In the European Union, the new 'debt sustainability analysis' framework embedded in the fiscal rules approved in 2024 (Heimberger et al., 2024) pushes its member states to cut public spending, while in the United States, the second Trump administration is planning federal budget reductions of up to USD 6.2 trillion (Reuters, 2024). These cuts limit the ability of governments to implement direct policies, posing significant risks to achieving climate targets. Accordingly, the European Commission estimates that to meet the 2050 emissions target, an additional annual investment of EUR 750 to 800 billion is required, emphasizing that public support will be essential (Draghi, 2024, p. 59).

The estimations results reinforce the hypothesis of public investment in energy R&D as key determinant of renewable energy diffusion. Additionally, non-market based instruments and GDP per capita are found to be significant drivers of renewables. However, the estimations reveal an inverted U-shaped relationship of regulatory instruments and a negative effect of GDP growth on the renewables share in primary energy, in line with post-growth perspectives. On the other hand, price-based instruments fall short in promoting renewable energy diffusion, although effective in constraining fossil fuel consumption. Therefore, relying on these policies as the primary tools risks exacerbating energy inequality and deepening energy poverty.

The article is structured as follows. After this introduction, Section 3.2 provides a brief review of the mainstream environmental policy framework and the empirical literature on renewable energy diffusion. Section 3.3 outlines the data and methodology. Section 3.4 discusses the results, followed by concluding remarks in Section 3.5.

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[1] Within the European Union sustainable finance tools, green finance refers to existing environmental-friendly private companies and segments, while transition finance refers to private projects.

3.2 Environmental policies effectiveness and the role of public spending

In the environmental economics literature, the way in which the debate on the efficiency of different types of policy has taken place reflects its deep roots in the foundations of neoclassical economics. Based on the idea of scarcity of natural resources, the main focus is to optimize resource allocation through market incentives to enhance productivity through more efficient use of natural resources, waste reduction and lower energy consumption. Representing the theoretical foundation of the so-called green growth agenda, the idea is that the harmful impacts on economic performance due to environmental degradation could be mapped, and the efforts to mitigate negative externalities represent an opportunity to improve economic growth (Reilly, 2012). A central debate within this framework revolved around whether to control pollution through prices or quantities, shaping the development of market-based and regulatory instruments as the two main policy approaches. The former includes instruments such as emissions taxes and subsidies, designed to create incentives for firms to reduce emissions by minimizing costs. The latter, often referred to as command-and-control instruments, encompasses emission-reduction targets and technology standards, relying on enforcement mechanisms as sanctions to ensure compliance.

Market-based incentives are generally accepted in this literature as more cost-efficient than controlling emission quantities (Requate, 2005; Bergquist et al., 2013). Besides the cost efficiency, the literature highlights that command-and-control regulations provide no incentives for firms to reduce emissions beyond the required targets, while market-based instruments theoretically encourage additional reductions since cutting emissions reduces costs (Requate, 2005). Additionally, the emphasis on market-based mechanisms finds support in the Ecological Modernization Theory (EMT), which emerged in the 1980s as the dominant framework in the Politics of Environmental Performance literature. A core principle of EMT is the notion that the relationship between economic growth and environmental sustainability can be transformed into a mutually beneficial dynamic (Jahn, 2016).

A key hypothesis within this framework is the decoupling of environmental degradation from economic growth at higher stages of development. A more nuanced expression of this idea is the inverted U-shaped Environmental Kuznets Curve (EKC), which suggests that pollution increases at lower levels of economic development but declines beyond a turning point as economic growth drives improvements in environmental performance (Stern et al., 1996). This perspective aligns with the prosperity cleaning-up hypothesis, where market-based innovation and competition are seen as key drivers of ecological modernization (Jahn, 2016; Duit et al., 2023). As in the environmental economics literature, the EMT highlights a declining role of the state in environmental governance, relegating its direct actions to a secondary position. Instead, it emphasizes the increasing institutional importance of non-governmental organizations and market-led initiatives, promoting regulatory optimization through public–private partnerships, product labeling, voluntary environmental programs, and network governance (Duit et al., 2023).

Although the last decade has seen the introduction of a few new policy instruments aimed specifically at expanding renewable capacity—such as feed-in tariffs, auctions, and portfolio standards[2]—offering alternatives to traditional efficiency-driven approaches, instruments such as carbon pricing remain predominant (Lamperti et al., 2024). Framing climate change mitigation as a matter of resource allocation, productivity, and efficiency ultimately relates to carbon intensity of production (CO2 emissions per unit of output). However, for a given energy mix, improving energy efficiency reduces total emissions only if the efficiency gains outpace the rate of output growth. This explains why the absolute level of CO2 emissions continue to rise globally despite improvements in carbon intensity, as illustrated in Figure 3.2.

Between 1965 and 2024, the carbon intensity of GDP declined by approximately 50%, yet total emissions have continued to rise. While efficiency gains can soften emissions growth in the short term, they cannot improve indefinitely, as energy use per output unit cannot reach zero given the current living standards. Even if a hypothetical maximum efficiency is achieved, economic growth would inevitably increase energy demand and, consequently, CO2 emissions. This inherent limitation implies that efficiency improvements and resource allocation optimization are, by logical construction, insufficient to drive a near-zero emission scenario, revealing a theoretical shortage of this framework in addressing the climate crisis, reflected in the low effectiveness of the green growth agenda in terms of driving the ecological transition (Jackson and Victor, 2019). Therefore, reducing CO2 emissions necessarily requires transitioning from fossil fuels to renewable, non-polluting energy sources, and investigating the determinants of renewable energy diffusion is precisely the focus of this article.

The empirical literature on this topic is vast, though many studies have relied on exploratory analysis or country-level case studies, which is not the approach

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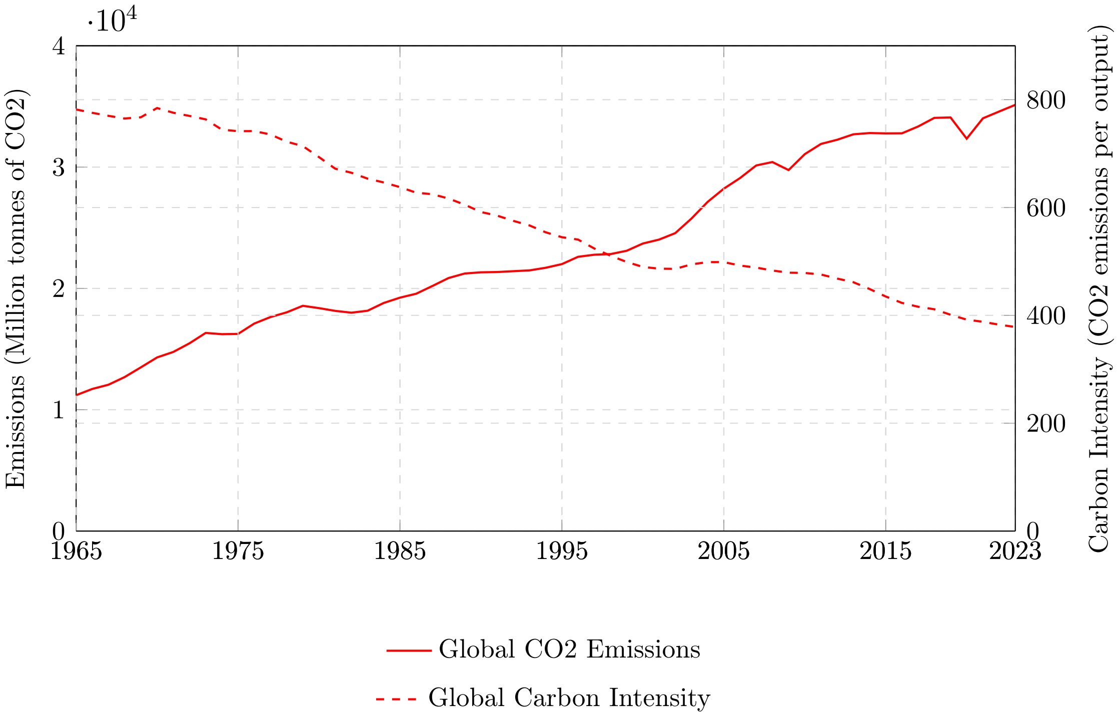
[2] Feed-in tariffs guarantee fixed payments for renewable energy producers, auctions allocate renewable energy contracts to bidders offering the lowest price, and portfolio standards mandate a minimum share of renewables in the energy mix of electricity suppliers.

