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Orientação:

Professor João Estevão

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Abstract

This dissertation investigates whether environmentally related technological capabilities translate into export competitiveness in G20 economies. Although green innovation and technological capabilities are increasingly presented in the literature as potential sources of international competitive advantage, limited evidence exists on whether these capabilities generate measurable effects on aggregate export performance across a heterogeneous group of advanced and emerging economies. Using panel data for 19 G20 countries over the period 1996-2024, the analysis estimates fixed-effects models with year effects and standard errors clustered at the country level. Export performance, measured as exports of goods and services as a percentage of gross domestic product (GDP), is used as a proxy for international competitiveness. Environmentally related technological development is measured through environment-related inventions per million inhabitants, while research and development (R&D) intensity captures broader technological capabilities. The results show that environmentally related technological development is not significantly associated with aggregate export performance. R&D intensity provides only weak and statistically non-robust evidence of delayed effects. By contrast, imports emerge as the most robust determinant of export performance across specifications. The findings suggest that green technological capabilities do not automatically generate export competitiveness at the aggregate level, while imports appear to be more strongly and consistently associated with export performance. This study contributes to the literature by highlighting the limits and conditions under which innovation-related capabilities are transformed into international competitiveness.

Keywords: International competitiveness; export performance; technological capabilities; environmental innovation; R&D; G20.

Resumo

Esta dissertação analisa se as capacidades tecnológicas ambientalmente relacionadas se traduzem em competitividade exportadora nas economias do G20. Embora a literatura apresente a inovação verde e as capacidades tecnológicas como potenciais fontes de vantagem competitiva internacional, continua a existir evidência limitada sobre se estas capacidades geram efeitos mensuráveis no desempenho agregado das exportações, sobretudo em grupos heterogéneos de economias avançadas e emergentes. O estudo utiliza dados em painel para 19 países do G20 no período de 1996 a 2024. A análise estima modelos de efeitos fixos com efeitos anuais e erros-padrão agrupados por país. O desempenho exportador, medido pelas exportações de bens e serviços em percentagem do produto interno bruto (PIB), é utilizado como proxy da competitividade internacional. O desenvolvimento tecnológico ambientalmente relacionado é medido através das invenções ambientais por milhão de habitantes, enquanto a despesa em Investigação e Desenvolvimento (I&D) representa as capacidades tecnológicas mais gerais. Os resultados mostram que o desenvolvimento tecnológico ambientalmente relacionado não está significativamente associado ao desempenho agregado das exportações. A intensidade de I&D apresenta apenas evidência fraca e estatisticamente não robusta de efeitos desfasados. Em contraste, as importações emergem como o determinante mais robusto do desempenho exportador nas diferentes especificações. Os resultados sugerem que as capacidades tecnológicas verdes não geram automaticamente competitividade exportadora ao nível agregado e que a integração comercial desempenha um papel mais imediato na explicação do desempenho das exportações. O estudo contribui para a literatura ao evidenciar os limites e as condições em que as capacidades relacionadas com a inovação podem ser transformadas em competitividade internacional.

Palavras-chave: Competitividade internacional; desempenho das exportações; capacidades tecnológicas; inovação ambiental; I&D; G20.

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As a final note, and in the spirit that defined this journey: "Esforço, Dedicação, Devoção e Glória."

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List of Abbreviations

ADF: Augmented Dickey-Fuller

ENVTECH: Environmentally related technological development

EU: European Union

FDI: Foreign Direct Investment

GDP: Gross Domestic Product

IMF: International Monetary Fund

OECD: Organisation for Economic Co-operation and Development

R&D: Research and Development

RQ: Research Question

VIF: Variance Inflation Factor

Chapter 1 – Introduction

International competitiveness is increasingly shaped by countries' technological capabilities rather than exclusively by relative costs or traditional comparative advantages. As global markets become more knowledge-intensive, innovation, R&D investment and technological upgrading play a central role in explaining differences in export performance across countries. Technological capabilities strengthen competitiveness by improving productivity, supporting product differentiation and enabling economies to participate in more sophisticated segments of international markets. Therefore, competitiveness is increasingly associated with non-price factors related to innovation and productive sophistication (Fagerberg, 1988; Greenhalgh et al., 1994; Madsen, 2008). Early contributions also emphasised that technological leadership creates temporary competitive advantages by allowing countries to produce differentiated goods before new technologies are diffused to competitors (Posner, 1961; Vernon, 1966).

Despite this established relationship between innovation and export performance, an important gap remains regarding the role of environmentally related technological development. The global transition towards cleaner production systems and low-carbon technologies has increased the relevance of green technologies as potential sources of competitive advantage. However, existing evidence does not sufficiently explain whether environmentally related technological development translates into export performance at the aggregate level, nor whether this relationship differs between advanced and emerging economies. Much of the literature focuses either on conventional innovation, environmental outcomes or firm-level evidence, while comparatively less attention has been devoted to cross-country analyses of export competitiveness and green technological capabilities (Fankhauser et al., 2013; Fabrizi et al., 2024). In addition, many studies concentrate on specific regional contexts, particularly European economies, limiting the understanding of these relationships across more heterogeneous groups of countries (Braja & Gemzik-Salwach, 2019, 2020). Given these gaps in the literature, this dissertation seeks to answer the following research question (RQ):

To what extent do environmentally related technological capabilities and R&D intensity translate into export performance in G20 economies, and how do trade integration and countries' level of economic development shape this relationship?

This study addresses this gap by examining the relationship between environmentally related technological development and export performance in G20 economies over the period 1996–2024. Export performance is used as a proxy for international competitiveness, while environmentally related technological development is measured using the Organisation for Economic Co-operation and Development (OECD) indicator on the development of environment-related technologies, expressed as inventions per million inhabitants. Although this indicator is reported within the OECD green growth statistics, it is interpreted in this study as a proxy for environmentally related technological development rather than as a measure of green economic growth. The empirical analysis uses panel data methods, including fixed effects, lagged explanatory variables and heterogeneity analysis between advanced and emerging economies. The model also incorporates R&D intensity as a measure of technological capability and includes controls associated with international competitiveness, namely imports, foreign direct investment, inflation and economic growth. This study contributes to the literature on innovation and international competitiveness by providing comparative evidence on the relationship between environmentally related technological development and export performance across heterogeneous G20 economies. While previous studies often assume that green innovation enhances international competitiveness, the findings suggest that this relationship is weaker than commonly expected once country heterogeneity, time effects and macroeconomic controls are considered. The study further contributes by examining whether these relationships differ between advanced and emerging economies and by assessing the relative importance of other determinants of export performance, including trade integration, foreign direct investment and macroeconomic conditions. In doing so, the analysis highlights the conditions and limitations under which technological capabilities may translate into export competitiveness within increasingly sustainability-oriented international markets. The remainder of the dissertation is structured as follows. Chapter 2 reviews the literature on technological capabilities, environmentally related technological development and international competitiveness. Chapter 3 presents the methodology, data and econometric framework. Chapter 4 reports the empirical results. Chapter 5 discusses the findings. Chapter 6 presents the theoretical and policy implications. Chapter 7 concludes with the main findings, limitations and future research.

Chapter 2 – Literature Review

2.1 International competitiveness and technological capabilities

According to Martí and Puertas (2023), the capacity to develop and accumulate technological capabilities is a key determinant of international competitiveness. As international markets become increasingly dependent on knowledge, innovation and product sophistication and R&D, countries need to invest in technological upgrading to improve productivity, modernise productive structures and strengthen their position in external markets (Nelaeva & Nilssen, 2022). Therefore, R&D expenditure constitutes a key mechanism through which economies generate innovation and technological capabilities (Cohen & Levinthal, 1990), thereby supporting export performance and international competitiveness (Fagerberg, 1988). Technological change has long been identified as a determinant of trade patterns. Soete (1987) argues that differences in technological capabilities help explain variations in international trade performance, as innovation enables countries to develop competitive advantages and strengthen their position in the international markets. Innovation can create temporary competitive advantages by allowing countries to produce differentiated goods before new technologies are diffused to competitors (Posner, 1961; Vernon, 1966). In this sense, innovation generates advantages that are not based solely on price competitiveness, but also on product differentiation, quality improvements and technological sophistication (Fagerberg, 1988; Greenhalgh et al., 1994). The literature also shows that technological competitiveness may be more relevant than price competitiveness in explaining export performance. Fagerberg (1988) argues that differences in technological capabilities help explain why some countries achieve stronger performance in international markets. Similarly, Greenhalgh et al. (1994) show that innovation capacity contributes to competitiveness through quality improvements and product differentiation. Madsen (2008) also demonstrates that innovation improves the explanatory power of export demand models, suggesting that export performance depends not only on external demand or prices, but also on domestic technological capacity. This relationship is particularly important in high-technology sectors. In these sectors, competitiveness depends more on innovation, R&D intensity and technological sophistication than on cost advantages. Bottega and Romero (2021) show that technological competitiveness has a stronger effect on export performance in high-technology sectors. However, this effect is not automatic, since countries differ in their ability to transform R&D investment into export competitiveness (Braja & Gemzik-Salwach, 2020). Therefore, technological capabilities are central to international competitiveness, but their effects depend on the productive, institutional and structural conditions of each economy. Countries with stronger innovation systems, higher absorptive capacity and more developed industrial structures are more likely to convert R&D expenditure into export performance (Krammer, 2017; McCann & Ortega-Argilés, 2015). This is particularly relevant for the G20, where advanced and emerging economies coexist and present different levels of technological development. Although this literature provides strong evidence on the role of conventional technological capabilities, less attention has been given to environmentally related technological development as a specific source of export competitiveness. This gap is relevant because the global transition towards cleaner production systems and low-carbon technologies may create new competitive advantages for countries able to develop and apply green technological capabilities (Fankhauser et al., 2013; Algieri et al., 2025).

