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# O impacto da complexidade econômica e das políticas verdes na eficiência ambiental.

# The impact of economic complexity and green policies on environmental efficiency

**Chiara Grazini**[1]
**Giulio Guarini**[2]

**Resumo:** A transição ecológica só pode ser alcançada combinando Progresso Tecnológico Ecológico com Mudança Estrutural Ecológica nos sistemas econômicos (Guarini e Oreiro, 2023). No contexto capitalista, a eficiência ambiental não é apenas um critério, mas representa um fator crucial para a lucratividade e sustentabilidade das empresas. A transferência de trabalho e recursos dos setores poluentes para os verdes, a Mudança Estrutural Ecológica é essencial para melhorar a dimensão ecológica da produção, especialmente para economias emergentes. Sendo um fenômeno multidimensional, ela abrange uma dimensão social associada às preferências e hábitos verdes dos consumidores e instituições. Ainda assim, é principalmente um fenômeno tecnológico relacionado à acumulação de capital. Em conformidade com o novo conceito de desenvolvimentismo de sofisticação produtiva e tecnológica (Bresser-Pereira, 2019), a mudança estrutural ecológica pode ser considerada uma sofisticação ecológica de fatores tecnológicos, sociais e culturais. Este artigo visa contribuir para o Ecodesenvolvimentismo analisando a mudança estrutural ecológica através do impacto crítico da complexidade econômica e rigor da política ambiental na eficiência ambiental, implementando um estimador de Mínimos Quadrados Generalizados para ajustar o modelo econométrico em um conjunto de dados em painel extraído do banco de

[1] University of Tuscia, Viterbo, Italy, & Structuralist Development Macroeconomics Research group. ORCID: https://orcid.org/0000-0002-7305-4945. Email: c.grazini@unitus.it.
[2] University of Tuscia, Viterbo, Italy, & Structuralist Development Macroeconomics Research group. ORCID: https://orcid.org/0000-0002-9159-3360. email: giulioguarini@unitus.it.

dados da OCDE para 35 países, abrangendo o período de 1990 a 2020. Os resultados sugerem que políticas ambientais rigorosas combinadas com uma sofisticação tecnológica e de exportações podem representar uma estratégia vencedora para facilitar a Mudança Estrutural Ecológica, embora a transição ecológica não pareça envolver mudanças estruturais no sistema de produção para três países latino-americanos considerados: Brasil, Chile e México.

**Palavras- chave:** complexidade econômica e políticas verdes

**Abstract:** The ecological transition can only be achieved by combining Ecological Technological Progress with Ecological Structural Change in economic systems (Guarini and Oreiro, 2023). In the capitalist context, environmental efficiency is not only a criterion, but it represents a crucial driver of firms' profitability and sustainability. Shifting labour and resources from the brown sectors to green ones, the Ecological Structural Change is essential to improve the ecological dimension of output production, especially for emerging economies. Being a multidimensional phenomenon, it encompasses a social dimension associated with the green preferences and habits of consumers and institutions. Still, it is mainly a technological one related to capital accumulation. In line with the new developmentalism concept of productive and technological sophistication (Bresser-Pereira, 2019), the ecological structural change could be considered an ecological sophistication of technological, social, and cultural factors. This paper aims to contribute to the eco-developmentalism by analysing the ecological structural change through the critical impact of the economic complexity and environmental policy stringency on environmental efficiency by implementing a Feasible Generalised Least Squares estimator to fit the econometric model on a panel dataset extracted from the OECD database for 35 countries covering the period 1990-2020. Findings suggest stringent environmental policies combined with a sophistication of technology and exports could represent a winning strategy to facilitate Ecological Structural Change, although the ecological transition does not seem to involve structural changes in the production system for three Latin American countries considered: Brazil, Chile and Mexico.

**Key-words:** economic complexity and green policies

## Introduction

The ecological transition entails Ecological Technological Progress and Ecological Structural Change (Guarini and da Costa Oreiro, 2023). The augmentation of environmental efficiency or green productivity exemplifies the former. At the same time, Ecological Structural Change can consist of the relocation of output and employment from "brown" sectors to "green" sectors, which can make economic growth compatible with the reduction of CO2 emissions by increasing the environmental efficiency of output production. Being a multidimensional phenomenon, ecological structural change encompasses a social dimension associated with the green preferences and habits of consumers and institutions, but it is mainly a technological one related to capital accumulation.

