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Institutional and Technological Dynamics for Ecological Structural Change: An Econometric Analysis

Chiara GRAZINI
https://orcid.org/0000-0002-7305-4945
Department of Economics, Engineering, Society and Business Organization
University of Tuscia[1], Italy
c.grazini@unitus.it

Giulio GUARINI
https://orcid.org/0000-0002-9159-3360
Department of Economics, Engineering, Society and Business Organization
University of Tuscia, Italy
giulioguarini@unitus.it

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Abstract:

This paper investigates the dynamics between institutional and technological factors driving ecological structural change in OECD countries from 1990 to 2020 by employing a feasible generalised least squares estimation on panel data. In particular, it explores how the pro-environmental institutional attitude and the green technological gap co-evolve and shape the ecological transition. Grounded in the post-Keynesian ecological macroeconomics, the analysis emphasises that green technological catching-up processes depend not only on technological capabilities but also on supportive institutional environments.

Results indicate that environmental policy stringency positively influences technological advancement and green productivity. Indeed, robust institutional frameworks foster the diffusion of green technologies, reduce ecological disparities, and strengthen environmental performance. At the same time, findings suggest a positive impact of green innovations on pro-environmental institutional attitude. However, diminishing returns emerge as pro-environmental institutional attitude intensifies, suggesting the emergency of institutional and social resistance to continuous policy tightening. Overall, the study underscores how coherent ecological policies, institutional learning, and green absorptive capacities are key to narrowing the green technology gap and advancing green institutional change by highlighting the importance of sustained political commitment and international cooperation to ensure that ecological transition contributes to equitable and resilient economic development.

Keywords: ecological structural change; green technological gap; pro-environmental institutional attitude; green innovations.

JEL Classification: E12; F43; Q55; Q56.

[1] Via del Paradiso, 47 - 01100 Viterbo (VT), Italy

Introduction

The environment has become increasingly pivotal in the analysis of economic growth and development, as prevailing growth trajectories are unsustainable, resulting in the depletion of substantial natural resources and fueling environmental degradation and climate change. Ecological challenges can be addressed through an ecological transition driven by Ecological Technological Progress and Ecological Structural Change. The latter involves increasing the proportion of green activities within economic output, thereby reducing CO_2 and other greenhouse gas emissions per unit of production by enhancing green productivity, understood as the reciprocal of environmental pressure intensity in the economic system (Guarini & Oreiro, 2023). Regulatory measures foster technological innovation and represent a crucial component of a successful ecological transition. However, environmental innovations by themselves cannot be relied upon to achieve enhanced socioecological harmony and equality inherently (Hickel, 2019).

Despite its environmental and economic advantages, the transition from brown (polluting) to green (environmentally sustainable) sectors may generate new 'winners and losers,' thereby exacerbating existing vulnerabilities and social inequalities (Sovacool et al., 2021). The ecological transition toward a low-carbon economy entails a movement toward greater energy efficiency, lower greenhouse gas emissions, and a more balanced relationship between economic development and environmental sustainability. Achieving this transition requires comprehensive climate policies, major technological innovations, increased investment in green technologies, and profound social and political transformations (Roy, 2024). Therefore, environmental concerns are focusing attention in contemporary debates within the field of international political economy (Galindo et al., 2020).

Economic development necessitates a process of convergence in per capita GDP between low- and high-income countries, implying that low-income economies must experience faster growth rates than their high-income counterparts. Especially, in a centre–periphery framework, disparities in technology and production capacities play a decisive role in determining patterns of economic growth and income distribution. An external constraint often limits economic expansion in peripheral regions, since these economies tend to specialize in sectors characterized by low-income elasticity of demand and limited technological progress. Moreover, the technological gap vis-à-vis the centre countries undermines the periphery's capacity to develop green innovations and to adopt production methods that exert less pressure on natural resources. So, socio-economic and ecological burdens resulting from environmental degradation remain disproportionately borne by low-income countries, with the most severe impacts experienced by impoverished populations.