2.2 Green innovation and environmentally related technological capabilities

The growing importance of environmental sustainability has increased the relevance of green technologies in the global economy. Environmental innovation is increasingly viewed as a potential source of competitive advantage, as it may contribute to productivity improvements, technological upgrading and long-term economic growth (Fankhauser et al., 2013; Porter & van der Linde, 1995). As countries face stronger environmental pressures, climate change challenges and stricter environmental regulations, innovation related to environmental technologies has become increasingly important for maintaining competitiveness and adapting to sustainability-oriented markets (Porter & van der Linde, 1995; Fankhauser et al., 2013). In this context, environmentally related technological development is not only associated with environmental protection, but also with broader economic and competitive outcomes (Porter & van der Linde, 1995; Fabrizi et al., 2024). The relationship between environmental regulation and competitiveness has been widely discussed in the literature. Traditional approaches argue that environmental regulation increases production costs and reduce competitiveness by imposing additional constraints on firms and industries (Peuckert, 2014). However, the Porter Hypothesis suggests that properly designed environmental regulation can stimulate innovation and improve competitiveness by encouraging firms to adopt more efficient technologies and production processes (Porter & van der Linde, 1995). From this perspective, environmental pressures generate incentives for technological upgrading, efficiency improvements and the development of innovative products capable of strengthening competitive performance. Green technologies have therefore become increasingly associated with new forms of comparative advantage. Countries investing in renewable energy technologies, cleaner production systems and environmentally related innovation may improve productivity while positioning themselves in expanding international markets linked to sustainability and low-carbon production. Fankhauser et al. (2013) argue that the transition towards greener economies creates a “green race”, in which countries capable of developing strong environmental technological capabilities may obtain long-term competitive advantages in future global markets. The literature also suggests that environmentally related technological development contributes to competitiveness through several mechanisms. Green innovation supports energy efficiency, long-term cost reductions and productive modernisation. At the same time, environmental technologies contribute to product sophistication and facilitate compliance with international environmental standards, which are becoming increasingly important in global trade. Consequently, countries capable of generating and applying environmental technologies may be better positioned to strengthen export competitiveness, not only through technological leadership, but also through their ability to adapt to changing environmental and market conditions. Empirical evidence generally supports the existence of a positive relationship between environmental technological capabilities and competitiveness. Algieri et al. (2025) show that countries with stronger green innovation performance tend to exhibit higher levels of competitiveness, particularly in technologically advanced sectors. Similarly, Fabrizi et al. (2024) demonstrate that environmental research networks and collaborative innovation positively influence green export performance by facilitating technological diffusion and knowledge sharing across countries. These findings suggest that environmentally related technological development depends not only on domestic innovation efforts, but also on countries’ integration into broader technological and research networks. However, the literature also highlights that the effects of green technologies on competitiveness are not uniform across economies. The development of environmental technologies requires substantial investment, technological capabilities and institutional support. Countries with weaker innovation systems may therefore face greater difficulties in transforming environmental innovation into export competitiveness (Fankhauser et al., 2013; Krammer, 2017). Advanced economies generally possess stronger absorptive capacity, more developed R&D infrastructures and greater financial resources to support green technological transitions (Cohen & Levinthal, 1990; Krammer, 2017). By contrast, emerging economies often experience structural constraints that limit the competitive benefits associated with environmental technological development (Fankhauser et al., 2013; Krammer, 2017). Although the literature increasingly recognises the economic importance of environmentally related technological development, important limitations remain. Much of the existing evidence focuses on environmental performance, firm-level outcomes or specific green sectors rather than on aggregate export competitiveness. Furthermore, many studies concentrate on specific regional contexts, particularly European economies, limiting the understanding of how green technological capabilities affect competitiveness across more heterogeneous groups of countries (Fabrizi et al.2024; Algieri et al., 2025). These limitations reinforce the need to analyse broader and more diverse country groups, such as G20, where advanced and emerging economies coexist and differ substantially in their innovation systems, productive structures and levels of technological development.

2.3 Boundary conditions in innovation-led competitiveness

Although technological and environmental innovation may strengthen export competitiveness, their effects are not uniform across countries and may depend on the institutional context in which innovation takes place (Yi et al., 2013; Cohen & Levinthal, 1990; Krammer, 2017). The literature suggests that the capacity to transform innovation efforts into competitive advantages depends on several structural and macroeconomic conditions, including absorptive capacity, trade integration, foreign direct investment (FDI) and macroeconomic stability (Cohen & Levinthal, 1990; Krammer, 2017).

Therefore, the relationship between technological capabilities and export performance is influenced not only by innovation itself, but also by the broader economic environment in which innovation takes place. One of the most important concepts in this debate is absorptive capacity, which refers to the ability of firms and economies to recognise, assimilate and exploit external knowledge and technologies (Cohen & Levinthal, 1990). Countries with stronger innovation systems, more developed industrial structures and greater technological readiness are better positioned to absorb international knowledge spillovers and transform innovation into competitive outcomes (Krammer, 2017; Nelaeva & Nilssen, 2022). Consequently, advanced economies may be more capable of converting innovation efforts into export competitiveness than emerging economies, since they generally possess more mature technological infrastructures, stronger institutional frameworks and higher levels of productive sophistication. The literature also highlights the importance of trade integration in supporting technological upgrading and competitiveness (Keller, 2004; Amiti & Konings,2007; Bottega & Romero, 2021). Imports facilitate access to foreign technologies, capital goods and technologically sophisticated intermediate inputs, allowing countries to accelerate innovation and productive modernisation. In this sense, international trade contributes not only to market expansion, but also to technological diffusion and knowledge transfer.

Keller (2004) identifies international trade as one of the principal channels through which technology diffuses across countries, enabling economies to benefit from foreign knowledge embodied in imported goods and production technologies. Similarly, Amiti and Konings (2007) show that access to imported intermediate inputs enhances productivity by providing higher-quality technologies, greater input variety and knowledge embodied in foreign goods. These mechanisms contribute to technological upgrading and strengthen countries' productive capabilities, thereby improving their potential to compete in international markets. Consistent with this perspective, Bottega and Romero (2021) argue that export performance increasingly depends on structural and technological competitiveness rather than exclusively on price conditions, particularly in technology-intensive sectors. FDI may also influence innovation-led competitiveness through technology transfer and spillover effects. Multinational firms can contribute to the diffusion of technological knowledge, managerial practices and productive capabilities within host economies. Therefore, FDI may support domestic innovation and export competitiveness by facilitating integration into global value chains and international production networks (Krammer, 2017; Falahat et al., 2020). However, the literature also suggests that these benefits depend on countries' absorptive capacity and institutional conditions (Cohen & Levinthal, 1990; Krammer, 2017; Yi et al., 2013). In economies, characterised by weak innovation systems or limited technological readiness, FDI may generate fewer spillovers and weaker effects on domestic competitiveness (Cohen & Levinthal, 1990; Krammer, 2017; Yi et al., 2013). Macroeconomic stability represents another important condition affecting innovation and competitiveness.

Innovation activities usually involve long-term investment decisions, high uncertainty and substantial financial commitments, making them particularly sensitive to uncertainty and financial constraints (Aghion et al., 2010). As a result, unstable macroeconomic environments may discourage investment in R&D and technological development. Inflation increases uncertainty, reduces investment predictability and shortens firms' planning horizons, thereby limiting incentives for innovation and technological upgrading. Aghion et al. (2010) argue that macroeconomic volatility negatively affects long-term investment and the composition of investment decisions, reducing the capacity of firms and economies to engage in innovation efforts and transform technological capabilities into export competitiveness. Institutional and policy conditions also influence the effectiveness of innovation strategies. The literature on smart specialisation and innovation systems argues that competitiveness depends on countries' ability to coordinate industrial, technological and innovation policies.

Krammer (2017) emphasises that innovation performance is strongly influenced by institutional coordination and productive specialisation strategies capable of supporting technological upgrading. Similarly, Foray et al. (2009) argue that innovation policies become more effective when aligned with countries' productive capabilities and existing technological structures. Taken together, these contributions show that innovation-led competitiveness is shaped by the broader economic and institutional context in which innovation takes place. Absorptive capacity, trade integration, FDI, macroeconomic stability and policy coordination influence countries' ability to transform technological capabilities into export performance. This perspective is particularly central to the present study because it suggests that environmentally related technological development and R&D intensity should not be analysed in isolation, but in relation to the structural and macroeconomic conditions that may facilitate or constrain their translation into export competitiveness.