Hidalgo and Hausmann (2009) elucidate economic development as a learning process aimed at increasing the production (and export) of more intricate products. Employing methods grounded in network theory, they demonstrate that a nation's developmental trajectory is contingent upon its ability to amass the necessary capabilities for producing diverse and notably sophisticated goods. Consequently, the comprehensive complexity of a country's productive framework emerges as the pivotal variable for elucidating growth and development. The disparate ability of countries in accumulating capabilities serves to account for variations in their performance (Felipe et al., 2012). According to Hidalgo and Hausmann's theory of capabilities, economic development involves not only the ongoing enhancement of producing the same array of goods but, more significantly, the acquisition of more intricate sets of capabilities. This acquisition is necessary for transitioning towards new activities linked to higher levels of productivity. This idea is in line with the new developmentalism concept of productive and technological sophistication, which is the pillar of a deep industrialization or structural change (Bresser-Pereira, 2019). Therefore, ecological structural change could be considered an ecological sophistication regarding technological, social, and cultural factors (Guarini and Oreiro, 2022).

Increasing the share of green activities could not only ensure the environmental sustainability of the economy but also represent a significant growth factor by fostering international competitiveness through strategies based mainly on environmental innovations (Grazini and Guarini, 2023). Already, Foster et al. (2008) support the existence of a virtuous cycle starting from innovation, leading to enhanced productivity and increased export market share. Environmental innovations can reduce ecological risk, pollution and other negative impacts of resource use (including energy use), but they require the support of stricter environmental regulations being more complex than traditional ones (Kemp and Pearson, 2007; Rennings, 2000). Opposing the mainstream vision of environmental regulation as a factor of erosion of profitability and competitiveness, Porter and Van der Linde (1995) sustain that a flexible environmental policy can improve the firms' performance by stimulating the adoption of innovations and promoting international competitiveness. This empirical study, within the eco-developmentalist approach, aims to investigate whether economic sophistication and environmental policy stringency can improve the environmental efficiency of production systems through an econometric analysis concerning OECD countries and three Latina American countries: Mexico, Chile (that are members of OECD) and Brazil (a non-member country that has working relationships with OECD). Moreover, the analysis verifies whether ecological structural change may represent a critical strategy to sustain ecological transition, especially in Latin American countries characterised by lower economic complexity (Benavente, 2016).

## 2. Descriptive Analysis

A preliminary empirical evidence of the possible relationship between ecological structural change, production sophistication and severity of environmental regulation can be obtained by observing the linear correlation between the Economic Complexity Index, environmental efficiency and Environmental Policy Stringency Index. In response to the growing international concern for sustainable development, the OECD provides reliable and harmonised data on environmental issues (Grazini and Guarini, 2023). To represent environmental efficiency, this study adopts the inverse of the pollution intensity of GDP indicated by the greenhouse emissions level per unit of GDP (ENV_EFF). Proposed in 2014 by the OECD and updated in 2022, the Environmental Policy Stringency Index (EPS) allow the spatial and temporal comparison of the stringency of different environmental policy measures, divided mainly into market instruments, non-market ones, and the strength of technology support policies that allow isolating upstream and downstream instruments supporting direct innovations in clean technologies.

The Porter hypothesis posits that meticulously formulated environmental regulations possess the potential to instigate innovation and enhance competitiveness among firms, concurrently yielding favourable ecological outcomes. Conversely, the absence of such instruments implies that firms may lack the capacity to discern or capitalise on technological and market opportunities for innovation aimed at mitigating their environmental footprint. Table 1 shows a 1% significant and positive correlation between the Environmental Policy Stringency Index and ecological efficiency, which seems to support the idea that stringent green policies can influence global trade patterns, shaping the complexity of transactions and vice versa. However, the low coefficient (0.533) could be attributed to the fact that strict environmental regulation stimulates green innovation, but some of these technologies are characterised by uncertainty of outcomes and ecological performance (Savona and Ciarli, 2019).