The economic structure carries significant distributive and political economy implications that have a direct bearing on the functioning and quality of democracy (Bárcena & Porcile, 2022). So, the influence of technological, financial, and productive asymmetries on economic development is related to power asymmetries in shaping the rules of the game at both the international and domestic political levels. Grabowski (2013) contends that politically marginalised groups can hinder technological advancement. Historically, import substitution policies enacted by elites in emerging economies have caused technological stagnation in agriculture. This dynamic is especially relevant for low-income countries striving to close the technological gap and advance environmental innovations (ECLAC, 2020).

Ecological structural change demands diverse policy interventions, requiring extensive international cooperation and alignment of interests among varied domestic actors, despite frequent conflicts and inconsistencies in their priorities (Grazini et al., 2024). Indeed, identifying the sustainable growth path is not automatic, but it is the result of an intensive political negotiation and iterative economic policymaking, in which the prevailing outcome is determined mainly by the distribution of power among the actors involved (Porcile, 2024).

For instance, a sustainable development strategy that relies exclusively on technological advancement and environmental policies may lead to increased income inequality and higher unemployment rates (D'Alessandro et al., 2020). At the same time, the reorganisation of production systems necessitated by the ecological transition demands substantial short-term investments from capitalists (Stilwell, 2021). As suggested by Gatti (2022), political and social attitudes significantly influence the formulation of rules of the game and the design of policy incentives that may foster ecological transition. Therefore, this paper aims to contribute to the literature by empirically examining the relationship between the institutional and technological dynamics with respect to the ecological structural change. Specifically, the goal is to analyse the interaction between the green technological gap and the pro-environmental institutional attitude for 40 OECD countries by implementing the Feasible Generalised Least Squares Estimator on a panel data extracted from the OECD database on environmental export goods and EPS for the period 1990-2020.

The rest of the article is structured as follows: Section 1 introduces the research background of the empirical analysis. Section 2 describes data and the estimation strategy. The final section, instead, concludes with some relevant policy implications.

1. Research Background

Placing itself within post-Keynesian literature, the paper's theoretical framework is represented by the Balance of Payments constrained growth model (BOPCG), which highlights structural limitations hindering low-income countries' growth and emphasises how trade with technologically advanced countries restricts their long-term expansion potential. In particular, this model assumes that non-price competitiveness depends on the technological gap (Porcile et al., 2007). Low-income economies remain far from the technological frontier and are typically specialized in low-tech sectors and a narrow range of commodities whose international demand expands more slowly than that for technologically advanced goods (Felipe et al., 2012). Expanding the periphery's production into advanced market sectors like high-tech industries increases the flexibility of export and import demand. Achieving this diversification hinges on closing the technology gap with core economies, fostering greater international competitiveness and growth (Nassif et al., 2016). Nowadays, green technological change can serve as a key determinant of international competitiveness, as green innovation enhances price competitiveness by lowering production costs and strengthens non-price competitiveness by improving environmental performance and product quality as perceived in global markets (Guarini & Oreiro, 2023).

Environmental innovations and the development of technological capabilities mitigate environmental pollution, as green innovations typically involve higher technological sophistication and greater knowledge intensity compared to conventional innovations (Barbieri et al., 2020; Horbach et al., 2013). So, De Marchi (2012) identifies them as representing the new technological frontier. However, environmentally friendly technologies tend to originate predominantly in advanced economies, while the need for adaptation technologies is most acute in lower-income countries. Sbardella et al. (2018) note that, although industrialized nations such as the US, France, and Germany have historically led green innovation, the locus of inventive activity has increasingly shifted toward Asia. In contrast, Latin American and African countries have remained minimally represented in green technologies from 1980 to 2010 because of the uneven innovative capacity of institutional factors that either enable or constrain sustainable economic development. Different institutional settings and social norms can lead to divergent technological capacities, patterns of specialization, and trajectories of economic growth.

Institutional change is propelled by power struggles and conflicts among opposing political coalitions; however, asymmetrical power dynamics between these coalitions can produce highly fragile institutional changes (Rennkamp, 2019). The integration of ecological concerns emerges from a political process marked by conflict, collaboration, and ongoing negotiation - amid evolving power dynamics - among state actors, private enterprises, and civil society organisations (Shwom, 2011). Thus, sustainable development can be considered a contested political process involving environmental advocates, sustainable agricultural producers, industrial farmers, and government institutions (Hess, 2014). In fact, the author observes that reforms promoting sustainable transitions are more likely in countries with limited fossil fuel industry dominance, stronger emphasis on green technologies, and democratic institutions that foster greater political opportunities. So, a pro-environmental social and institutional orientation constitutes a prerequisite for any green development strategy aimed at forging an eco-developmental coalition of workers, entrepreneurs, and institutions (Dávila-Fernández & Sordi, 2020).