Figure 3.2: Evolution of global CO2 emissions and carbon intensity



Source: Energy Institute (2024), World Bank national accounts data, and OECD National Accounts data files. Carbon intensity is calculated by dividing CO2 emissions (tonnes) by GDP output (in millions of USD at constant 2015 prices). Author's elaboration.

taken in this article. Focusing on panel data analysis, the dependent variable is typically either renewable energy capacity in terawatts-hour (TWh) (Popp et al., 2011; Shrimali and Kniefel, 2011; Pfeiffer and Mulder, 2013; Bersalli et al., 2020) or the share of renewable energy in total electricity production (Marques et al., 2010; Marques and Fuinhas, 2012; Zhao et al., 2013; Kilinc-Ata, 2016; da Silva et al., 2018). Regarding the determinants of renewable energy diffusion, previous contributions can be categorized into two main strands. Following Marques et al. (2010), one strand examines key factors divided into political/institutional, socio-economic, and country-specific determinants (see also Marques and Fuinhas (2012); Aguirre and Ibikunle (2014); da Silva et al. (2018)). The other strand focuses on policy process comparisons, primarily analyzing market-based instruments such as feed-in tariffs, tax incentives, and renewable energy auctions, as well as regulatory instruments like renewable portfolio standards, emissions targets, and energy efficiency mandates (Shrimali and Kniefel, 2011; Pfeiffer and Mulder, 2013; Zhao et al., 2013; Polzin et al., 2015; Bersalli et al., 2020; Abbruzzese et al., 2024).

Not surprisingly, the results are mixed due to differences in countries, regions, time periods, and explanatory variables considered, although some consistencies can be highlighted. Variables that capture a country's wealth, such as GDP per capita, generally have a positive effect on renewable energy diffusion (Marques et al., 2010; Pfeiffer and Mulder, 2013; da Silva et al., 2018).The reasoning is straightforward: high-income countries have greater capacity to invest in green innovation, either due to financial resources or advanced technology. Overall, regulatory instruments are found to be effective in expanding renewable energy, but mixed results emerge when policies are analyzed individually (Pfeiffer and Mulder, 2013; Polzin et al., 2015; Bersalli et al., 2020). Among market-based instruments, feed-in tariffs stand out as a significant factor in fostering renewable energy adoption (Bersalli et al., 2020; Marques and Fuinhas, 2012; Zhao et al., 2013; Polzin et al., 2015; Abbruzzese et al., 2024). In this literature, the policies are commonly treated as dummies or categorical (count of policies) explanatory variables. Therefore, the stringency of the policy is disregarded.

Furthermore, a count variable assumes a linear effect of policy adoptions, which might be problematic. Accordingly, Zhao et al. (2013) include a quadratic term for the policy count variable and identify an inverted U-shaped relationship between the number of policies and renewable energy diffusion, suggesting diminishing returns as policies increase. Next, while higher fossil fuel prices are expected to incentivize renewable energy production, empirical findings show mixed results, including cases where rising fossil fuel prices affect renewable energy negatively. One explanation is that fossil fuels are often better substitutes for each other, leading to a shift within fossil sources rather than toward renewables. As discussed in da Silva et al. (2018), this dynamic may occur in lower-income countries due to resource diversion or in high energy-intensity countries where strong reliance on fossil fuels and constrained renewable capacity hinder the transition.

To date, no research has directly examined the impact of public green R&D investment on renewable energy generation, making this an original contribution of the present study.[3]. While Aguirre and Ibikunle (2014) and Polzin et al. (2015) consider public direct investment in a broad pool of policies, they treat it as a binary variable, which only indicates the presence or absence of such policies. Hence, this approach is not intended to capture the actual size of investment, which is a crucial factor in assessing its impact. More recently a few works employed government expenditures on research and development in energy technologies in a similar context, but not to investigate its impact directly on renewable energy diffusion. Using a panel data for G7 economies, Herzer (2022) and Herzer (2023) reveal, respectively,

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[3] It is worth mentioning that the availability of this data is quite recent, as the Energy Technology RD&D Budgets database of the International Energy Agency is publicly available since 2020.

that government-funded clean energy R&D have negative effects on domestic CO2 emissions and positive effects on domestic green innovation. Likewise, estimations for OECD countries presented by Deleidi et al. (2020) suggest that public direct investment in renewable electricity projects mobilizes private investment in the sector, with multipliers between 0.18 and 0.28. In line with Deleidi et al. (2020) and Herzer (2023), the World Energy Investment Report highlights that public spending on energy R&D increased by 7% globally in 2023, signaling its role in driving corporate R&D investments and fostering innovative energy companies (IEA, 2024a, pp. 150–176).

The viability of shifting towards renewables requires substantial investments in infrastructure and innovation, including grid systems, power plants, electricity storage, refitting of existing facilities, and transmission and distribution networks, among others. Given the urgency of the investments needed and considering the high uncertainty of its returns, the state emerges as a key actor, capable of playing a critical role in actively planning, coordinating efforts, and mobilizing resources to drive the ecological transition[4]. Although the financial challenges of the transition are beyond the scope of this article, it is worth noting that carbon pricing mechanisms are likely insufficient to correct financial system failures in mobilizing the volume of resources required for low-carbon investments at the necessary scale and pace Campiglio et al. (2018). In this context, macroprudential regulation and state-owned financial institutions play fundamental roles in ensuring that financial markets effectively support the ecological transition (Campiglio, 2016; Feil and Feijo, 2021).[5]

Beyond the financial dimension, the scale of transformation required demands systemic intervention. In this regard, the concept of mission-oriented innovation policy offers a compelling approach for framing the state's active role in driving the ecological transition. As defined by Mazzucato (2018), these policies involve systemic public interventions that apply frontier knowledge to achieve specific societal challenges, and fighting climate change definitely falls within these challenges. Mission-oriented policies highlight the inter-sectoral nature of public R&D spending and its positive spillover effects, particularly in mobilizing private-sector investments. This is particularly relevant given the substantial investments required The state's role thus extends beyond merely correcting market negative externalities, as framed in the dichotomy between market-based versus command-and-control in-

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[4] In 2019, the European Commission estimated an annual green investment gap of 260 billion euros to meet the -40 percent emissions reduction target (Claeys et al., 2019).

[5] See Dafermos (2022) for a comprehensive discussion about the financial and monetary challenges in financing the transition to a low-carbon economy.

struments. Rather than that, it encompasses implementing direct climate actions, shaping industries, stimulating innovation, mitigating risks for private firms, and fostering the emergence of new markets through strategic planning and coordination.

In this framework, public investment plays a fundamental role, which conflicts with the predominance of fiscal consolidation measures focused on reducing public deficits. Austerity became a central economic policy tool following the 2008–09 financial crisis (Blyth, 2013), when the proponents of Expansionary Austerity Theory (EAT) argued that deep and sustained cuts to public expenditures would signal fiscal discipline, foster optimism among private agents, enhance trust in public debt solvency, and reduce financial market vulnerabilities and interest rates. These mechanisms, they claimed, would stimulate profitability, private investment, and economic growth (Alesina et al., 2018). However, beyond theoretical and empirical fragilities (see Botta and Tori (2018)), these policies failed to deliver on their promises[6]. Moreover, by sidelining public spending—a critical component of aggregate demand— austerity policies gave up on a crucial instrument for restimulating the economy during periods of weak private demand. In the context of climate change, neoliberalism and the ecological transition are fundamentally conflicting (Saad-Filho and Feil, 2024), with predominance of market-based instruments and austerity policies being key manifestations of this incompatibility, as they hinder climate action by constraining the state's capacity to make the urgent investments needed to mitigate climate change. If private firms are discouraged from investing—at least at the scale required for a rapid transition—due to high risks and uncertain profitability, the question is about who could drive this transition if the state remains constrained by austerity.

While austerity policies further limit the already insufficient public budgets for energy R&D[7], these investments still represented a form of direct public climate action in recent decades. Hence, investigating their effectiveness contributes not only to the empirical environmental policy literature but also to the broader discussion on the political economy of the green transition. By focusing on public green R&D spending—an unexplored connection in the literature—and building on previous contributions, this article examines the determinants of renewable energy diffusion and its impact on climate change mitigation through different forms of state action.

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[6] Despite low interest rates and labor market reforms, private investment remained subdued, economic growth stagnated, and financial markets stayed precarious, while economic stagnation and inequality worsened (Pariboni et al., 2020; Deleidi and Mazzucato, 2019).

[7] Considering that the budget of the European Union amounts to around 1% of GDP of the EU, direct public green investment will inevitably have a secondary participation given the large volume of resources required.