2.4 Synthesis and research hypotheses

The literature reviewed in this chapter shows that technological capabilities are central to international competitiveness and export performance. Innovation and R&D investment support productivity growth, product differentiation and technological upgrading, allowing countries to compete through non-price advantages rather than exclusively through costs or traditional comparative advantages (Fagerberg, 1988;

Greenhalgh et al., 1994; Madsen, 2008; Martí & Puertas, 2023). Within this broader debate, environmentally related technological development has emerged as a relevant but still insufficiently understood dimension of export competitiveness. Green technologies may contribute to efficiency gains, productive modernisation and adaptation to sustainability-oriented markets (Porter & van der Linde, 1995; Fankhauser et al, 2013; Fabrizi et al., 2024). However, the literature also suggests that these effects are not automatic, since the transformation of technological capabilities into export performance depends on structural, institutional and macroeconomic conditions, including absorptive capacity, trade integration, FDI and macroeconomic stability (Cohen & Levinthal, 1990; Krammer,2017; Yi et al., 2013; Aghion et al, 2010). Despite these contributions, important gaps remain. Existing studies often analyse conventional innovation and environmentally related technological development separately, focus on firm-level evidence or specific regional contexts, and devote less attention to the conditions under which green technological capabilities translate into aggregate export performance. These gaps justify analysing the G20 as a relevant empirical setting for assessing whether environmentally related technological development and R&D intensity translate into export performance beyond narrower regional or sectoral contexts. Based on the literature reviewed above, this study proposes the following hypotheses:

H_1: Environmentally related technological development positively affects export performance in G20 economies.

H_2: R&D intensity positively affects export performance in G20 economies.

H_3: The effect of environmentally related technological development on export performance differs between emerging economies and advanced economies.

H_{4a}: Imports positively affect export performance by facilitating access to foreign technologies and intermediate goods.

H_{4b}: FDI positively affects export performance through technology transfer and knowledge spillover effects.

These hypotheses provide the theoretical basis for the empirical analysis developed in the following chapter.

Chapter 3 – Methodology

3.1 Research Design

This study adopts a quantitative research design based on panel data analysis. The empirical objective is to examine the relationship between environmentally related technological development, broader technological capabilities and export performance in G20 economies, while accounting for trade and macroeconomic conditions. Figure 1 presents the empirical framework guiding the analysis.

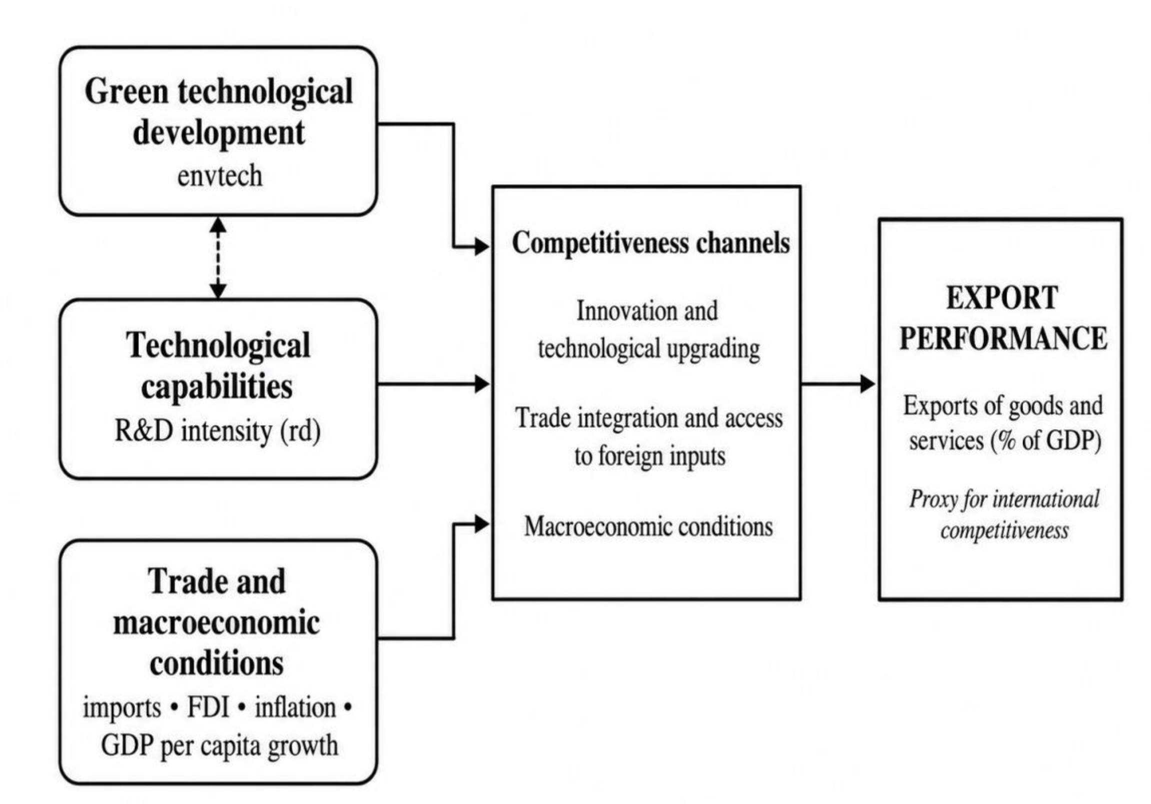

Fig. 1. Empirical framework of export performance determinants
Source: own elaboration.

It summarises the main explanatory dimensions considered in the study- green technological development, technological capabilities, trade integration and macroeconomic conditions- and shows how these factors are expected to relate to export performance through competitiveness-related channels.

The unit of analysis is the country, and the dataset is organised at the country year level.

This structure allows the observation of multiple countries over time and provides the basis for analysing both cross-country differences and within-country changes in export performance. The study is explanatory in nature, as it seeks to identify statistically significant relationships between innovation-related variables and export performance.

Given the observational character of the data, the analysis focuses on identifying empirical associations rather than establishing definitive causal effects. A panel data approach is particularly appropriate because export performance and technological development are shaped by both country-specific characteristics and temporal dynamics.

By combining cross-sectional and time-series dimensions, panel data allow the analysis to exploit variation across countries and over the time, while controlling for factors that cannot be directly observed. The empirical strategy relies on fixed-effects estimation, year effects, lagged explanatory variables and robust standard errors clustered at the country level. Fixed effects are used to control for unobserved country-specific characteristics that remain relatively stable over time and may influence export performance. Lagged variables are introduced to reflect the delayed nature of innovation processes strengthen the empirical strategy and improve the robustness of relationships under investigation.

3.2 Data and Sample

The empirical analysis focuses on G20 economies, which together account for a substantial share of global GDP, international trade flows and technological investment.

Given their dominant role in global production, trade and innovation, the G20 provides a relevant setting for examining the determinants of international competitiveness. The sample includes 19 G20 member countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russian Federation, Saudi Arabia, South Africa, Republic of Korea, Turkey, the United Kingdom and the United States. The European Union (EU) is not included as a separate observation in the empirical analysis. Although the EU is represented in the G20, it is a supranational entity rather than a sovereign country. Its inclusion could reduce comparability with country-level observations and create overlap with EU member states already included in the sample, namely France, Germany and Italy. Including both advanced and emerging economies allows for the comparative analysis of export competitiveness across different stages of development, levels of technological capability and macroeconomic conditions.

This is particularly relevant because differences in technological performance have long been recognised as central determinants of cross-country variation in export performance and international competitiveness (Fagerberg, 1988). Moreover, much of the empirical literature has focused primarily on OECD or European economies, limiting the scope for broader comparisons between advanced and emerging countries (Madsen, 2008; Fabrizi et al., 2024). The period of analysis spans from 1996 to 2024. This period was selected because it represents the longest time frame for which comparable data are available across the main variables used in the study. The dataset has a panel structure combining cross-sectional and time-series dimensions. The panel is unbalanced because data availability varies across countries, years and indicators, particularly for R&D expenditure and environmentally related technological development. Missing observations are not imputed. Instead, the analysis uses all available country-year observations for the variables included in each model specification. Consequently, the number of observations varies across models according to data availability, without excluding countries from the sample. The study relies on internationally recognised statistical databases to ensure data reliability and cross-country comparability. Data on exports, imports, GDP per capita growth, inflation and FDI are obtained from the World Bank's World Development Indicators. Data on R&D expenditure are also sourced from the World Bank. Indicators of environmentally related technological development are collected from OECD Statistics. A detailed description of the variables and data sources is provided in Table 1.