Specifically, the econometric model is grounded on the theoretical model proposed by Grazini et al. (2024). This model focuses on institutions that promote green technological advancement, comprising a broad spectrum of political and social actors, extending beyond parties focused solely on environmental issues. This institutional setting embodies the increasing awareness within civil society and political organisations of the imperative to prioritize environmental protection in policy agendas and societal demands. From the model, two main equations emerge: the green technological function and the green institutional function.

In the *green technological function*, ecological structural transformation depends on building a pro-environmental institutional attitude (G) to bridge the green technology gap (Z) and accelerate the diffusion of sustainable innovations. So, the growth rate (z) of the green technology gap depends on the levels of the gap itself (Z) and the pro-environmental institutional attitude (G), which is formalized as follows:

$$z = h_0 - h_g G - h_z Z \tag{1}$$

Where the green technological gap equals $Z = \log(\frac{T^F}{T})$, in which T^F are the green technological capabilities on the international technological frontier, and T the country's capabilities. A wider technological gap (Z) increases the potential for the follower country to achieve catch-up due to knowledge spillovers from leading to lagging economies, enabling the latter to accelerate technological progress through imitation and catch-up mechanisms (Castellacci, 2002). These countries should prioritise developing institutions that support technological learning. Enhancing green productivity does not result from automatic technological spillovers but arises from "green absorptive capabilities", represented by G (Grazini et al., 2024). Absorptive capability refers to a firm's capacity to discern the significance of external knowledge, assimilate and integrate it within its operations, and leverage it to stimulate productivity growth and innovation (Cohen & Levinthal, 1990). They differ across countries, shaped by the international diffusion of technology, which contributes to narrowing the gap, and by the pace of innovation in the global North, which tends to widen it (Fagerberg & Srholec, 2017; Lundvall et al., 2002). The enhancement of the absorptive capabilities can positively affect the country's international competitiveness. In particular, green absorptive capability is increasingly significant for competitiveness, as growing recognition of climate impacts and international attention for environmental sustainability (G) can influence trade negotiations and spur possible carbon-based barriers, spurring green innovations. Indeed, closing the technological gap requires "technological policies and structural change towards renewables and green technologies" (Porcile, 2024, p. 8), so so environmental innovations, changes in environmental friendly habits and attitudes can cause improvement of green absorptive capabilities. Therefore, a pro-environmental institutional attitude fosters more advanced learning institutions in low-income countries and promotes a regulatory framework that facilitates the diffusion of green technologies, supporting green technological catching up (Grazini et al., 2024).

In the *green institutional function*, the growth rate of the pro-environmental institutional attitude (g) falls with the green technology gap (Z) and the political power it has already acquired (G), as follows:

$$g = j_0 - j_g G - j_z Z \tag{2}$$

In low-income countries, the commodity-based specialisation strengthens brown institutions that can exert substantial economic influence, thereby anchoring the economy in low-tech sectors. So, the influence of the pro-environmental institutional attitude diminishes as the green technology gap widens, since its impact on the economic structure and overall performance becomes weaker than the influence of brown institutions. Moreover, a lack of social consensus on environmental issues hampers the adoption of green policies. Yet, as the pro-environmental institutions consolidate influence and strengthen institutions supporting green innovation, societal attitudes evolve, becoming increasingly favorable toward such measures (Dávila-Fernández & Sordi, 2020). However, assuming a scenario of decreasing returns of power accumulation, as the influence of pro-environmental institutional attitude increases, compensating forces and institutions gradually emerge in society to prevent the pro-environmental institutions from monopolizing political power.