The transition to greener production fundamentally depends on renewable energy availability, with public investment representing a direct form of intervention. On the other hand, and more compatible with austerity, carbon pricing and regulatory measures influence this process indirectly, driving change through incentives and compliance mechanisms over time. The empirical analysis in the following section evaluates the effectiveness of direct, indirect, and regulatory actions in expanding renewable energy generation, contributing to the broader discussion on the political economy of the green transition.

3.3 A panel cointegration analysis

This section presents the methodology to investigate the effectiveness of different policies in expanding renewable energy and their broader impact on climate change mitigation performance within a Panel-ARDL framework. Building on the discussion outlined in Section 3.2, the policies can be categorized based on distinct forms of state action. First, public direct investment, such as green R&D expenditures, reflects a direct mechanism, capable of mobilizing resources and generating positive spillovers. Second, price controlling instruments like carbon pricing represent indirect mechanisms by fostering market-driven adjustments. Third, institutional adaptations and environmental legislation, such as industry-specific emissions targets, are a form of regulatory intervention. In sum, while public investment is directly constrained by public budget cuts, mainstream market-based and regulatory policies are generally in harmony with austerity measures.

Although it is considered, in line with the mission-oriented framework, that a comprehensive strategic plan to launch the low carbon transition requires coordination of policies reflecting distinct forms of state intervention, definitive answers regarding the ideal policy mix do not exist, nor does this study aim to propose one. Hence, this analysis' hypothesis holds that public direct investment emerges as a primary instrument to effectively expand renewable energy capacity and tackle climate change, given the urgency of rapidly reducing carbon emissions.

3.3.1 Variables and data

The dataset covers the period from 1995 to 2023, featuring annual observations for 22 OECD economies[8] over a span of 29 years. The analysis primarily examines renewable power generation as the main dependent variable, while additional

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[8] The countries in the sample are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, and United Kingdom.

specifications test the share of renewables in primary energy and climate change mitigation performance as alternative dependent variables.

The dependent variables are intended to capture distinct aspects related to the energy transition and the effectiveness of the different policies addressed. First, the non-hydro renewable power generation (ren_gen) is a variable regarding the production side, based on gross generation from renewable sources including wind, geothermal, solar, biomass and waste, and not accounting for cross-border electricity.[9] Second, the share of renewables in total primary energy[10] (ren_sh) reflects the consumption side, and is expected to capture also policy effects on fossil energy consumption. The third dependent variable, the climate change mitigation performance (epi) is obtained from the Environmental Performance Index (EPI) and is aimed to capture the effects on emissions. The EPI ranges from 1 to 100, where 100 is the best performance score, and considers three policy objectives: climate change mitigation, environmental health, and ecosystem vitality (Block et al., 2024). In this article, epi expresses only the index for “climate change" policy objective, which is calculated using indicators related to pollutant emissions.[11]

Following the distinct forms of state intervention under consideration, the explanatory variables include government R&D expenditures in energy technologies ($gov\_r\&d$), implicit fossil fuel taxation $fossil\_tax$, and non-market-based instruments (pol_nmb), representing direct, indirect and regulatory policy categories, respectively. The ($gov\_r\&d$) is obtained from the Energy Technology RD&D Budgets database of the IEA (IEA, 2024b). Since the inclusion of this variable is pivotal in this study, the selection of countries in the sample followed primarily the availability of this data[12]. Next, the implicit fossil fuel taxation is a proxy for carbon-pricing policies and is measured in million USD per exajoule, calculated by dividing the

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[9] Although hydropower is a non-fossil based electricity, it is not considered in the renewable power generation by the Statistical Review of World Energy (Energy Institute, 2024). Accordingly, hydropower projects are increasingly viewed as unsustainable due to serious negative environmental impacts. As a result, recent works typically focus on non-hydro renewable energy, although small hydroelectric power plants are also considered when the data allows for a distinction.

[10] It is calculated by 'input-equivalent' basis, indicating the equivalent amount of fossil fuel input required to generate that amount of energy in a standard thermal power plant.

[11] The climate change index is composed by the following 11 indicators (weights within the parenthesis): adjusted emissions growth rate for carbon dioxide (25%), adjusted emissions growth rate for carbon dioxide (country-specific targets) (1.67%), adjusted emissions growth rate for methane (10%), adjusted emissions growth rate for F-gases (6.67%); adjusted emissions growth rate for nitrous oxide (3.33%), adjusted emissions growth rate for black carbon (5%), net carbon fluxes due to land cover change (3.33%), GHG growth rate adjusted by emissions intensity (20%), GHG growth rate adjusted by per capita emissions (20%), projected emissions in 2050 (3.33%), and projected cumulative emissions to 2050 relative to carbon budget (1.67%).

[12] Although the IEA dataset contains information about non-OECD economies, the length of the series are usually significantly shorter with respect to the economies in the sample, which would make the panel strongly unbalanced.

fossil fuel tax revenue (million USD) by its total consumption (exajoules). The third explanatory variable counts the number of climate action and non-market based policies (pol_nmb) adopted. Obtained from the OECD Climate Actions and Policies Measurement Framework (see Nachtigall et al. (2022)), pol_nmb considers sectoral non market based policies (electricity, industry, transport, and buildings) and cross-sectoral GHG emissions target, summing up to a maximum of 15 policies adopted.[13] To control for income levels and economic growth effects, GDP per capita (gdp_{pc}) is included as a control variable among the regressors. Table 3.1 describes the definition of the variables, the data sources and the summary statistics.

Table 3.1: Variables description, data sources and summary statistics

Variable	**Definition**	**Source**	**Obs**	**Mean**	**Std.Dev.**	**Min**	**Max**
ren_gen	Total non-hydro renewable power generation (Terawatt-hour).	Statistical Review of World Energy (Energy Institute, 2024).	632	20.78	34.7	0.02	252.8
ren_sh	Share of renewable energy in total primary energy consumption (%).	Statistical Review of World Energy (Energy Institute, 2024).	637	16.4	16.4	0.2	72.3
epi	Environmental Performance Index (0-100), climate change policy objective.	Yale Center for Environmental Law and Policy (Block et al., 2024).	638	50.7	8.7	26.4	71.8
$gov\_r\&d$	Government expenditures on research and development in energy technologies (millions USD).	IEA Energy Technology RD&D Budgets database (IEA, 2024b).	564	463.4	677.14	1.56	3,599.2
$fossil\_tax$	Measured in million USD/exajoule, it is calculated by dividing the tax revenue related to fossil fuels (million USD) by total fossil fuel consumption (exajoules).	OECD Environmental Related Tax Revenue Database (ERTR) and Energy Institute (Energy Institute, 2024).	611	4,917.3	1,832.4	1,336.7	9,213.4
pol_nmb	Adopted sectoral non-market based instruments (count variable).	OECD Climate Actions and Policies Measurement Framework (CAPMF).	616	8.3	3.6	1	15
gdp_{pc}	Gross Domestic Product per capita (constant 2015 million USD).	World Bank.	638	38,213.0	18,462.6	5,628.4	97,316.9

3.3.2 Unit root tests and cointegration analysis

A panel data structure with a large number of groups and long time-series observations allows the detection of long-run effects when variables are non-stationary and cointegrated. Essentially, non-stationary time series are cointegrated if a linear combination of them produces a stationary series $I(0)$. To verify stationarity, the

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[13] As an example, the list includes ban on the construction of new and phase out of existing unabated coal power plants, fuel economy standards, and energy efficiency mandates. See the metadata in Nachtigall et al. (2022) for the full list.

Im-Pesaran-Shin and Fisher-Augmented Dickey-Fuller unit root tests are applied at the panel level. The results, presented in Table 3.2, reveal that the null hypothesis of all panels containing unit roots cannot be rejected in levels for most variables, including all three dependent variables. The exceptions are GDP_{pc}, which is found to be an $I(0)$ process, and $fossil\_tax$, which presents mixed results. Instead, the existence of unit roots is rejected at the first differences with a 0.01 significance level for all variables, confirming the non-stationarity of the panel. The stationarity of GDP_{pc} in levels and the mixed results yielded of $fossil\_tax$ do not pose an issue within a panel cointegration framework, which accommodates both $I(0)$ and $I(1)$ variables (Pesaran et al., 1999).