3.3 Variables

Table 1 provides a detailed description of the variables, including their definitions, data sources and supporting authors. The dependent variable is export performance, measured as exports of goods and services as a percentage of GDP. Although this indicator does not capture all dimensions of international competitiveness, it is widely used in macroeconomic studies as a proxy for countries' ability to participate in international markets (Fagerberg, 1988; Madsen, 2008). Given the country-level focus of this study, export performance provides suitable operational measure of external competitiveness and international market integration. The main explanatory variable related to environmental innovation is environmentally related technological development. This variable is measured using the OECD indicator on the development of environment-related technologies, expressed as the number of environment-related technological inventions per million inhabitants. Although the OECD labels this indicator under green growth statistics, in this study it is interpreted as a proxy for environmentally related technological development rather than a measure of green economic growth.

Accordingly, the variable is labelled as envtech in the empirical analysis. This indicator captures countries' capacity to generate environmentally oriented technological knowledge and is used as a proxy for green technological capabilities (Porter & van der Linde, 1995; Fankhauser et al., 2013; Algieri et al., 2025). Broader technological capabilities are measured through R&D expenditure as a percentage of GDP. R&D investment reflects countries' efforts to generate new knowledge, foster innovation and support technological upgrading, which are widely recognised as important drivers of competitiveness and export performance (Greenhalgh et al., 1994; Braja & Gemzik-Salwach, 2020). Several control variables are included to account for alternative determinants of export performance. Imports, measured as a percentage of GDP, capture countries' integration into international markets and access to foreign technologies, capital goods and intermediate inputs. FDI inflows, expressed as a percentage of GDP, are included to account for potential technology transfer and knowledge spillover effects.

Economic performance is proxied by GDP per capita growth, measured as the annual percentage growth rate of GDP per capita. Macroeconomic stability is measured through the inflation rate, defined as the annual percentage change in consumer prices. To account for heterogeneity across countries, a dummy variable is constructed to distinguish emerging from advanced economies. The variable takes the value of 1 for emerging economies and 0 for advanced economies, based on International Monetary Fund (IMF) country classification. This allows the analysis to assess whether the relationship between environmentally related technological development, R&D intensity and export performance varies according to countries' level of economic development.

The classification of countries used to construct this dummy variable is presented in Appendix 1.

Table 1: List of variables and definitions

Variable type	Name	Acronym	Description	Source	Authors
Dependent variable	Exports	*exports*	Exports of goods and services as a percentage of GDP. Used as a proxy for export performance	World Bank	Fagerberg (1988); Madsen (2008)

Variable type	Name	Acronym	Description	Source	Authors
			and international competitiveness at the country level.		
Independent variables	Environmentally related technological development	*envtech*	Number of environmentally related technological inventions per million inhabitants. Measures green innovation intensity.	OECD Statistics	Porter & van der Linde (1995); Fankhauser et al. (2013); Algieri et al. (2025)
	Research and Development	*rd*	Gross domestic expenditure on research and development as a percentage of GDP. Proxy for innovation capacity.	World Bank	Greenhalgh et al. (1994); Braja & Gemzik-Salwach (2020)
	Foreign Direct Investment	*fdi*	Net inflows of FDI as a percentage of GDP. Measures external capital investment.	World Bank	Krammer (2017); Falahat et al. (2020)
	Imports	*imports*	Imports of goods and services as a percentage of GDP. Captures the level of integration in international trade.	World Bank	Keller (2004); Amiti & Konings (2007); Bottega & Romero (2021)
	Inflation	*inflation*	Annual percentage change in consumer price index. Reflects macroeconomic stability.	World Bank	Aghion et al. (2010)
	Gross Domestic Product	*gdp*	Annual percentage growth rate of GDP per capita based on constant local currency. Reflects economic growth dynamics.	World Bank	Madsen (2008); Krammer (2017)

Variable type	Name	Acronym	Description	Source	Authors
	Emerging economy	*Emerging*	Dummy variable identifying emerging economies (1= emerging economy; 0= advanced economy).	Author's classification based on IMF country classification	Krammer (2017)

Source: own elaboration.

3.4 Descriptive Statistics and Preliminary Analysis

Before estimating the econometric models, descriptive statistics and preliminary diagnostic analyses are conducted to characterise the sample and assess the suitability of the data for panel estimation. Table 2 reports the descriptive statistics of the variables used in the analysis. Export performance presents an average value of approximately 26.880% of GDP, with values ranging from 6.730% to 62.112%, indicating substantial variation in export intensity across G20 economies. Imports also show considerable variation, with an average of 25.159% of GDP. R&D expenditure presents an average value of 1.592% of GDP, while envtech records a mean of 14.200 environment-related technological inventions per million inhabitants. The wide range observed for envtech, from 0.000 to 136.230, reflects strong cross-country differences in environmentally related technological capabilities. Inflation exhibits the highest dispersion among the macroeconomic variables, with a maximum value of 219.884% recorded in Argentina in 2024. This observation reflects an episode of extreme macroeconomic instability and suggests the presence of outliers that may influence the econometric results.

Table 2: Descriptive statistics

Variable	Mean	Std. dev.	Min	Max	N
exports	26.880	10.309	6.730	62.112	580
imports	25.159	8.454	8.320	53.434	580
gdp	2.924	3.589	-13.127	14.150	580
rd	1.592	.987	.042	5.211	485
envtech	14.200	22.778	0.000	136.230	512

inflation	6.426	15.375	-1.401	219.884	558
fdi	2.089	1.809	-3.601	12.609	580

Source: own elaboration.

Table 3 presents the Pearson correlation matrix. The results provide a preliminary assessment of the relationships between the variables included in the empirical analysis.

Although several statistically significant correlations are observed, the coefficients do not indicate severe multicollinearity problems overall. Exports and imports present a strong positive correlation (0.876), suggesting that economies with higher export intensity also tend to display higher import intensity. This association may reflect broader external openness and participation in international production networks.

A strong positive correlation is also observed between envtech and R&D intensity (0.852), which reinforces the need to assess potential multicollinearity more formally through the Variance Inflation Factor (VIF) test reported in Table 4.

Table 3: Pearson correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) exports	1.000						
(2) fdi	0.015	1.000					
	(0.715)						
(3) rd	0.081*	-0.055	1.000				
	(0.076)	(0.228)					
(4) inflation	-0.069*	-0.075*	-0.325***	1.000			
	(0.102)	(0.076)	(0.000)				
(5) envtech	0.164***	-0.162***	0.852***	-0.241***	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)			
(6) imports	0.876***	0.106**	0.169***	-0.099**	0.234***	1.000	
	(0.000)	(0.010)	(0.000)	(0.019)	(0.000)		
(7) gdp	-0.002	0.088**	-0.164***	-0.031	-0.192***	-0.040	1.000
	(0.954)	(0.033)	(0.000)	(0.460)	(0.000)	(0.331)	

This table presents the Pearson correlations of the variables used in this study. *** *p<0.01,* ** *p<0.05,* * *p<0.1*

Source: own elaboration.

Table 4 presents the results of the VIF test. This diagnostic is used to assess potential multicollinearity among the explanatory variables. High levels of multicollinearity affect the precision of coefficient estimates and complicate the interpretation of the econometric results.

Table 4: Results of the VIF test

Variable	VIF	1/VIF
envtech	4.290	.233
rd	4.080	.245
inflation	1.140	.876
fdi	1.130	.886
imports	1.120	.892
gdp	1.060	.948
Mean VIF	2.140	-

Source: own elaboration.

The VIF results indicate that multicollinearity is not a major concern. All VIF values are below the conventional threshold of 10, suggesting that multicollinearity does not constitute a serious concern in the estimated models (Meng et al., 2017). The mean VIF is 2.140. Although envtech and R&D intensity present the highest VIF values, 4.290 and 4.080 respectively, these values remain within acceptable limits. Therefore, the explanatory variables can be included simultaneously in the regression models without serious multicollinearity concerns.

Table 5 presents the results of the Fisher-type Augmented Dickey-Fuller (ADF) panel unit root tests. The null hypothesis of the test is that all panels contain unit roots and are therefore non-stationary.

Table 5: Panel unit root test results

	Level	First Difference
exports	32.654	429.667***
envtech	27.065	173.779***
rd	19.544	161.205***

inflation	186.546***	-
fdi	160.752***	-
imports	57.729**	-
gdp	248.063***	-

Fisher-type ADF unit root test. Level of significance: *** *p<0.01*, ** *p<0.05*, * *p<0.1*

Source: own elaboration.

The results indicate that inflation, fdi, imports and gdp are stationary in levels. By contrast, exports, envtech and R&D are non-stationary in levels but become stationary after first differencing. These findings suggest that exports, envtech and R&D are integrated of order one, I (1), whereas the remaining variables are integrated of order zero, I (0). Overall, the results indicate mixed orders of integration across variables. Since no variable is integrated of order two, the analysis proceeds with fixed-effects specifications, while the results are interpreted as conditional associations rather than long-run causal relationships.