2. Data and Estimation Strategy

We empirically test the ideas suggested in the previous section, which discusses the dynamics of Z and G. This paper uses panel data from the OECD database on environmental export goods and environmental policy stringency for 40 OECD countries from 1990 to 2020 to capture long-run movements in the green political power and the green technology gap. The econometric method is the Feasible Generalised Least Squares Estimator to control for heteroscedasticity and multicollinearity (Blackwell III, 2005; Wooldridge, 2019). The following two econometric equations approximate the *green technological function*:

i) $\mathrm{d.EPATGAP}_t = \alpha_1 - \beta_1\mathrm{EPATGAP}_{t-1} - \gamma_1\mathrm{EPS}_{t-1} + \delta_1\mathrm{POP}_{t-1} + \varepsilon_1\mathrm{d.GDP}_{t-1} + \varphi_1\mathrm{EU} + \sigma_1\,\mathrm{time} + \tau_1\,\mathrm{time}^2$

ii) $\mathrm{d.GREENPROD\_GAP} = \alpha_2 - \beta_2\mathrm{GREENPROD\_GAP} - \gamma_2\mathrm{EPS}_{t-1} + \delta_2\mathrm{POP}_{t-1} + \varepsilon_2\mathrm{d.GDP}_{t-1} + \varphi_2\mathrm{EU} + \sigma_2\mathrm{time} + \tau_2\mathrm{time}^2$

The following two econometric equations approximate the *green institutional function*:

iii) $\mathrm{d.EPS}_t = \alpha_3 - \beta_3\mathrm{EPATGAP}_{t-1} - \gamma_3\mathrm{EPS}_{t-1} + \delta_3\mathrm{POP}_{t-1} + \varepsilon_3\mathrm{d.GDP}_{t-1} + \varphi_3\,\mathrm{EU} + \sigma_3\,\mathrm{time} + \tau_3\,\mathrm{time}^2$

iv) $\mathrm{d.EPS}_{\,t} = \alpha_4 - \beta_4\mathrm{GREENPROD\_GAP}_{t-1} - \gamma_4\mathrm{EPS}_{t-1} + \delta_4\mathrm{POP}_{t-1} + \varepsilon_4\mathrm{d.GDP}_{t-1} + \varphi_4\,\mathrm{EU} + \sigma_4\,\mathrm{time} + \tau_4\,\mathrm{time}^2$

All variables are expressed in terms of logarithms, symbol “d.” indicates the difference of logarithms that approximates the growth rate, and symbol “t-1” means one year of temporal lag (in Table 2, this paper will also consider two year of temporal lag). The green technological gap is approximated by the “environmental patents gap” (EPATGAP) in equations i) and iii) and by the “green productivity gap” (GREENPROD_GAP) in equations ii) and iv). For estimating the environmental patents gap, the triadic patent variable is built starting by green patent date sourced from OECD PATSTAT by considering environment-related technologies (Haščič & Migotto, 2015); in particular, following Fabrizi et al. (2018), patents are referenced by their priority date, for which corresponding applications have been filed with the three major offices, the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO), and the Japan Patent Office (JPO). The green productivity, instead, is calculated as the reciprocal of GDP pollution intensity, measured as greenhouse gas emissions per unit of GDP. Then, both gaps are calculated as the ratio between the maximum value and the current value of the variables.

The pro-environmental institutional attitude is approximated by the Environmental Stringency Policy Index (EPS) developed by Kruse et al. (2022) only for OECD countries. Introduced in 2014 to fill the gap created by the lack of standardised measures for spatial and temporal policy comparison, the EPS Index offered the first comprehensive cross-country and longitudinal assessment of the severity of diverse environmental policy instruments (Koźluk & Zipperer, 2014). Initially focused only on market-based and non-market instruments addressing climate and greenhouse gas emissions, the index was updated in 2022 to incorporate technology support policies, which allow dividing upstream and downstream instruments supporting innovations in clean technologies (Hassan et al., 2024).