Table 3.2: Unit Root Test Results

Variable	**IPS***		**Fisher-ADF****	
	Levels	Δ	Levels	Δ
ln(ren_gen)	3.152	-8.885***	0.358	-9.685***
	(0.999)	(0.000)	(0.639)	(0.000)
ln(ren_sh)	4.725	-14.507***	4.158	-19.603***
	(1.000)	(0.000)	(1.000)	(0.000)
ln(EPI)	3.719	-7.610***	-0.393	-6.905***
	(1.000)	(0.000)	(0.347)	(0.000)
ln(gov_rd)	0.433	-12.889***	1.906	-14.634***
	(0.668)	(0.000)	(0.970)	(0.000)
ln(fossil_tax)	-1.045	-12.090***	-2.454***	-12.172***
	(0.148)	(0.000)	(0.008)	(0.000)
pol_nmb	5.351	-11.754***	5.874	-17.824***
	(1.000)	(0.000)	(1.000)	(0.000)
ln(GDP_pc)	-2.498***	-12.172***	-2.629***	-16.632***
	(0.006)	(0.000)	(0.0049)	(0.000)

* Z-t-tilde-bar test.

** Inverse logit t-test, 1 lag.

p-value in parentheses.

Confirmed that the panel is non-stationary, various tests are conducted to examine whether the variables are cointegrated[14]. The results of the cointegration tests

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[14] A word of caution should be expressed when dealing with both stationarity and cointegration tests, as they were originally developed for time-series econometrics and later adapted for panel data. Therefore, the panel-level results should be interpreted carefully, as the properties may vary across countries. For this reason, more than one test is conducted.

are summarized in Table 3.3. The null hypothesis for all the tests is that there is no cointegration. However, the alternative hypotheses differ: for the Pedroni test, it assumes that all panels are cointegrated; for the Westerlund test, it assumes that some panels are cointegrated; and for the Johansen-Fisher test, it assumes the existence of at least one (or more) cointegrating relationships.

Table 3.3: Cointegration Test Results

DepVar	**Pedroni**			**Westerlund**	**Johansen-Fisher**	
	PP-mod	PP	ADF	VR	Trace	Max-eigen
ln(ren_gen)	2.150**	-1.644**	-1.173	-2.020**	518.1***	327.4***
	(0.016)	(0.050)	(0.120)	(0.021)	(0.000)	(0.000)
ln(ren_sh)	0.908	-5.036***	-4.012***	-3.053***	458.7***	294.6***
	(0.182)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
ln(EPI)	3.346***	0.783	2.288**	-2.131**	481.8***	306.1***
	(0.000)	(0.217)	(0.011)	(0.016)	(0.000)	(0.000)

p-value in parentheses.

In qualitative terms, all the tests provide the same result, and the null hypothesis of no cointegration is rejected across all model specifications at the 0.05 significance level using the Pedroni, Westerlund, and Johansen-Fisher[15] tests. For the Johansen-Fisher test, both the Trace and maximum eigenvalue statistics reject the null at the 0.01 level. These results confirm the variables are cointegrated, indicating a long-run equilibrium relationship.

Given that the panel is non-stationary and cointegrated, the error term is stationary ($I(0)$) for all cross-sectional units (Blackburne III and Frank, 2007). The cointegration property highlights the variables' tendency to adjust toward equilibrium after deviations, justifying the use of an error correction model (ECM). The Panel ARDL framework, incorporating the ECM, allows for capturing both the short-term dynamics of the variables and their adjustments to long-run equilibrium, providing a comprehensive tool for the analysis.

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[15] The Johansen Fisher Panel Cointegration Test hypothesizes the number of cointegration equations (CE). In Table 3.3, the null hypothesis tested is the absence of CE (none). However, it is worth noting that the test rejects the null hypothesis of at most two CE at a 0.01 significance level, suggesting the presence of at least two cointegration equations.

3.3.3 A Panel Autoregressive Distributed Lags (ARDL) Model

Macro panels with large N (number of cross-sectional units) and large T (time series lenght) integrate features from panel data and time-series econometrics, inspiring a new strand of estimators in the late 20^{th} century (Pesaran and Smith, 1995). With sufficiently large T, heterogeneous regressions with unique slopes for each cross-sectional unit became feasible, replacing pooled regression models. This framework also facilitates applying time-series techniques to panels, such as addressing non-stationarity and cointegration. The econometrics of non-stationary heterogeneous dynamic panels combine the strenghts of increased statistical power from the cross-sectional data with the time-series methods of dealing with non-stationary data (Baltagi and Kao, 2000).

The model is specified in Equation 3.1 as an autoregressive distributed lag (ARDL) dynamic panel.

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{i,j} X_{i,t-j} + \mu_i + \epsilon_{it} \tag{3.1}$$

Where the number of groups $i = 1, 2, ..., N$; the number of periods $t = 1, 2, ..., T$; X_{it} is a $k \times 1$ vector of explanatory variables; δ_{it} are the $k \times 1$ coefficient vectors; λ_{ij} are the scalar coefficients for the lagged dependent variable; p and q_k represent the maximum number of lags of the dependent and k explanatory variables, respectively; μ_i is the group-specific effect; and ϵ_{it} is the error term.

Considering the panel is non-stationary and cointegrated, Equation 3.1 can be reparameterized into an error correction equation (Equation 3.2):

$$\Delta y_{it} = \phi_i \left(y_{i,t-1} - \theta'_i X_{it} \right) + \sum_{j=1}^{p-1} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q-1} \delta'_{i,j} X_{i,t-j} + \mu_i + \epsilon_{it} \tag{3.2}$$

Where the parameter ϕ_i is the error-correcting speed of adjustment term. If $\phi_i = 0$, there is no evidence of a long-run relationship. If $\phi_i > 0$, the model is explosive and the long-run relationship is not stable. The error-correcting term is expected to be negative ($\phi_i < 0$) and statistically significant under the assumption that the variables return to long-run equilibrium after deviations. Finally, the vector θ'_i contains the long-run relationships.

The three main techniques for estimating non-stationary dynamic panels, as in Equation 3.2, are the Dynamic Fixed Effects (DFE), Mean-Group (MG) (Pesaran and Smith, 1995), and Pooled Mean-Group (PMG) estimators (Pesaran et al., 1999).The DFE relies on traditional fixed-effects methods for short T, allowing group-specific intercepts but constraining slopes and error variances to be identical. However,Pesaran et al. (1999) showed that DFE produce inconsistent estimates when the slope coefficients are not identical. As the assumption of homogeneous slopes tends not to hold for panels with large T, the MG and PMG estimators emerged as alternatives.

The MG fits a separate regression for each group, allowing the intercepts, slopes and error variances allowed to differ across groups, with coefficients averaged to obtain estimates. The PMG is considered an intermediate estimator, combining both averaging and pooling: the short run coefficients and intercepts are heterogeneous, as in the MG, while the long run coefficients are constrained to be equal, as in the DFE. This assumption of a common long-run relationship is plausible for structurally similar groups, such as OECD countries-the case of this analysis-, where shared characteristics suggest comparable long-run responses. If this long-run homogeneity holds, PMG is more efficient than MG, leveraging similarities between groups to improve precision. The Hausman test assesses this assumption, and for the three dependent variables analyzed, the null hypothesis is not rejected, supporting the PMG as the preferred estimator.

3.4 Results and discussion

In a Panel ARDL framework, short-run dynamics are estimated using differences, which, for log-transformed variables, effectively represent growth rates. In contrast, the long-run analysis leverages cointegration techniques, allowing non-stationary variables to be used in levels. This approach captures structural and persistent relationships, rather than temporary fluctuations, which is particularly relevant for the topic of renewable energy diffusion and offers an advantage over purely short-run models.

Therefore, the interpretation of the coefficients provides different insights. If the long-run coefficient is significant, there is a stable structural relationship, meaning that the dependent variable reacts to persistent changes in the regressor and converges back to equilibrium over time. If both long-run and short-run effects are significant, the short-run coefficient measures the additional contemporaneous effect caused by growth rate fluctuations, while the long-run coefficient captures the persistent equilibrium relationship. If only the long-run coefficient is significant, then short-run fluctuations do not influence the dependent variable, indicating that only persistent changes in levels shape the equilibrium relationship, and short-run deviations are not relevant for the adjustment process. If only the short-run coefficient is significant, the dependent variable responds to shocks, but the effects are temporary and do not alter the long-run equilibrium in levels.

In sum, the long-run coefficients reflect the response of the dependent variable to persistent changes in the level of a regressor. Conversely, the short-run coefficients measure the effect of transitory fluctuations in the growth rate. This feature is particularly relevant to this study. For variables such $gov\_r\&d$, the absolute level of public investment in energy R&D is expected to matter more for renewable energy diffusion than its rate of change.[16] A similar rationale applies to the accumulated number of non-market-based policies adopted (pol_nmb). First-differences assume that a one-unit change has the same effect regardless of the total number of policies, whereas using levels in the long run captures their cumulative impact. However, this level specification also imposes a linearity assumption–that each additional policy has an identical incremental effect–so a quadratic term of pol_nmb is included to account for potential non-linearities.