3.5 Econometric Strategy

To empirically examine the relationship between environmentally related technological development, technological capabilities and export performance, this study employs panel data econometric techniques. The baseline specification includes country fixed effects and year fixed effects. Country fixed effects control for time-invariant country-specific characteristics, such as geography, institutional background and structural features of the economy. Year fixed effects control for common shocks affecting all countries each year. The baseline model is estimated with robust standard errors clustered at the country level to account for heteroskedasticity and serial correlation within countries over time. The contemporaneous baseline specification is defined as follows:

$$exports_{it} = \beta_0 + \beta_1 envtech_{it} + \beta_2 rd_{it} + \beta_3 imports_{it} + \beta_4 fdi_{it} + \beta_5 gdp_{it} + \beta_6 inflation_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where *i* represents the country and *t* represents the year. μ_i denotes country fixed effects, λ_t denotes year fixed effects and ε_{it} is the error term.

To account for the possibility that innovation affects export performance with a delay, a second specification introduces one-year lags for the innovation-related variables, envtech and R&D. This approach reflects the idea that technological capabilities and environmentally related technological development require time to influence productive structures and international competitiveness:

$$exports_{it} = \beta_0 + \beta_1 envtech_{it-1} + \beta_2 rd_{it-1} + \beta_3 imports_{it} + \beta_4 fdi_{it} + \beta_5 gdp_{it} + \beta_6 inflation_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Comparing the contemporaneous and lagged specifications allows assessing whether the effects of innovation-related variables on export performance emerge immediately or materialise over time. To examine whether these effects differ between emerging and advanced economies, an additional specification includes interaction terms between the emerging economy dummy and the innovation-related variables:

$$exports_{it} = \beta_0 + \beta_1 envtech_{it} + \beta_2 rd_{it} + \beta_3 (envtech_{it} \times emerging_i) + \beta_4 (rd_{it} \times emerging_i) + \beta_5 imports_{it} + \beta_6 fdi_{it} + \beta_7 gdp_{it} + \beta_8 inflation_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

The interaction terms allow assessing whether the relationship between innovation-related variables and export performance differs between emerging and advanced economies. Since the model includes country fixed effects, the time-invariant emerging economy dummy is absorbed by the country fixed effects and is therefore not included separately in the equation.

Several diagnostic tests are conducted to assess the adequacy of the econometric specification. The Hausman test is used to compare fixed-effects and random-effects estimators. The results of these tests are reported in Chapter 4. In addition, panel unit root tests are considered to assess the stationarity properties of the variables. To evaluate the robustness of the results, several additional specifications are estimated. First, given the strong correlation between exports and imports and the central role of imports in the baseline model, alternative specifications are estimated by excluding imports from the model and by introducing imports with a one-year lag. These robustness checks allow assessing whether the estimated effects of environmentally related technological development and R&D intensity are sensitive to the inclusion and timing of imports.

Second, the sensitivity of the results to alternative lag structures for the innovation-related variables is examined. Since environmentally related technological development and R&D investment may require more than one year to affect productive structures and export performance, models including one-year, two-year and three-year lags of envtech and R&D are estimated. Third, given the presence of extreme inflation values in some countries and years, the sensitivity of the results is assessed by excluding observations with inflation rates above 50%. Fourth, separate estimations are conducted for advanced and emerging economies.

Chapter 4 – Results

4.1 Diagnostic tests and model choice

Before estimating the baseline models, several diagnostic tests were conducted to assess the adequacy of the panel data specification and determine the most appropriate estimation strategy. The results are reported in Table 6.

Table 6: Diagnostic tests and model selection

Test	Statistic	p-value	Conclusion
Hausman test	15.780	0.327	FE retained on theoretical grounds
F test	63.630	0.000	Country effects present
Wooldridge test	71.250	0.000	First-order autocorrelation detected
Modified Wald test	842.600	0.000	Heteroskedasticity detected
Pesaran CD test	-	-	Not estimable due to highly unbalanced panel

Source: own elaboration.

The Hausman test does not reject the null hypothesis of no systematic differences between the fixed-effects and random-effects estimators ($\mathrm{X}^2 = 15.780$; $p = 0.327$).

This result indicates that the two estimators do not differ significantly from a statistical perspective. Nevertheless, the fixed-effects specification is retained on theoretical and econometric grounds, as it allows controlling for unobserved time-invariant country characteristics that may be correlated with export performance, such as institutional quality, productive structures and technological capabilities. The relevance of country-specific effects is further supported by the joint significance test of country effects. The null hypothesis that all country effects are equal to zero is strongly rejected ($F = 63.630;\ p < 0.01$), indicating the presence of statistically significant unobserved heterogeneity across G20 economies. The Wooldridge test rejects the null hypothesis of no first-order autocorrelation ($F = 71.250;\ p < 0.01$), indicating serial correlation in the idiosyncratic error term. The Modified Wald test also rejects the null hypothesis of groupwise homoskedasticity ($X^2 = 842.600;\ p < 0.01$), providing evidence of heteroskedasticity across panels. The Pesaran CD test for cross-sectional dependence could not be estimated due to the highly unbalanced structure of the panel and the insufficient number of common observations across countries. Overall, the diagnostic tests indicate the presence of statistically significant country-specific heterogeneity, first-order serial correlation and groupwise heteroskedasticity. Accordingly, the empirical analysis is based on fixed-effects models with year effects and robust standard errors clustered at the country level. This specification accounts for unobserved time-invariant country characteristics and provides more appropriate statistical inference in the presence of heteroskedasticity and within-country serial correlation.

4.2 Baseline and lagged fixed-effects results

Table 7 reports the results of the fixed effects estimates for the full sample of G20 economies. Column (1) presents the baseline specification using contemporaneous values of the explanatory variables. Columns (2), (3) and (4) introduce one-year, two-year and three-year lags of innovation-related variables, namely envtech and R&D intensity, to assess whether their effects on export performance materialize with delay.

Table 7: Baseline and alternative lagged fixed-effects results

Variables	(1) FE	(2) Lagged FE(t-1)	(3) Lagged FE(t-2)	(4) Lagged FE(t-3)

envtech	0.020 (0.013)	-	-	-
$envtech_{t-1}$	-	-0.001 (0.011)	-	-
$envtech_{t-2}$	-	-	0.009 (0.019)	-
$envtech_{t-3}$	-	-	-	0.041 (0.034)
rd	0.892 (0.755)	-	-	-
rd_{t-1}	-	1.252 (0.728)	-	-
rd_{t-2}	-	-	0.737 (0.889)	-
rd_{t-3}	-	-	-	-0.248 (1.498)
imports	1.045*** (0.062)	1.033*** (0.054)	1.021*** (0.055)	1.004*** (0.069)
fdi	-0.189 (0.155)	-0.110 (0.160)	-0.189 (0.147)	-0.150 (0.177)
gdp	0.070 (0.135)	0.091 (0.116)	0.058 (0.104)	0.128 (0.118)
inflation	0.030** (0.013)	0.041** (0.019)	0.033* (0.018)	0.035 (0.022)
Year fixed effects	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Clustered standard errors	Yes	Yes	Yes	Yes
Constant	-0.903 (1.728)	-1.144 (1.831)	0.978 (2.208)	1.758 (2.664)
Observations	433	434	435	422

Number of countries	19	19	19	19
Within R^2	0.743	0.752	0.700	0.692

Robust standard errors clustered at the country level are reported in parentheses. Level of significance: *** *p<0.01*, ** *p<0.05*, * *p<0.1*

Source: own elaboration.

4.2.1 Baseline results

The baseline fixed-effects estimates indicate that the coefficient envtech is positive but not statistically significant at conventional levels ($\beta = 0.020;\ p = 0.155$).

This suggests that, after controlling for country fixed effects, year effects and the remaining covariates, environmentally related technological development does not display a statistically significant contemporaneous association with export performance in G20 economies. R&D intensity also reports a positive coefficient ($\beta = 0.892;\ p = 0.253$). Although the sign of the coefficient is consistent with the expected relationship, the estimated effect is not statistically significant at conventional levels. Therefore, the baseline specification does not provide econometric evidence of a direct relationship between R&D intensity and export performance. Among the control variables, imports emerge as the strongest predictor of export performance. The estimated coefficient is positive and statistically significant at the 1% level ($\beta = 1.045; p < 0.01$). This indicates that, holding the remaining variables constant, a one-percentage-point increase in imports as share of GDP is associated with an estimated 1.045 percentage-point increase in exports as a share of GDP. This result is consistent with the literature emphasising the role of imports in facilitating access to foreign technologies, intermediate goods and knowledge spillovers. However, given the high correlation between exports and imports reported in the Pearson correlation matrix, the coefficient on imports should be interpreted with caution. Since both variables are measured as a percentage of GDP, the estimated coefficient may partly capture broader external openness and participation in international production networks, rather than a purely independent import effect. Inflation is also positively associated with export performance and is statistically significant at the 5% level ($\beta = 0.030; p = 0.039$). Nevertheless, this result should be interpreted cautiously, given the presence of extreme inflation episodes in some countries included in the sample.

By contrast, FDI and GDP per capita growth do not report statistically significant coefficients in the baseline model. Overall, the baseline results indicate that imports are the only variable with a strong and statistically significant association with export performance in the contemporaneous fixed-effects specification. In contrast, envtech and R&D intensity do not display statistically significant effects once country heterogeneity year effects and macroeconomic controls are accounted for.