To attain inclusive green growth, nations must take into account a diverse array of economic, social, and environmental factors (Stojkoski et al., 2023). These considerations are frequently encapsulated by metrics of economic complexity derived from trade geography. In particular, production sophistication can be expressed through the Economic Complexity

Index (ECI). Developed by Hidalgo and Haussman in 2009 within Harvard's Growth Lab as a predictive tool for economic growth and income inequality, this index estimates the current country's production know-how using trade data and evaluating the diversification and complexity of its export basket. According to their values, the atlant of Economic Complexity computes an annual global ranking of countries (Figure 1 is the last available classification for 2021) and assesses a country's change since 1995. The linear correlation between environmental efficiency and the Economic Complexity Index is strongly significant at 1% and equals 0.3416 (see Table 1), meaning that higher knowledge concentration and economic complexity can contribute to better environmental performance because trade complexity is associated with a higher sophistication of exported products (Boleti et al., 2021; Lapatinas et al., 2019).

Mealy and Teytelboym (2022) have already highlighted how nations exhibiting higher Green Complexity Index are characterised by high environmental patenting rates, lower pollution intensity, and more rigorous environmental policies. Therefore, stringent green regulation could support the supplication of the production structure and trade, as indicated by the positive and significant 1% and positive correlation of 0.4217 between the two indices in Table 1. Therefore, both positive correlations seem to support the idea that both factors can represent critical drivers of ecological structural change.

Figure 1. The 2021 ranking of countries respects the Economic Complexity Index from the Atlant of Economic Complexity

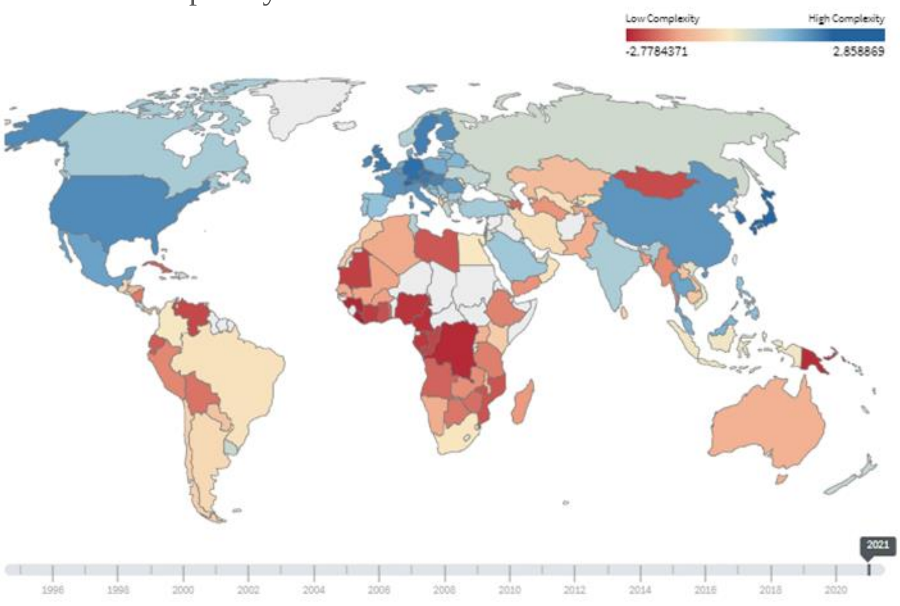

Table 1. The correlation matrix of ECI, EPS and environmental efficiency (ENV_EFF)

| | ENV_EFF | ECI | EPS |
|---|---|---|---|
| ENV_EFF | 1.0000 | | |
| ECI | 0.3416*** | 1.0000 | |
| EPS | 0.5331*** | 0.4217*** | 1.0000 |

ENV_EFF, ECI and EPS stand for Environmental Efficiency, Economic Complexity Index, and Environmental Policy Stringency Index, respectively. *** indicates a p-value < .01