On the other hand, $fossil\_tax$ and GDP_{pc} are expected to be elucidative in both the short and long run, albeit with distinct interpretations. In the short run, changes in the growth rate of $fossil\_tax$ capture price shocks driven by taxation rate of change, whereas the long run reflects persistent changes in the level of fossil fuel tax. Similarly, GDP_{pc} in levels captures the effect of a country's income, while in the short run, the coefficients express the influence of the output growth rate.

Table 3.4 presents the estimated long- and short-run coefficients for the three dependent variables considered. The error correction terms are negative and significant in all specifications. It confirms the long-run relationship between the variables and that the system moves back toward the equilibrium, correcting for shocks and deviations.

In the long-run coefficients, the overall results reveal that government expenditures in energy R&D are positive and significant at the 1% level for renewable energy generation, renewables share, and climate change mitigation performance. Since both variables are log-transformed, the $gov\_r\&d$ coefficients are interpreted as elasticities describing proportional differences in equilibrium. Specifically for model (1) it indicates that a country with a level of $gov\_r\&d$ 1% higher tends to present, on average, a level 0.38% higher in renewable energy power generation. Beyond its direct impact on fostering ren_gen on the production side, the significant effects on the renewables share (ren_sh) and emissions mitigation performance (epi) suggest that $gov\_r\&d$ may also contribute to reducing fossil fuel consumption. Regarding the latter, this effect may arise through substitution due to expanded renewable capacity, as expanded renewable capacity can displace fossil fuels, or through energy

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[16] In Appendix 3.A, the figures from 3.A1 to 3.A7 illustrate the evolution of the variables at the country level.

Table 3.4: Panel ARDL - Pooled Mean Group Estimation Results

	$ln(ren\_gen)$ (1)	$ln(ren\_sh)$ (2)	$ln(epi)$ (3)
Long-Run Coefficients			
$ln(gov\_r\&d)$	0.383***	0.257***	0.130***
	(0.123)	(0.046)	(0.027)
$ln(fossil\_tax)$	-0.076	0.815***	0.265**
	(0.553)	(0.222)	(0.134)
pol_nmb	0.611***	0.089*	0.223***
	(0.125)	(0.051)	(0.030)
pol_nmb^2	-0.035***	-0.0023	-0.013***
	(0.006)	(0.003)	(0.002)
$ln(GDP_{pc})$	3.097***	0.320	-0.601***
	(0.693)	(0.242)	(0.216)
Constant	-2.172***	-1.375***	0.302*
	(0.730)	(0.466)	(0.155)
Short-Run Coefficients			
EC Term	-0.071***	-0.149***	-0.045*
	(0.023)	(0.048)	(0.024)
$\Delta ln(gov\_r\&d)$	0.008	-0.001	0.005
	(0.022)	(0.020)	(0.006)
$\Delta ln(fossil\_tax)$	0.051	0.261**	0.002
	(0.081)	(0.104)	(0.0603)
Δpol_nmb	-0.088*	-0.056	-0.012
	(0.0531)	(0.0562)	(0.0125)
Δpol_nmb^2	0.004*	0.002	0.001
	(0.002)	(0.003)	(0.001)
$\Delta ln(GDP_{pc})$	0.007	-0.793***	-0.552*
	(0.355)	(0.235)	(0.301)
Observations	518	518	517

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

efficiency-improving technologies. These findings reinforce this work's hypothesis on the role of public spending in driving the transition toward a low-carbon economy.

Analyzing the models individually, the long-run results of specification (1) indicate that, in addition to $gov\_r\&d$, non-market-based policies and GDP per capita are key determinants of renewable energy diffusion. The result for GDP_{pc} is in line with previous studies. The coefficient suggests that, in the long run, a 1% higher GDP per capita is associated with a higher 3% renewable energy generation in TWh, likely reflecting a country's capacity to invest in expensive technologies such as renewables. Instead, despite the strong long-run relationship, either $gov\_r\&d$ and

GDP_{pc} are not found to be significant in the short run, reinforcing the interpretation that, for these variables in this context, analyzing the levels are more relevant than fluctuations in growth rates.

Regarding pol_nmb, the long-run results reveal a positive but diminishing effect (inverted U-shape) on both ren_gen and epi, as captured by the negative coefficient of the squared term (pol_nmb^2). On average, an additional policy is associated with a 0.6% higher renewable power generation, although this effect weakens as the total number of policies rises. In the short run, however, the negative and significant coefficient at the 10% level suggests that an incremental policy initially has a negative impact, though the squared term indicates an eventual increase. This likely reflects the time required for market adaptation and compliance by firms and institutional actors. Taken together, these findings suggest that non-market-based policies take time to yield positive effects on renewable energy generation and that their effectiveness diminishes as the total number of policies grows.

On the other hand, $fossil\_tax$ is found to be non-significant. As discussed, previous studies report mixed findings on the impact of rising fossil fuel prices, including potential negative effects on renewables. Given that the sample consists of OECD countries, mostly advanced and industrialized economies, their high energy-intensity may indicate a deeper reliance on fossil fuels, which could explain the non significant results. If renewable technology remains relatively expensive, an increase in the price of one fossil fuel may lead to a shift toward another, effectively diverting resources away from renewables. This finding challenges the central role often attributed to instruments like carbon pricing in unlocking the low-carbon transition, both in the literature and among policy makers.

In a context where renewables generation is largely insufficient to meet total energy demand, it is more likely that price increases are primarily accommodated by adjusting total energy consumption rather than shifting toward renewables production. Therefore, the specifications (2) and (3) not only represent auxiliary models for robustness checks, but also provide complementary insights to the analysis. Their results suggest that $fossil\_tax$ is an effective policy for both increasing the renewables share in primary energy consumption and improving mitigation performance. The long-run coefficient in (2) suggests that a sustained 1% increase in fossil fuel taxation is associated with a 0.8% relative increase in the renewables share. Moreover, the coefficient remains positive and significant in the short run, indicating that the renewables share responds effectively to transitory shocks in fossil fuel prices.[17]

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[17] Recall that the PMG estimator fits one regression for each country, allowing intercepts and slopes to vary. The results presented in Table 3.4 represent cross-country averages.

In sum, these results suggest instruments such as $fossil\_tax$, which ultimately affect energy prices, can reduce fossil fuel consumption but are not effective in fostering renewable energy generation. As discussed in Section 3.2, these effects are, at best, insufficient to drive the energy transition, as fossil fuel consumption cannot be indefinitely reduced without alternative sources given current living standards. Moreover, this raises concerns about energy poverty and the social justice implications of the energy transition (Walker and Day, 2012; Carley and Konisky, 2020). Energy is an essential good, and systems such as home heating remain heavily dependent on natural gas, making households particularly vulnerable to fossil fuel price shocks. Naturally, the extent to which rising fossil energy prices impact consumers depends on the accessibility and affordability of renewable alternatives. In this regard, a higher share of renewables has been linked to energy poverty alleviation (Śmiech et al., 2025). Therefore, if price-based instruments—including carbon pricing and fossil fuel taxation—are not complemented by policies that effectively promote renewable energy generation, their adoption becomes highly questionable, not only due to their inefficiency in driving the energy transition but also because of their potential to exacerbate energy poverty and vulnerability.

Furthermore, models (2) and (3) provide additional context for interpreting GDP_{pc} within the broader ecological transition. While model (1) suggests that countries with higher GDP per capita tend to have greater renewable energy generation capacity, model (2) indicates a negative effect of GDP growth on the renewables share in primary energy. Additionally, model (3) reveals that GDP_pc has a negative impact on emissions mitigation performance in both the short and long run. Despite their opposite signs, these results are not contradictory. Rather, they complement each other and should be interpreted jointly.

In model (2), the short-run coefficient captures the effect of GDP_{pc} growth, which inevitably drives up aggregate energy demand. Consequently, if economic output grows at a faster pace than renewable energy generation—assuming constant energy efficiency—the renewables share in primary energy consumption necessarily declines. The non-significance of the long-run coefficient likely reflects the two-way effect of GDP_{pc} on the renewables share, as it positively impacts both renewables generation and total energy consumption.

Accordingly, the negative coefficients of GDP_{pc} on emissions mitigation performance in model (3) might reflect, in a way, the isolated effect of economic growth on energy demand. An increase in output entails higher demand for energy, which, unless fully met by renewable sources, results in greater fossil fuel consumption. Following this logic, while economic growth contributes to rising pollutant emissions, a higher level GDP per capita is also associated with higher total demand for energy[18]. This explains the negative effects on mitigation performance observed in both the short and long-run estimations.