4.2.2 Lagged Effects

To assess whether innovation-related variables affect export performance with delay, the baseline specification was re-estimated using one-year, two-year and three-year lags of envtech and R&D intensity. The results show that the lagged coefficient envtech remains statistically insignificant across all specifications. In the one-year lagged model, the coefficient is close to zero and not statistically significant ($\beta = -0.001;\ p = 0.956$).

In the two-year lagged specification, the coefficient becomes positive but remains insignificant ($\beta = 0.009;\ p = 0.650$). Similarly, in the three-year lagged model, envtech reports a positive coefficient, but the effect is not statistically significant at conventional levels ($\beta = 0.041; p = 0.252$). These results indicate that environmentally related technological development does not display a statistically significant delayed association with aggregate export performance within the lag structures considered. The coefficient of lagged R&D intensity is also statistically insignificant across the three specifications. The one-year lagged coefficient is positive and larger than the contemporaneous estimate ($\beta = 1.252;\ p = 0.102$), suggesting a possible delayed relationship between R&D intensity and export performance. However, the coefficient remains slightly above the 10% significance threshold and is therefore not statistically significant at conventional levels. The two-year lagged coefficient is also positive but insignificant ($\beta = 0.737;\ p = 0.418$), while the three-year lagged coefficient becomes negative and remains statistically insignificant ($\beta = -0.248;\ p = 0.870$). Overall, the lagged specifications do not provide robust econometric evidence that R&D intensity affects export performance with a delay. The estimated effects of the control variables remain broadly consistent across the lagged models. Imports continue to report positive and statistically significant coefficients at the 1% level in all specifications, confirming the strong association between imports and export performance. Inflation remains positive and statistically significant at the 5% level in the one-year lagged model ($\beta =$

0.041; $p < 0.05$) and at the 10% level in the two-year lagged model ($\beta = 0.033$; $p < 0.10$), but loses statistical significance in the three-year lagged specification. FDI and GDP per capita growth remain statistically insignificant across all lagged models.

Overall, the lagged fixed-effects results do not materially alter the baseline findings. The absence of statistically significant coefficients for envtech across all lag structures suggests that the lack of effect is not explained solely by short adjustment periods. Similarly, the evidence for R&D intensity remains weak and non-robust.

4.3 Heterogeneity between advanced and emerging economies

To assess whether the relationship between innovation-related variables and export performance differs according to countries' level of economic development, the baseline fixed-effects model was extended by including interaction terms between the innovation variables and the emerging economy dummy. The results are presented in Table 8.

Table 8: Heterogeneity between advanced and emerging economies

Variables	FE with interactions
envtech	0.003 (0.016)
rd	1.726 (1.065)
envtech x emerging	-0.596 (0.604)
rd x emerging	-0.163 (1.393)
imports	1.018*** (0.061)
fdi	-0.222 (0.161)
gdp	0.049 (0.136)
inflation	0.027* (0.015)

Year fixed effects	Yes
Country fixed effects	Yes
Clustered standard errors	Yes
Observations	433
Number of countries	19
Within R^2	0.750

Robust standard errors clustered at the country level are reported in parentheses. Level of significance: *** *p<0.01, *** *p<0.05, ** *p<0.1*

Source: own elaboration.

The coefficient of envtech is positive but statistically insignificant for advanced economies, which constitute the reference group in the interaction model ($\beta = 0.003; p = 0.861$). This indicates that environmentally related technological development does not display a statistically significant associated with export performance among advanced economies. The interaction term between envtech and the emerging economy dummy is also not statistically significant ($\beta = -0.596;\ p = 0.337$), suggesting that there is no econometric evidence that the effect of envtech differs systematically between advanced and emerging economies. A similar pattern is observed for R&D intensity. The coefficient of R&D is positive but not statistically significant at conventional levels ($\beta = 1.726;\ p = 0.122$). this indicates that the estimated relationship between R&D intensity and export performance does not differ significantly across the two groups of countries. Among the control variables, imports remain positive and statistically significant at the 1% level ($\beta = 1.018;\ p < 0.01$), confirming the strong association between imports and export performance. Inflation is positive and weakly significant at the 10% level ($\beta = 0.027;\ p < 0.10$), while FDI and GDP per capita growth do not report statistically significant coefficients. Overall, the interaction model does not provide evidence of heterogenous effects between advanced and emerging economies. Both interaction terms are statistically insignificant, indicating that the effects of environmentally related technological development and R&D intensity on export performance do not differ significantly according to the advanced-emerging classification. Therefore, the results do not support H3.

4.4 Robustness checks

To assess the stability of the baseline findings, several robustness checks were conducted. Table 9 reports the results obtained after excluding observations associated with extreme inflation rates above 50%, estimating the model separately for advanced and emerging economies, excluding imports from the baseline specification and replacing contemporaneous imports with one-year lagged imports.

Table 9: Robustness checks

Variables	Baseline FE	Inflation <50	Advanced economies	Emerging economies	Without imports	$imports_{t-1}$
envtech	0.020 (0.013)	0.020 (0.014)	-0.012 (0.016)	-0.665 (0.605)	0.056 (0.037)	0.013 (0.017)
rd	0.892 (0.755)	0.884 (0.796)	2.027 (1.211)	1.413 (1.692)	1.025 (2.366)	0.542 (0.755)
imports	1.045*** (0.062)	1.042*** (0.066)	1.045*** (0.096)	0.992*** (0.081)	-	-
$imports_{t-1}$	-	-	-	-	-	1.098*** (0.075)
fdi	-0.189 (0.155)	-0.202 (0.159)	-0.091 (0.096)	-0.330 (0.415)	-0.073 (0.297)	-0.109 (0.155)
gdp	0.070 (0.135)	0.094 (0.130)	-0.135 (0.155)	0.076 (0.147)	0.277 (0.175)	0.022 (0.104)
inflation	0.030** (0.013)	0.021 (0.044)	0.027 (0.260)	0.043 (0.027)	0.090 (0.058)	0.039 (0.027)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	433	423	229	204	433	419
Countries	19	19	9	10	19	19
Within R^2	0.743	0.737	0.841	0.719	0.241	0.702

Robust standard errors clustered at the country level are reported in parentheses. Level of significance: *** *p<0.01*, ** *p<0.05*, * *p<0.1*

Source: own elaboration.

The exclusion of observations with inflation rates above 50% does not materially alter the main results. The coefficients of envtech and R&D intensity remain statistically insignificant at conventional levels and display magnitudes like those obtained in the baseline fixed-effects specification. Imports also remain positive and statistically significant at the 1% level ($\beta = 1.042;\ p < 0.01$), confirming the stability of its association with export performance. By contrast, the coefficient of inflation loses statistical significance once extreme inflation episodes are excluded, suggesting that the positive coefficient observed in the baseline model is sensitive to outlier observations.

The subsample estimations for advanced and emerging economies provide similar evidence. Envtech remains statistically insignificant in both groups, indicating that the absence of a statistically significant coefficient is not driven by the aggregation of advanced and emerging economies in the full sample. R&D intensity also fails to reach conventional levels of statistical significance in either subsample. Although the estimated coefficient of R&D is numerically larger in advanced economies, the lack of statistical significance prevents any firm conclusion regarding differences between the two groups.

The specification excluding imports provides an additional robustness check.

Envtech remains statistically insignificant, suggesting that its lack of significance is not driven by the inclusion of imports in the baseline model. This reinforces the stability of the main results regarding environmentally related technological development. R&D intensity, FDI and GDP per capita growth also remain statistically insignificant in this specification. The specification using one-year lagged imports further confirms the robustness of the import coefficient. The coefficient of imports_{t-1} is positive and statistically significant at the 1% level ($\beta = 1.098; p < 0.01$, indicating that the association between imports and exports performance is not limited to contemporaneous variation. In this specification, envtech remains statistically insignificant ($\beta = 0.013$), and R&D intensity also remains insignificant ($\beta = 0.542$). Overall, the robustness checks support the baseline results. Across the alternative specifications, envtech remains statistically insignificant, while imports retain a positive coefficient statistically significant at the 1% level. The evidence for R&D intensity remains weak and non-robust, and the significance of inflation appears sensitive to extreme observations.

Chapter 5 – Discussion

5.1 Green technological capabilities and export performance

The empirical results indicate that environmentally related technological development is not significantly associated with export performance in G20 economies. This finding does not support H1 and contrasts with substantial body of literature that identifies environmental innovation as a potential source of international competitiveness.

Porter and van der Linde (1995) argue that environmental innovation can improve competitiveness by stimulating efficiency gains and technological upgrading, while Fankhauser et al. (2013) suggest that countries investing in green technologies may develop new comparative advantages in emerging low-carbon markets. More recent studies also report positive associations between green innovation and competitiveness, particularly in technologically advanced sectors (Algieri et al., 2025; Fabrizi et al., 2024).