## 3. The econometric analysis

The positive correlations described in the previous section provide a first indication of the nature of the relationship between a country's environmental performance, its level of sophistication and the rigour of environmental standards. To empirically examine the direct impact and the joint effect of economic sophistication and severe environmental regulation on environmental efficiency, this study implements a Feasible Generalised Least Squares (FGLS) estimator to fit the econometric model on a panel dataset extracted from the OECD database for 35 countries covering the period 1990-2020. The methodology allows us to consider the possible heteroscedasticity and serial correlation in the error term despite the small sample size. The dependent variable of the model is represented by the environmental efficiency (ENV_EFF), as defined in the previous section, while the independent variables are the Economic Complexity Index (ECI), the Environmental Policy Stringency Index (EPS), and the dummy variable (LA) representing the three Latin American countries present in the OECD database: Mexico, Chile (that are members of OECD) and Brazil (a non-member country that has working relationships with OECD). Moreover, we use the GDP per capita (GDPPC) to consider different economic developments. All variables are transformed in logarithms. The baseline econometric model is the following:

$$\mathrm{ENV\_EFF}_{it} = \alpha_0 + \alpha_1 \mathrm{GDPPC}_{it} + \alpha_2 \mathrm{LA} + \sum_{t=1}^{n} \tau_t \mathrm{YEAR}_t + v_{it} \quad (1)$$

where where $\sum_{t=1}^{n} \tau_t \mathrm{YEAR}_t$ and vit are time dummies and the white noise residual, respectively.

Then, we individually estimate the effect of the Economic Complexity Index and the Environmental Policy Stringency Index, with a time lag reasonable for the development of these effects and to take into account potential endogeneity issues:

$$ENV\_EFF_{it} = \beta_0 + \beta_1 GDPPC_{it} + \beta_2 LA + \beta_3 ECI_{it-1} + \sum_{t=1}^{n} \tau_t YEAR_t + v_{it} \quad (2)$$

$$ENV\_EFF_{it} = \gamma_0 + \gamma_1 GDPPC_{it} + \gamma_2 LA + \gamma_3 EPS + \sum_{t=1}^{n} \tau_t YEAR_t + v_{it} \quad (3)$$

Finally, we examine the joint effects of the three variables ECI, EPS, and LA:

$$ENV\_EFF_{it} = \delta_0 + \delta_1 GDPPC_{it} + \delta_2 LA + \delta_3 ECI_{it-1} + \delta_4 EPS_{it-1} + \delta_5 ECI_{it-1} * EPS_{it-1} + \sum_{t=1}^{n} \tau_t YEAR_t + v_{it} \quad (4)$$

$$ENV\_EFF_{it} = \theta_0 + \theta_1 GDPPC_{it} + \theta_2 LA + \theta_3 ECI_{it-1} + \theta_4 EPS_{it-1} + \theta_5 ECI_{it-1} * EPS_{it-1} + \theta_6 ECI_{it-1} * LA + \theta_7 EPS_{it-1} * LA + \theta_8 ECI_{it-1} * EPS_{it-1} * LA + \sum_{t=1}^{n} \tau_t YEAR_t + v_{it} \quad (5)$$

The results of regressions are shown in Table 2. Ecological transition is a complex phenomenon that can reinforce social and economic inequalities and intensify “preexisting divides between North and South, rich and poor, frontier and interior, but also introduce new ones related to innovation patterns, local pollution sinks, and volatile employment and economic growth” (Sovacool et al., 2021, p. 12). Countries possessing limited capabilities typically face diminished incentives to cultivate additional ones, potentially resulting in a predicament characterised by stunted economic development. The convergence of ecological transition and economic complexity represents a pivotal paradigm shift, fostering sustainability and innovation. Concurrently, economic complexity serves as a crucial metric reflecting a country’s capacity for sophisticated production and innovation in green technologies. While the coefficients of GDPPC e LA are not significant, the impact of the Economic Complexity Index (ECI) on environmental efficiency (ENV_EFF) heralds a new era where ecological stewardship and economic intricacy harmoniously shape our global trajectory, as indicated by the significant and positive coefficient of 0.0794 in model 2 and the slightly lower ones in models 4 and 5.

Green innovations are more complex than the standard ones, not only from the technological point of view but also from that of the experience and knowledge required. Therefore, the ecological transition requires significant green investments, which, however, still depend heavily on public support being hampered by higher fixed costs, risk, uncertainty and greater technological complexity (Grazini and Guarini, 2023). As described briefly in the introduction, technology-push and market-pull factors could not provide enough incentives to develop green innovations, so environmental regulations could constitute an essential tool to ensure economic, social, and sustainable development (Rennings, 2000). The significant and positive coefficient of the Environmental Policy Stringency Index (EPS) in Model 3 confirms that appropriate green policies give firms more significant incentives to innovate (Ambec et al., 2013), guaranteeing the economic and environmental sustainability of the ecological transition simultaneously. Looking at model 5, this impact seems stronger for Latin American countries, for which not only the coefficient of LA becomes significant, but the coefficient of interaction term $EPS_{t-1} * LA$ (0.326) is significantly greater than the single effect of EPS (0.0744).