Finally, the empirical findings support the main conclusions drawn from the analytical model developed in Chapter 2 of this thesis, which suggests that expanding renewable energy generation within a low-growth scenario is more conducive to advancing the energy transition. In sum, continuous economic growth drives a corresponding rise in energy demand, making the phase-out of fossil fuels more challenging. This conclusion aligns with post-growth perspectives, highlighting that slowing economic growth effectively extends the timeframe available for carrying out the energy transition.

3.5 Concluding remarks

By analyzing the effects of public investment in energy R&D on the deployment of non-pollutant energy sources and overall climate change mitigation performance, this article makes a novel contribution to the empirical literature on environmental policy effectiveness and the determinants of renewable energy diffusion. At the same time, it foments a broader discussion on the political economy aspects of the ecological transition regarding the state's role and the threat of fiscal austerity premises.

Altogether, the results of the panel-ARDL estimation suggest that a comprehensive strategy for the ecological transition requires a mix of state interventions, with direct actions such as public investment in energy R&D playing a key role in both expanding renewable energy capacity and improving climate change mitigation performance. Meanwhile, regulatory non-market-based policies come up as important complementary actions. However, an inverted U-shaped relationship suggests their effectiveness diminishes as the number of policies in place increases. In contrast, market-based instruments such as carbon pricing and fossil fuels taxation ultimately constrain fossil fuel consumption but fail to drive the expansion of renewable energy generation. Therefore, an exclusive emphasis on these policy instruments proves ineffective in driving the energy transition and risks exacerbating fuel accessibility inequalities and deepening energy poverty. However, it is important to approach these results with caution. While the estimates are statistically significant and produce coefficients of reasonable magnitude (as well as the expected sign), the nature of panel analysis means that the results should be seen as an average across the

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[18] Graph XXX in Appendix illustrates the relationship between the GDP per capita and energy consumption per capita for the countries in the sample.

countries included in the estimation. As a result, the policy implications drawn from them are general in nature and should be tailored to each country individually.

Given the inherent limitation of energy efficiency improvements and resource allocation optimization in driving a near-zero emission scenario, decarbonizing the economy ultimately depends on expanding renewable energy capacity generation. In this context, public investment in energy R&D represents a climate action instrument directly impacting its deployment. Moreover, as highlighted by previous studies discussed in this article, public investment in energy R&D generates positive spillovers. It helps mitigate the high risks and uncertain returns associated with large-scale renewable energy projects, ultimately crowding in private resources. Thus, the state's role goes beyond merely correcting negative market externalities; rather, it can actively shape the structural conditions necessary for the energy transition.

Nevertheless, public direct investment remains a marginal instrument within the mainstream climate policy toolkit, which continues to prioritize market-based and price-controlling mechanisms as the primary instruments to drive the energy transition. These policies are compatible with the fiscal austerity discourse. In this sense, the already insufficient public budgets for climate action are increasingly at risk, as the deepening of political and institutional commitments to fiscal consolidation and public spending cuts across several advanced economies further constrains the state's ability to support the ecological transition.

In this context, the political economy dimension of the ecological transition cannot be overlooked, as disputes over how much to spend and where to allocate public resources highlight that these are inherently political decisions. Extending Blyth 's influential book titled *"Austerity: The History of a Dangerous Idea"* (2013), austerity has unfolded as an environmentally dangerous idea in the face of the ecological crisis.

Appendix

3.A Panel variables at country-level

Figure 3.A1: Renewable energy generation (TWh)

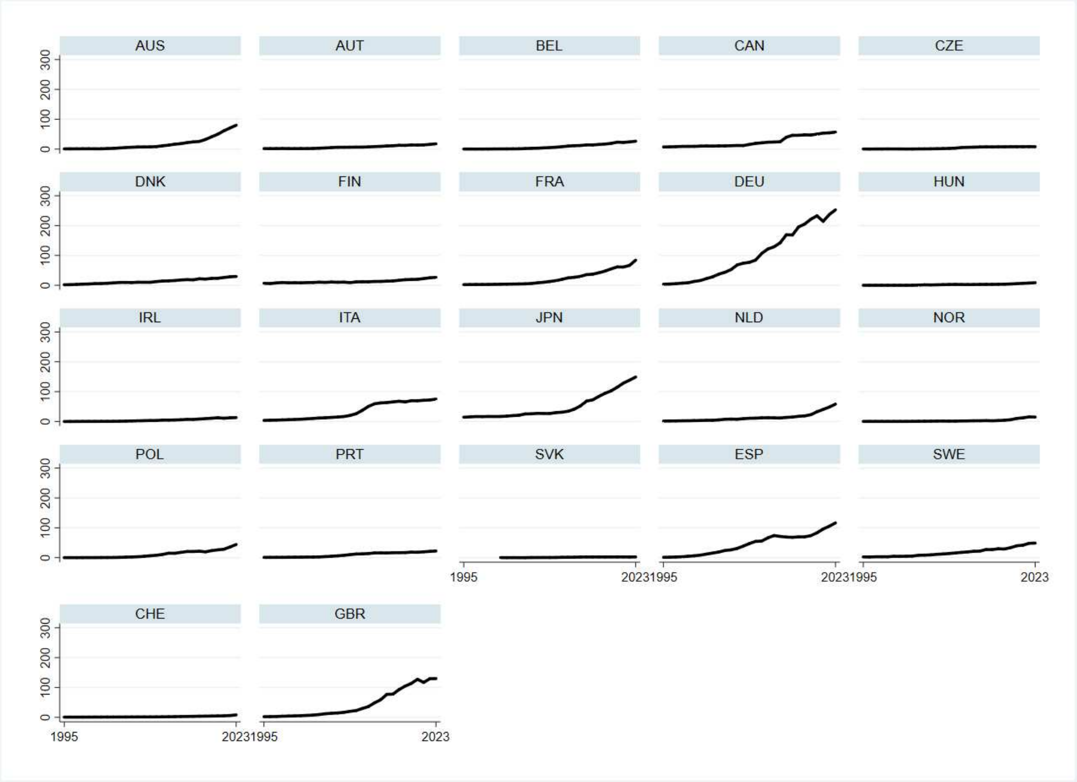


Figure 3.A2: Renewables share in primary consumption

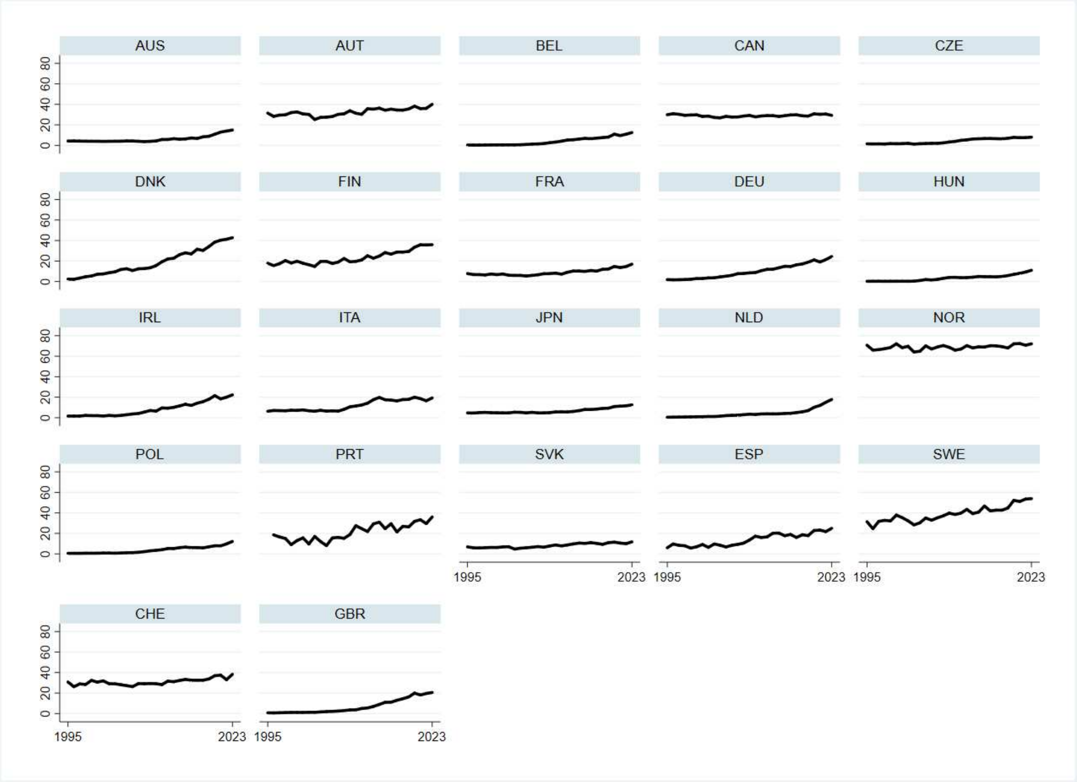


Figure 3.A3: Environmental Performance Index (climate change mitigation)