A possible explanation for the difference between these expectations and the present results relates to the indicator used. Environmentally related technological development is measured through environment-related inventions, which capture the generation of technological knowledge rather than its commercialisation, diffusion or integration into export-oriented production. Therefore, the existence of green technological capabilities does not necessarily imply an immediate effect on aggregate exports. The lagged specifications reinforce this interpretation. The coefficients of envtech remain statistically insignificant when one-year, two-year and three-year lags are introduced. This suggests that the absence of significant effects is not merely due to short adjustment periods. Rather, environmentally related technological development may not translate directly into aggregate export performance within the time horizons considered.

Another explanation concerns the dependent variable. Export performance is measured as total exports as a percentage of GDP, which may be too broad to capture the specific effects of green innovation. Environmentally related technologies may influence sectors, such as renewable energy, environmental goods or advanced manufacturing, but these effects can be diluted when all exports are analysed together. In this sense, green technological capabilities may affect more specific forms of export performance rather than aggregate exports. Finally, the results suggest that the competitiveness effects of green innovation may depend on complementary conditions. Cohen and Levinthal (1990) and Krammer (2017) emphasize the role of absorptive capacity, institutional quality and industrial capabilities in transforming innovation into economic outcomes. Since G20 economies differ substantially in productive structures and innovation systems, these conditions may influence whether environmentally related technological development generates export benefits. Overall, the findings suggest that green technological development alone is not sufficient to improve aggregate export performance. Rather than rejecting the relevance of green innovation, the results indicate that its contribution to competitiveness is likely to depend on sectorial specialisation, commercialisation capacity and broader structural conditions.

5.2 Imports and export performance

The empirical results identify imports as the most robust determinant of export performance across all model specifications. This finding is consistent with the literature emphasising the role of imports in supporting competitiveness and export performance through access to foreign technologies, intermediate inputs and international production networks. Bottega and Romero (2021) argue that export performance depends not only on domestic innovation capabilities but also on the interaction between technological factors and trade dynamics. Similarly, Romero and McCombie (2018) highlight the close relationship between export and import performance, suggesting that imports constitute an important component of countries' participation in international markets. One possible explanation is that imports provide access to intermediate goods, capital equipment and foreign technologies, which may contribute to productive efficiency and export capacity.

International technology diffusion can occur through trade channels, particularly when countries import technologically advanced goods and inputs (Keller, 2004). In addition, imported intermediate inputs may improve productivity by increasing input variety, quality and access to foreign technologies (Amiti & Konings, 2007). In the context of global value chains, countries often rely on imported inputs to sustain production and participate in international markets. This interpretation is also consistent with Krammer's (2017) argument that competitiveness increasingly depends on access to external sources of knowledge and technology. However, the strong role of imports should be interpreted with caution. Since both exports and imports are expressed as a percentage of GDP, the strong relationship between the two variables may partly capture overall trade openness or participation in global value chains rather than a direct technological diffusion mechanism. This concern is reinforced by the high correlation between exports and imports reported in the preliminary analysis. Therefore, although imports emerge as the most consistent determinant of export performance, the result should not be interpreted as evidence of a purely causal effect of imports on export competitiveness. The robustness checks support this interpretation. Imports remain relevant under alternative specifications, while environmentally related technological development remains statistically insignificant when imports are excluded from the model. This suggests that the absence of a measurable effect of envtech is not simply explained by the dominant role of imports in the baseline specification. Overall, the findings suggest that imports are strongly associated with export performance in G20 economies. Therefore, the results provide support for H4a, which proposed that imports positively affect export performance by facilitating access to foreign technologies and intermediate goods, although this relationship should be interpreted considering the methodological caution discussed above. By contrast, H4b is not supported. FDI does not exhibit a statistically significant effect on export performance across the estimated models. This suggests that FDI does not automatically translate into export competitiveness in the G20 sample. While FDI may represent a potential channel for technology transfer and knowledge spillovers, its effects are likely to depend on domestic absorptive capacity, institutional conditions and the strength of linkages between foreign firms and the domestic economy.

5.3 R&D intensity and export competitiveness

The empirical results provide limited evidence regarding the contribution of R&D intensity to export performance. In the baseline specification, R&D presents a positive but statistically insignificant coefficient, indicating that no robust direct relationship can be established between broader technological capabilities and exports in G20 economies.

This finding only partially aligns with the literature that identifies innovation and technological capabilities as long-term drivers of competitiveness. Fagerberg (1988), Greenhalgh et al. (1994) and Madsen (2008) argue that R&D can support export performance through productivity gains, product differentiation and technological upgrading. From this perspective, a stronger and statistically significant relationship between R&D intensity and exports would be expected. However, the results of this study suggest that the transformation of R&D investment into export competitiveness is not automatic. This interpretation is consistent with Cohen and Levinthal's (1990) concept of absorptive capacity, which emphasizes that the economic value of knowledge depends on the ability to assimilate and apply it effectively. Similarly, Krammer (2017) highlights that innovation-related advantages depend on complementary structural and institutional conditions. In this sense, R&D intensity may represent the existence of technological effort, but not necessarily the successful conversion that effort into export performance.

The absence of robust statistical significance may also reflect the aggregate nature of the dependent variable. R&D may contribute more directly to specific forms of export competitiveness, such as high-technology exports, innovation-intensive sectors or more sophisticated export baskets, rather than to total exports of goods and services as a percentage of GDP. Overall, R&D intensity remains theoretically relevant as a component of technological capability, but its empirical effect on aggregate export performance is weak and non-robust in this study. Consequently, the evidence does not provide sufficient support for H2.

5.4 Heterogeneity between advanced and emerging economies

The results indicate that the relationship between technological capabilities and export performance does not differ significantly between advanced and emerging economies. Neither the interaction between environmentally related technological development and the emerging economy dummy nor the interaction involving R&D is statistically significant. Consequently, the findings do not support H3, which proposed that the relationship between environmentally related technological development and export performance would differ between advanced and emerging economies. This result contrasts with part of literature suggesting that advanced economies may be better positioned to transform innovation into competitiveness. Cohen and Levinthal (1990) emphasize the importance of absorptive capacity in converting knowledge into economic outcomes, while Krammer (2017) argues that more developed innovation systems are generally associated with stronger competitiveness effects. Based on these arguments, differences between advanced and emerging economies would be expected, but the empirical evidence does not confirm such differences in the present sample. However, the empirical evidence does not support this expectation. One possible explanation is that the distinction between advanced and emerging economies is too broad to capture the substantial diversity that exists within each group. As noted by Nelaeva and Nilssen (2022), countries differ considerably in terms of technological capabilities, industrial specialisation and internationalisation patterns, even when they belong to the same development category. The composition of the G20 reinforces this point, as several emerging economies have developed significant technological and industrial capabilities, while advanced economies also differ substantially in their innovation performance and productive structures. The findings therefore suggest that export performance is shaped by broader set of structural and institutional characteristics than countries' level of economic development alone.

Overall, the evidence suggests that the advanced-emerging distinction provides limited explanatory power for understanding the competitiveness effects of environmentally related technological development and R&D intensity in the G20 context. Rather than indicating that development level is irrelevant, the results suggest that this binary classification may be too broad to capture the conditions through which innovation-related capabilities are transformed into export performance. Consequently, H3 is not supported.

Chapter 6 – Theoretical and policy implications

6.1 Theoretical implications

This study contributes to the literature on innovation and international competitiveness by providing evidence that environmentally related technological development does not necessarily translate into higher export performance at the aggregate level. While previous studies frequently identify innovation as an important driver of competitiveness (Fagerberg, 1988; Greenhalgh et al. 1994; Madsen, 2008), the findings suggest that the relationship between green technological capabilities and export performance is more complex than often assumed. A first contribution concerns the literature on environmental innovation and competitiveness. Studies such as Porter and van der Linde (1995), Fankhauser et al. (2013) and Fabrizi et al., (2024) emphasize the potential of green technologies to generate competitive advantages. However, the results indicate that environmentally related technological development alone is not sufficient to improve export performance. This finding suggests that the competitiveness effects of green innovation depend on additional mechanisms that facilitate the transformation of technological capabilities into commercial and export outcomes. A second contribution relates to the role of technological capabilities. Although R&D presents a positive coefficient, the results do not provide robust statistical evidence of a direct effect on export performance. This finding supports the view that innovation processes are cumulative and may require time before generating measurable competitiveness gains.

Consequently, the study highlights the importance of considering temporal dynamics when analysing the relationship between innovation and export performance.

The study also contributes to the literature emphasising the role of imports and international trade-related channels in export performance. Among all explanatory variables, imports emerge as the most robust determinant of export performance. This result suggests that competitiveness should not be understood exclusively because of domestic innovation efforts, but also as a function of countries integration into international trade networks and their ability to access foreign technologies, intermediate goods and knowledge flows. Finally, the absence of significant differences between advanced and emerging economies contributes to the debate on innovation and development heterogeneity. The findings suggest that broad development classifications may provide limited explanatory power when analysing the competitiveness effects of technological capabilities. Instead, country-specific characteristics, including industrial specialisation, institutional conditions and technological structures, may play a more important role in shaping export performance. Overall, the findings challenge simplified interpretations of innovation-led competitiveness by showing that technological capabilities, particularly environmentally related technologies, do not automatically translate into export success. Rather, the relationship appears to depend on a broader set of economic, institutional and trade-related conditions that influence the capacity of countries to transform innovation into international competitiveness.