The results described above seem to support the idea that the interplay underlying the relationship between economic development, technological innovation, and environmental sustainability could be backed by more stringent and effective ecological policy. “Universities and governments can support firms in investing in environmental fields by offering economic incentives and by transferring complex knowledge” (Fabrizi et al., 2018, p. 1022). Economies characterised by elevated levels of economic complexity and more severe environmental regulation are likely to possess the resources and capabilities necessary for the development of more sustainable R&D and technologies (Saqib and Dincă, 2023). In line with this hypothesis, models 4 and 5 both show a positive and significant joint effect of the two indicators on the environmental performance of the country ($ECI_{t-1} * EPS_{t-1}$). Therefore, the combination of stringent environmental policies and a more diversified and sophisticated economic structure could accelerate efforts in environmental innovations, which could improve environmental efficiency and sustain environmental exports thanks to the novel structural competitive advantages (Hausmann et al., 2007).

Hausmann et al. (2007) sustain that nations engaged in the export of technology-intensive goods, characterised by complexity and heightened productivity, often experience enhanced growth and development. This phenomenon is attributed to their superior techniques and skills, facilitating the seamless assimilation of new technologies thereby fostering the acceleration of economic growth. In general, knowledge is concentrated in a few industrialised countries characterised by continuous technological progress and commercialised more complex products. In this context, environmental innovation can create new structural competitive advantages for firms, improving the environmental performance of processes and the environmental quality of products. In contrast, the other countries are trapped in “the periphery of the product space” (da Costa Teixeira and Filho, 2023). In fact, the ten most sophisticated products, including machinery and chemicals, are predominantly exported by high-income economies. Conversely, the ten least complex products, such as wood and agricultural items, are primarily shipped by countries with middle or low incomes (Felipe et al., 2012), supporting the existence of a direct relationship between economic complexity and economic development.

Focusing on the three Latin American countries, economic sophistication seems to have a lower impact on environmental efficiency, as expressed by the negative and significant coefficient of $ECI_{t-1} * LA$ (-0.606) in the model 5. These countries are characterised by less economic complexity of the productive structure of these countries, which still depend heavily on natural-resource-based products and services. According to OECD (2023), agriculture and industry contribute a more significant proportion to the value-added of Latin American and Caribbean regions compared to the OECD area. Given the region's abundant reserves of valuable minerals and substantial deposits of oil and natural gas, the mining and energy sectors emerge as pivotal components. Despite the progress of many of these countries in the ECI world ranking, there is a looming threat of diminished future income owing to the region's reliance on exports of greenhouse-intensive products and low diversification of products (Benavente, 2016). At the same time, Latin American and Caribbean nations, encompassing Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, and Peru, intensified their climate initiatives from the adoption of the Paris Agreement in 2015, exhibiting advancements in both the adoption and stringency of climate policies. However, these measures still do not seem sufficient (OECD, 2023). In this context, model 5 shows that the combination of green policies and economic complexity in the three Latin American countries appears ineffective for the ecological structural change: the coefficient of the interaction term $EC_{t-1} * EPS_{t-1} * LA$ results significant and negative (-2.026). Therefore, "the Latin American economies face the challenge of adding complexity to their production and export structure, implying less reliance on a few natural-resource-intensive products" (Benavente, 2016, p. 108). Greening manufacturing activities could have significant implications for narrowing the technological gap and enhancing economic complexity. From this perspective, the ecological structural change as a process of technological, social and environmental sophistication could represent a winning strategy for these countries to enhance the nation's economic complexity and stimulate green growth by diversifying production and exports.