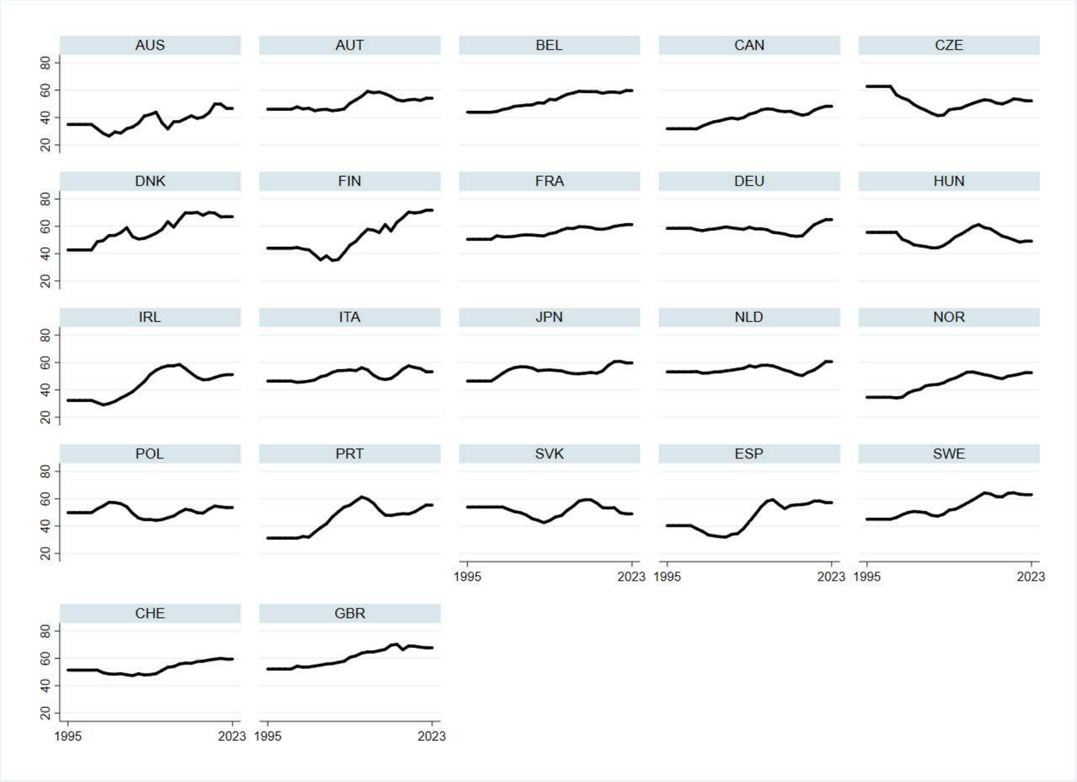


Figure 3.A4: Public investment in energy R&D (millions USD

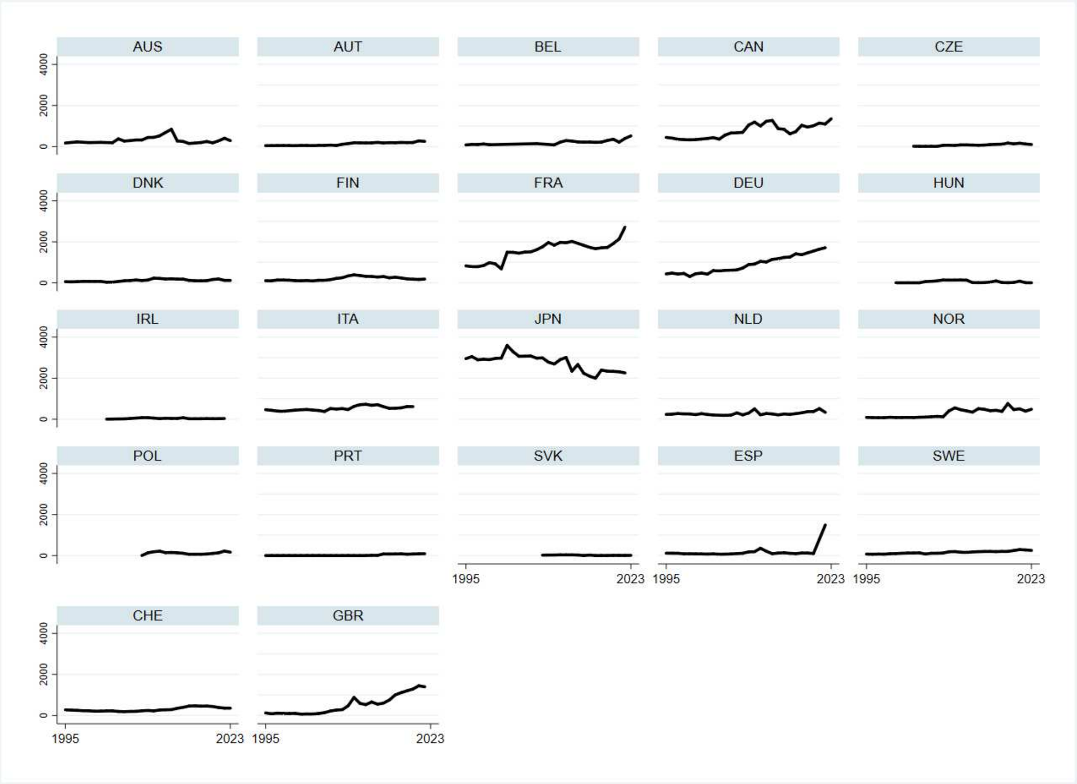


Figure 3.A5: Fossil taxation (million USD/exajoule)