This paper employs this proxy for two different reasons. From a theoretical point of view, the Porter Hypothesis sustain that environmental regulation can stimulate technological innovation and generate efficiency improvements that surpass the costs associated with compliance (Kriechel & Ziesemer, 2009; Porter & Van der Linde, 1995). Indeed, the majority of investments in green innovations are undertaken by public institutions or supported through public subsidies directed toward environmentally oriented R&D, education, and training (Guarini & Porcile, 2016). From an operational point of view, instead, the EPS index represents one of the few tools currently available globally to measure the severity of environmental policies, which can be used as a proxy for the sensitivity of the institutional and social context towards environmental issues. Finally, the model controls for the population (POP), GDP growth rate (d.GDP), a dummy for European Union countries (EU), and a nonlinear temporal trend (time and time2).

3. Research Results

Table 1 shows that the theoretical equations, presented in the conceptual framework, are verified, a result which is also confirmed in Table 2, in which the variables present the same effects.

In column 1 of Table 1, $\mathrm{EPATGAP}_{t-1}$ shows a significant at 1% and negative effect of the environmental patents gap, supporting the existence of increasing returns in the technological change because the current innovations largely depend on past innovative performance that reduces the technological gap (Breschi et al., 2000). In column 2, $\mathrm{GREENPROD\_GAP}_{t-1}$ supporting the idea that eco-innovations lead to more efficient production processes, foster green productivity growth, and strengthen environmental performance, thereby narrowing the green productivity gap and providing firms with a competitive edge (Grazini & Guarini, 2025). Indeed, technological progress fosters the creation of complex products and services that integrate diverse scientific and technical knowledge, while simultaneously inducing structural change by reallocating resources and labour toward a higher value-added sector (Oreiro et al., 2020). Building on the role of productive and technological sophistication in development (Bresser-Pereira, 2019), ecological structural change can be viewed as a multifaceted process of ecological sophistication involving technological, social, and cultural dimensions, reliant on diverse green knowledge. Greater economic complexity enhances technological capacity, facilitating green innovation and eco-innovation diffusion (Boleti et al., 2021; Hartmann et al., 2017), by reducing the green technological gap. Finally, $\mathrm{EPATGAP}_{t-1}$ and $\mathrm{GREENPROD\_GAP}_{t-1}$ show a significant and negative effect on $\mathrm{d.EPS}_t$ in columns 2 and 4, respectively. Reducing the environmental patents gap and the green productivity gap, the development and diffusion of novel environmental innovations can stimulate additional R&D investment and the advancement of green technologies (Maghyereh et al., 2025), which may, in turn, foster the emergence of pro-environmental institutional orientations that support the adoption of more stringent environmental policies.

Similarly, in column 1, the significant (1%) and negative coefficient of EPS_{t-1} suggests that, in a pro-environmental institutional context, they will be more careful to adopt environmental policies capable of stimulating technological progress (reducing Z) (Lanoie et al., 2008). At the same time, increasing production costs can favour structural change towards sectors with higher aggregate value, such as green sectors (Fabrizi et al., 2024). When the institutional framework evolves toward greater environmental orientation, policies promoting green growth, sustainable investment, and improved technological capabilities are likely to diminish dependence on environmentally harmful final and intermediate goods within production processes, thereby enhancing green productivity and mitigating environmental degradation (Avenyo & Tregenna, 2022; Magacho et al., 2022; Romero & Gramkow, 2021). This result seems to be confirmed by the negative and significant (1%) of EPS_{t-1} in column 2, indicating an adverse effect on the green productivity gap. Green innovations can reduce ecological risks and increase green productivity; however, their effectiveness hinges on implementing stricter environmental standards than those governing traditional practices (Rennings, 2000).

Table 1: Interaction of green technology gap and institutional pro-environmental attitudes (lag 1 year).

	(1) $d.EPATGAP_t$	(2) $d.GREENPROD\_GAP_t$	(3) $d.EPS_t$	(4) $d.EPS_t$
$EPATGAP_{t-1}$	-0.0575*** (-5.64)		-0.00595*** (-2.84)	
$GREENPROD\_GAP_{t-1}$		-0.391*** (-15.49)		-0.0110** (-2.00)
EPS_{t-1}	-0.0529** (-2.05)	-0.125*** (-4.31)	-0.0799*** (-7.39)	-0.0792*** (-8.45)
POP_{t-1}	0.0158* (1.73)	0.00970 (0.87)	0.00154 (0.63)	-0.00118 (-0.52)
$d.GDP_{t-1}$	1.001* (1.70)	-1.106* (-1.81)	0.0505 (0.37)	-0.122 (-0.87)
Constant	Yes	Yes	Yes	Yes
EU dummy	Yes	Yes	Yes	Yes
Temporal trend	Yes	Yes	Yes	Yes
Observations	870	982	956	1001
N_g	39	37	40	39
N_t	28	29	29	29
chi2	39.43112	252.9978	71.35223	89.71148

Note: *t* statistics in parentheses * p < .1, ** p < .05, *** p < .01.
Source: Authors' elaboration.