Table 2. The effects of environmental policy stringency Index (EPS) and Economic Complexity Index (ECI) on Environmental Efficiency (ENV_EFF): Feasible GLS models

| | (1) ENV_EFF | (2) ENV_EFF | (3) ENV_EFF | (4) ENV_EFF | (5) ENV_EFF |
|---|---|---|---|---|---|
| GDPPCt | 0.000863 | -0.00123 | 0.000566 | -0.00130 | -0.00171 |
| | (0.36) | (-0.49) | (0.26) | (-0.52) | (-0.66) |
| LA | 0.300 | 0.0415 | 0.235 | 0.0878 | 0.309*** |
| | (1.16) | (0.28) | (0.96) | (0.62) | (3.25) |
| ECIt-1 | | 0.0794*** | | 0.0638*** | 0.0655*** |
| | | (6.23) | | (4.97) | (5.16) |
| EPSt-1 | | | 0.0552*** | 0.0704*** | 0.0744*** |
| | | | (4.84) | (5.16) | (5.39) |
| ECIt-1 * EPSt-1 | | | | 0.0316** | 0.0318** |
| | | | | (2.41) | (2.43) |
| ECIt-1 * LA | | | | | -0.606*** |
| | | | | | (-3.31) |
| EPSt-1 * LA | | | | | 0.326*** |
| | | | | | (2.98) |
| ECIt-1 * EPSt-1 * LA | | | | | -2.026*** |
| | | | | | (-4.51) |
| constant | 1.629*** | 1.660*** | 1.581*** | 1.582*** | 1.580*** |
| | (68.60) | (75.89) | (59.97) | (59.52) | (59.51) |
| Time Dummies | YES | YES | YES | YES | YES |
| Observations | 837 | 625 | 797 | 624 | 624 |
| $chi^2$ | 705.3771 | 712.0104 | 674.5156 | 740.1909 | 791.5746 |

t statistics in parentheses. * p-value < .1, ** p-value < .05, *** p-value < .01

## 4. Concluding remarks

Attaining environmental sustainability necessitates the combination of Ecologically Efficient Technological Progress and Ecological Structural Change, which demands an ongoing advancement in production sophistication in the context of economic complexity, a progression not inherently spontaneous due to numerous market failures and associated risks inherent in investments related to cleaner technologies and innovations. Countries with a more complex economic structure have a better ability to manage resources and invest in environmental innovations. This study has provided an original contribution to the eco-developmentalism by analysing the ecological structural change through the critical impact of economic sophistication and environmental policies on environmental efficiency, both as individual effects and joint ones. Indeed, in achieving ecological transition, econometric results suggest that stringent environmental policies combined with a sophistication of technology and exports could represent a winning strategy to facilitate ecological structural change. With reference to the Latin American countries observed, namely Brazil, Chile and Mexico, empirical evidence is ambivalent: they appear to have more effective green policies but with lower green impact of economic complexity and lower green complementarity between these two factors. This result seems to suggest that the ecological transition does not entail structural changes in the production system in these countries. Obviously, future research could better analyse this critical point.

In line with Guarini and Oreiro (2022), positive and significant coefficients of the general Feasible GLS model seem to support the idea of the employment of a composite blend of public policies encompassing fiscal, industrial, trade, and regulatory measures within a national eco-developmental strategy is advocated. This approach takes into account the accrued insights into structural transformation and the prudent management of natural resources. An overarching eco-developmental system at the national level necessitates foresight into enduring technological trajectories, market amalgamation, and the facilitation of incentives. This anticipation aims to facilitate the adaptive restructuring of the economy, enabling it to capitalise on ecological structural changes conducive to heightened environmental sustainability. It must be not only a national strategy to achieve environmental sustainability but also an international cooperation plan in increasing green global demand and improving international non-price competitiveness.

However, some nations possess an intricate sector for tradable products, but their research and innovation sectors are comparatively less sophisticated. Research and technology complexity can contribute, even if to a marginal extent, to the Ecological Structural Change modelling production processes, influencing the workers' skill sets and wages as well as the pollution intensity of economic system due to green investments are more technologically complex (Stojkoski et al., 2023). Therefore, the main limit of the Economic Complexity Index may be overlooking crucial information pertaining to innovative activities, such as environmental patents and R&D investments, which are essential to support ecological structural change. Future research will focus on examining in more depth the contribution of different metrics of economic complexity, such as research and technology complexity.

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