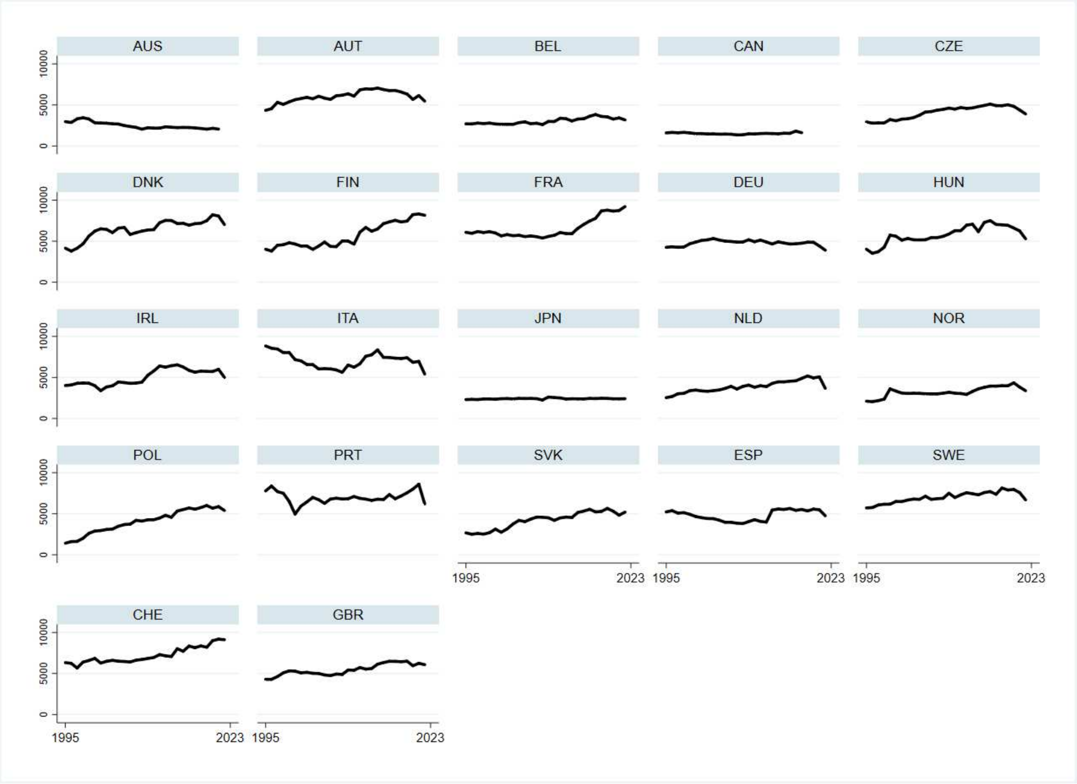


Figure 3.A6: Policies in place - non-market-based

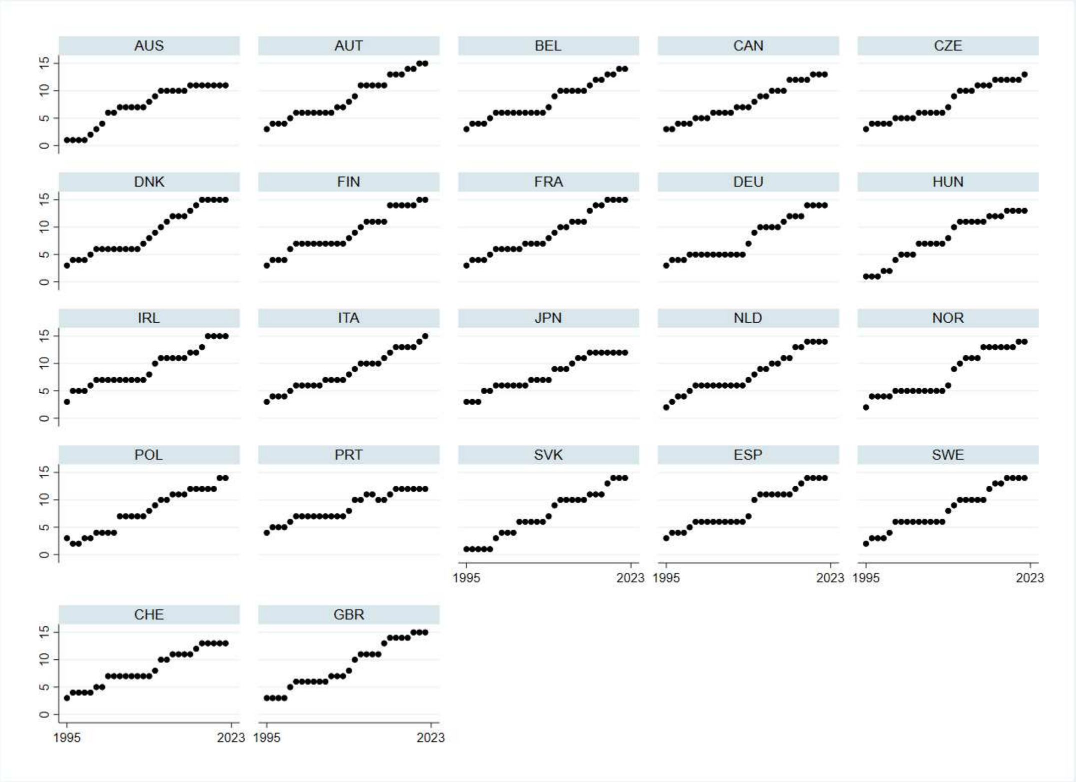


Figure 3.A7: GDP per capita (million USD)

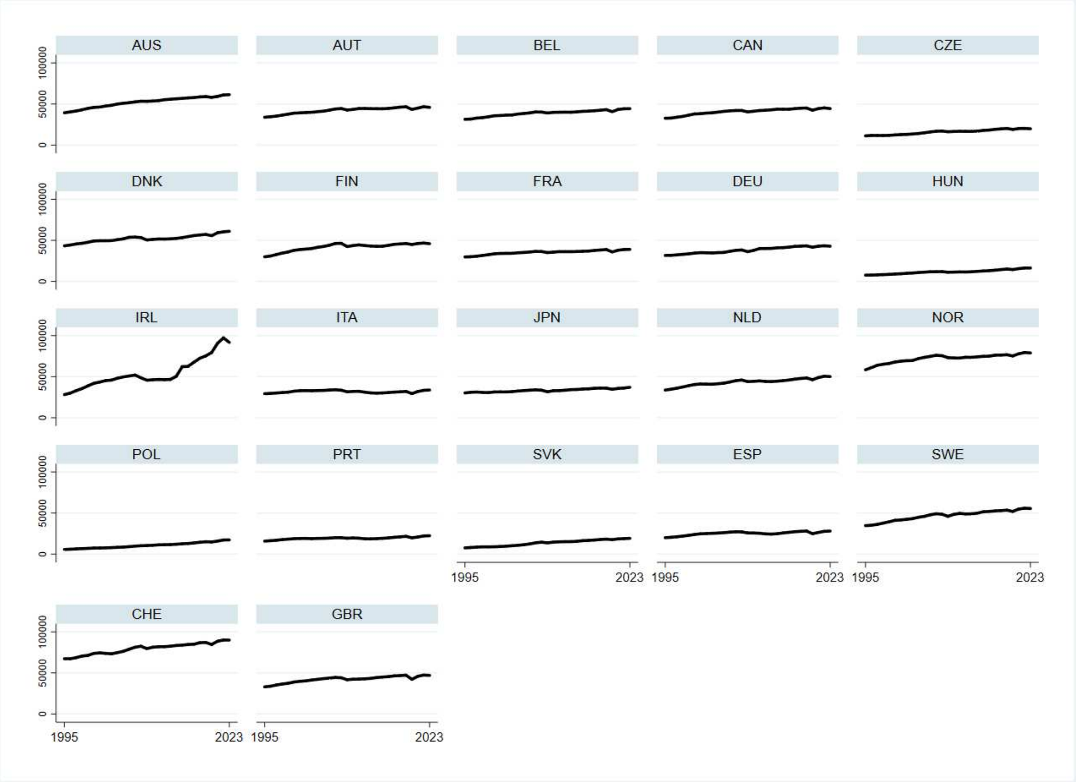
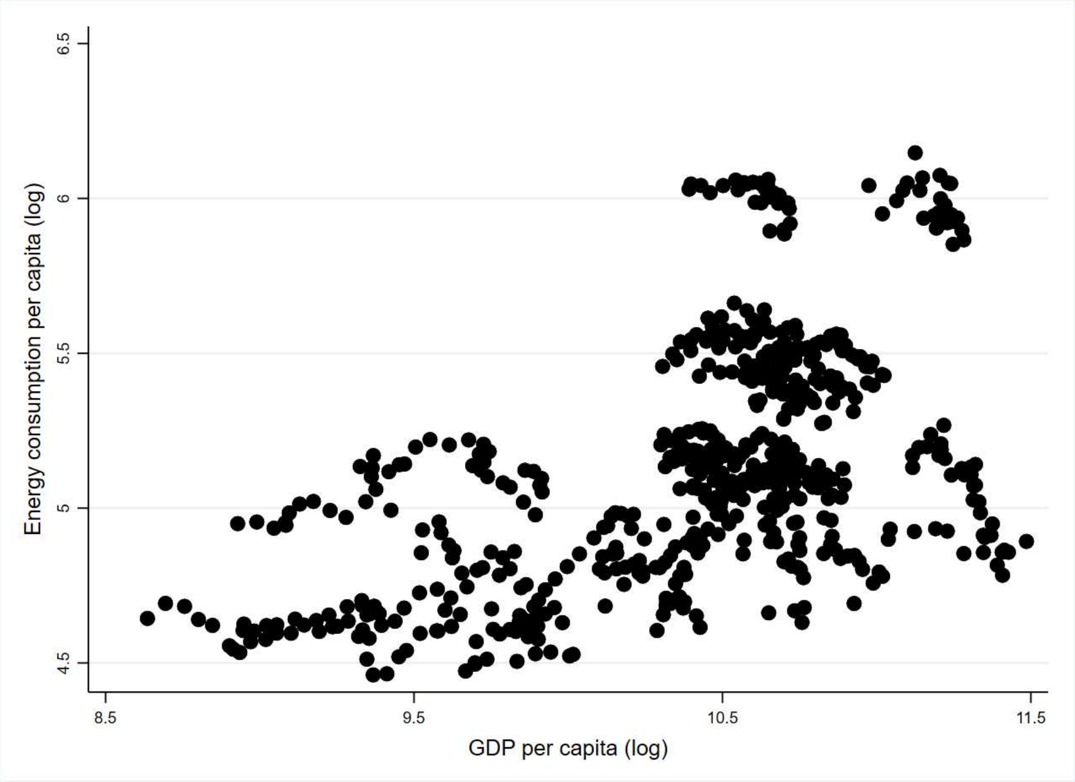


Figure 3.A8: Scatterplot GDP per capita and energy consumption per capita



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