Table 2: Interaction of green technology gap and institutional pro-environmental attitudes (lag 2 years)

	(1) $d.EPATGAP_t$	(2) $d.GREENPROD\_GAP_t$	(3) $d.EPS_t$	(4) $d.EPS_t$
$EPATGAP_{t-2}$	-0.0342*** (-4.12)		-0.00444** (-2.41)	
$GREENPROD\_GAP_{t-2}$		-0.267*** (-12.21)		-0.0123** (-2.38)
EPS_{t-2}	-0.0372* (-1.71)	-0.0715*** (-3.02)	-0.0497*** (-5.36)	-0.0561*** (-6.79)
POP_{t-2}	0.00473 (0.61)	0.0126 (1.36)	0.000653 (0.31)	-0.000233 (-0.11)
$d.GDP_{t-2}$	0.170 (0.32)	0.458 (0.83)	0.331*** (2.70)	0.316** (2.37)
Constant	Yes	Yes	Yes	Yes
EU dummy	Yes	Yes	Yes	Yes
Temporal trend	Yes	Yes	Yes	Yes
Observations	815	945	935	967
N_g	38	37	40	39
N_t	27	28	28	28
chi2	30.21911	150.3689	54.3239	73.73983

Note: *t* statistics in parentheses * p < .1, ** p < .05, *** p < .01.
Source: Authors' elaboration.

A sustainable strategy focuses on increasing the environmental efficiency of production through ecological macroeconomic policies designed to curtail CO_2 emissions, lessen reliance on fossil fuels, support industrial competitiveness, decrease energy costs, and advance productivity and economic growth, ultimately promoting environmental sustainability (Wenlong et al., 2023). In columns (3) and (4), the negative and significant (1%) coefficient of EPS_{t-1} seems to confirm the hypothesis of decreasing returns of power accumulation: As public attitudes toward climate policy become increasingly supportive, policymakers are better positioned to implement more stringent environmental regulations (Cafferata et al., 2021). However, political barriers to the accumulation of power emerges. Therefore, countries with greater pro-institutional attitude and with already very stringent environmental regulation will have more difficulty introducing new environmental policies, so that they will present a slower growth rate.

Conclusion

The The article, thanks to an econometric analysis, shows the significance of the interaction between institutional and technological dynamics for the ecological structural change.

Some relevant policy implications derive from the empirical evidence. First of all, Green policies can have a significant positive lagged impact on green technological catching up. The continuity of political green efforts appears difficult: the higher the level of efforts, the lower the growth, reflecting that there are always some political or social forces or mechanisms that make in discussion the relevance of the ecological transition, as in the case of critics about the New Green Deal in the European Union. This suggests the relevance of a continuous commitment to underline the emergence of environmental targets and the urgency of green interventions in order to maintain adequate social and political support. Another important policy implication concerns that the higher the green technological gap, the more substantial the reduction of this gap; this result suggests that policymakers should capture the opportunity of these green technological spillovers to invest in technological transfer and technological cooperation.

To the light of the limits of the article, the challenges for the new research activity can be the following: to enlarge the analysis to the low income countries; to consider other indicators that can better represent the institutional pro-environment attitude; to introduce other control variables for sounding the significance of the results; to more take into account the potential endogeneity across variables; to estimate the interaction between institutional and technological dynamics contemporaneously.

Credit Authorship Contribution Statement

Both authors contributed to: Conceptualization; Formal analysis; Investigation; Validation; Visualization; Writing - original draft; Writing- review & editing.

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Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The authors declare that there are no patents or copyrights to be asserted that are relevant to the work in the manuscript.

Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

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