6.2 Policy implications

The findings of this study generate several implications for policymakers seeking to strengthen international competitiveness in an increasingly sustainability-oriented global economy. First, the results suggest that investments in environmentally related technological development should not be viewed as a guarantee of improved export performance. Although green technologies remain important for achieving environmental and climate objectives, the evidence indicates that their competitiveness benefits may not materialise automatically. Policymakers should therefore complement support for green innovation with measures that facilitate the commercialisation, diffusion and industrial application of new technologies. Second the absence of a significant relationship between green technological development and aggregate export performance highlights the importance of broader innovation ecosystems. Investments in research, technological development and innovation should be accompanied by policies that strengthen human capital, industrial capabilities and knowledge transfer mechanisms. Such complementary conditions may increase the likelihood that technological advances are transformed into economic and export outcomes. Third, the strong and consistent effect of imports suggests that access to imported inputs, foreign technologies and international production networks may play a central role in supporting export competitiveness. Policies that facilitate access to foreign technologies, intermediate goods and capital equipment may contribute to strengthening productive capacity and export performance. In this respect, maintaining open trade channels and promoting participation in global value chains may be as important as fostering domestic innovation activities. The findings also indicate that policymakers should adopt a long-term perspective when designing innovation policies.

The positive but statistically weak relationship between R&D and export performance suggests that investments in technological capabilities may require time before generating measurable economic returns. Consequently, expectations regarding the competitiveness effects of innovation policies should be realistic and consider the cumulative nature of technological development. Finally, the absence of significant differences between advanced and emerging economies suggests that policy recommendations should not be based solely on countries' level of economic development. Instead, greater attention should be given to country-specific conditions, including industrial structure, technological specialisation, institutional quality and integration into international markets. Policies tailored to these characteristics are likely to be more effective than one-size-fits-all approaches. Overall, the results suggest that improving export competitiveness requires a combination of innovation, access to imported inputs and supportive institutional conditions. Investments in green technologies remain important, but their contribution to competitiveness is likely to depend on the broader economic environment in which they are developed and applied.

Chapter 7 – Conclusions, limitations and future research

7.1 Conclusions

This dissertation examined whether environmentally related technological capabilities translate into export competitiveness in G20 economies. The empirical analysis focused on the effects of environmentally related technological development, R&D intensity, imports, FDI and differences between advanced and emerging economies on export performance. The results do not provide econometric evidence that environmentally related technological development has a statistically significant effect on export performance at conventional levels. This finding remains unchanged in the lagged specifications and in the robustness checks, indicating that the absence of significance is not driven by the timing of the variable or by the alternative model specifications considered. Therefore, H1 is not supported. The evidence regarding R&D intensity is also weak and non-robust. Although R&D reports positive coefficients in the baseline model and in the shorter lagged specifications, the estimated effects do not reach conventional levels of statistical significance. The one-year lagged coefficient suggests a possible delayed association, but it remains slightly above the 10% significance threshold.

Therefore, the results do not provide sufficient econometric evidence that broader technological capabilities directly affect aggregate export performance in G20 economies. Consequently, H2 is not supported. The results do not provide statistically significant evidence of differences between advanced and emerging economies in the relationship between innovation-related variables and export performance. The interaction terms between the innovation-related variables and the emerging economy dummy are statistically insignificant, suggesting that there is no econometric evidence of heterogeneous effects between advanced and emerging economies. Thus, H3 is not supported. Among the control variables, imports are the only variable that consistently displays a positive and statistically significant coefficient across the main specifications.

In the baseline model, imports are statistically significant at the 1% level, and this result remains stable in the lagged and robustness specifications. This provides support for H4a and suggests that import intensity is strongly associated with export performance in G20 economies. However, this relationship should be interpreted with caution and not as a strictly causal effect, as it may also reflect broader external openness and participation in international production networks. By contrast, FDI is not statistically significant in the estimated models, meaning that H4b is not supported. In response to the RQ, the findings indicate that environmentally related technological development and R&D intensity do not translate directly into aggregate export performance in G20 economies.

Instead, the econometric results suggest that export performance is more consistently associated with imports, while the effects of green technological capabilities and R&D remain statistically insignificant across specifications. The central conclusion is therefore that green technological capabilities may be relevant for competitiveness, but they are not sufficient, on their own, to generate measurable export performance at the aggregate country level.

7.2 Limitations

This study has several limitations that should be acknowledged. First, export performance is measured as exports of goods and services as a percentage of GDP.

Although this indicator is suitable for macro-level analysis of export intensity, it does not capture all dimensions of international competitiveness. It does not distinguish between high-technology exports, environmental goods, export sophistication or sectoral export specialisation. Therefore, the use of aggregate exports may limit the ability to identify the specific channels through which green technological capabilities affect competitiveness. Second, environmentally related technological development is measured through environment-related inventions per million inhabitants. This indicator captures the generation of environmental technological knowledge, but it does not measure whether these inventions are commercialised, diffused or incorporated into export-oriented production. As a result, countries may display high levels of environmentally related technological activity without necessarily translating this knowledge into export performance. Third, the analysis is conducted at the country level and does not include sectoral data. This is an important limitation because the effects of green technological capabilities may be concentrated in specific industries, such as renewable energy, clean technologies, environmental goods or advanced manufacturing.

These effects may be diluted when export performance is measured at the aggregate level. Fourth, the G20 includes highly heterogeneous economies in terms of productive structures, innovation systems, institutional quality, trade integration and technological readiness. Although the study distinguishes between advanced and emerging economies, this binary classification may be too broad to capture the specific conditions that shape the transformation of technological capabilities into export competitiveness. In addition, the relatively small number of countries in each group may reduce the statistically power of the interaction analysis, meaning that the absence of statistically significant interaction terms should be interpreted as lack of econometric evidence of heterogeneity, rather than definitive evidence that heterogeneous effects do not exist. Fifth, potential endogeneity cannot be fully excluded. The relationship between innovation, imports and export performance may be bidirectional, since more export-oriented economies may also have stronger incentives to invest in innovation and technological upgrading. The use of fixed effects and lagged specifications helps reduce some of these concerns, but it does not allow for definitive causal interpretation. Sixth, the panel is unbalanced due to differences in data availability across countries, years and indicators, particularly for R&D expenditure and environmentally related technological development. Although the analysis uses all available country-year observations and preserves the country coverage of the sample, the variation in the number of observations across models may affect comparability between specifications. Seventh, the analysis only considers lagged effects up to three years. Innovation processes may require longer periods before influencing productive structures, export capacity and international competitiveness. Therefore, the absence of statistically significant lagged effects should be interpreted within the time horizons considered in this study. Finally, the role of imports should be interpreted with caution. Since both exports and imports are expressed as a percentage of GDP, the strong association between these variables may partly reflect broader external openness or participation in global value chains rather than a direct technological diffusion mechanism. Although robustness checks excluding imports and using lagged imports were conducted, future research should further disentangle these channels.

7.3 Future research

Future research could extend this study in several directions. First, future studies could use alternative dependent variables to capture more specific dimensions of export competitiveness. Instead of relying only on aggregate exports as a percentage of GDP, it would be relevant to examine green exports, environmental goods or high-technology exports. These indicators could provide a more precise assessment of whether environmentally related technological capabilities influence specific forms of international competitiveness. Second, future research could use sectoral-level data. The effects of green technological capabilities may be more visible in industries directly linked to renewable energy, clean technologies, environmental goods, sustainable manufacturing or high-technology production. A sectoral approach would make it possible to identify whether environmentally related technological development affects some export categories more strongly than others. Third, future studies could move from country-level analysis to firm-level analysis by focusing on companies operating in green technology-related sectors within G20 economies. This would allow researchers to examine whether firms directly involved in clean technologies, renewable energy or sustainable manufacturing are more capable of transforming green technological capabilities and R&D investment into export performance. In this context, future research could compare firms with different degrees of green-technology intensity, rather than relying only on the advanced-emerging country distinction. Fourth, future studies could measure absorptive capacity and institutional quality more directly. Variables related to human capital, technological readiness, innovation systems or institutional conditions could help explain why some countries or firms are better able to transform technological knowledge into commercial and export outcomes.

Overall, these research avenues would help clarify where, when and under which conditions green technological capabilities are more likely to generate measurable export competitiveness.

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Appendices

Appendix 1 - Classification of G20 economies

Table A1. Classification of G20 economies

Advanced economies	Emerging economies
Australia	Argentina
Canada	Brazil
France	China
Germany	India
Italy	Indonesia
Japan	Mexico
Republic of Korea	Russian Federation
United Kingdom	Saudi Arabia
United States	South Africa
	Turkey

Note: Emerging economies are coded as 1, and advanced economies as 0 in the empirical analysis.

Source: own elaboration based on IMF country classification.