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Innovation, Trade Openness, and Green Finance: Drivers of Industrial Performance Across Countries

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Abstract

This study examines the determinants of industrial competitiveness by analysing the roles of energy efficiency, economic development, trade openness, research and development, foreign direct investment, renewable energy, green finance, and capital formation within a unified empirical framework. The analysis is based on panel data obtained from the World Bank, covering multiple economies over the study period. A dynamic panel data methodology is employed, beginning with panel unit root tests to determine stationarity properties, followed by Pedroni, Kao, and Westerlund cointegration tests to confirm long-run relationships among variables. The autoregressive distributed lag model and cross-sectionally augmented autoregressive distributed lag approach are then applied to capture both short-run dynamics and long-run equilibrium effects while accounting for cross-sectional dependence and heterogeneity. The findings provide strong evidence of a stable long-run relationship between industrial competitiveness and its determinants. Research and development, foreign direct investment, and gross domestic product per capita exert positive and statistically significant effects, emphasising the importance of innovation, capital inflows, and economic scale in enhancing industrial performance. Trade openness demonstrates mixed effects, reflecting its dual role in promoting efficiency while exposing domestic industries to external competition. Energy efficiency exhibits a nuanced relationship, with positive effects in some models and negative or insignificant impacts in others, indicating the presence of short-term adjustment costs alongside long-term benefits. The results also confirm strong persistence in industrial competitiveness and significant adjustment toward long-run equilibrium. Overall, the study highlights the importance of integrating innovation, financial development, and sustainable energy strategies to strengthen industrial competitiveness in an increasingly interconnected global economy.

Keywords: *Industrial Competitiveness, Research and Development, Foreign Direct Investment, Energy Efficiency*

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1. INTRODUCTION

Globalisation, technological change and the environment have made competitiveness a major issue for policymakers and researchers. In a world economy that is becoming more interconnected, the competitiveness of industries is not only important for firms to succeed, but also for the economic development, job creation and structural change of nations (Gapa, 2024; Abdurrahman, 2025; Rodrik & Stiglitz, 2025). Industrial competitiveness is a multifaceted phenomenon that is affected by a variety of economic, technological and institutional factors and that affects productivity, innovation and market performance at the national level. It is not only competitiveness based on capital and labour but also on the capacity to innovate, technological progress and sustainability concerns in the eyes of those who say they define competitiveness with the times the economy has become integrated into global value chains (Yufriadi et al., 2024; Abbas et al., 2024; Mubarok et al., 2025). These dynamics are constantly changing and require a detailed understanding of the factors influencing industrial competitiveness in a coherent analytical framework. The capacity of the economies to create and incorporate new knowledge, to engage new technologies and to increase production efficiency is therefore strongly related to the competitiveness of industry. There is consistent empirical evidence, which associates higher R&D

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investment and technological capability with better industrial performance and sustained economic growth (Peretto, 1999; Ali & Rehman, 2015; Akhtar et al., 2024; Afifi & Eliza, 2025; Kim, 2025). It stresses the need for innovative strategies to improve the competitiveness of industry.

The infrastructure, institutional quality and market size needed for competitive industrial sectors are provided by higher levels of income and economic development (Ali & Naeem, 2017; Abaidoo & Agyapong, 2022; Khan et al., 2024; Chandran et al., 2025). Economic development helps to create access to technology, a skilled workforce, financial markets, and tools, all of which help to improve productivity and industrial efficiency (Audi & Ali, 2017; Ahmad et al., 2022; Sima et al., 2020; Ahmad et al., 2024; Li, 2024; Ali et al., 2025; Siahaan et al., 2025). Furthermore, the process of capital accumulation and investment is also crucial for the development of production capacity, the improvement of infrastructure, and the introduction of technologies. Yet, the benefit gained from investment requires the allocation and efficiency of the resources that are invested, since poorly allocated resources may reduce investment's contribution to industrial competitiveness (Wang et al., 2023; Yu et al., 2025; Arianpoor, 2025). Such factors show the value of both the amount and the quality of economic development in influencing industrial results. Industrial competitiveness is also affected by trade openness and FDI, which promote linkages with international markets and technology transfer. Trade openness enables companies to gain access to wider markets, economies of scale and access to more advanced production techniques through exposure to international competition (Siddiqi et al., 2014). Foreign direct investment, meanwhile, is also a source of capital inflows, managerial skills and technological spillovers that help to promote industrial development. The impacts of trade openness are not, however, always beneficial; that is, greater exposure to international competition can also put domestic industry under pressure, especially in economies with low absorptive capacity or poor institutional structure. The two aspects of openness to trade suggest the importance of complementary policies to boost the competitiveness of domestic industries and to reduce potential risks (Li et al., 2023; Seti et al., 2025; Mirzaye & Mohiuddin, 2025).

Sustainability has become an important part of industrial competitiveness in recent years. Within the framework of climate change and resource constraints, energy efficiency, renewable energy use and green finance have come to be recognised as crucial factors influencing the performance of industries. Reducing energy consumption in production can lower production costs, improve productivity and help increase competitiveness. There is a complex relationship between energy efficiency and industrial performance, however, because energy-efficient technologies can create initial costs and adjustment burdens for industry (Agupugo et al., 2024; Seidu et al., 2025). Likewise, the development of renewable energy and green finance further supports sustainable industrial development by encouraging green financing and alleviating the use of fossil fuels. These elements are consistent with the notion of green growth, which incorporates aspects of both economic and environmental goals (Ahmad et al., 2018; Bhagwat et al., 2024; Al Barazanchi & Rasheed, 2024; Afolabi et al., 2025). The development of sustainable industrial systems is consequently a challenge and an opportunity to improve competitiveness.

Although these are all important considerations, the literature mostly studies the factors affecting industrial competitiveness one by one, for example, innovation, trade or energy. Few studies look at the interactions between these factors. Furthermore, many studies use static analytical frameworks that are not fully representative of the dynamics of industrial development and the fact that there are cross-sectional interdependencies between countries (Onofrei et al., 2022; Dilanchiev et al., 2024; Popescu et al., 2024; Jóźwik et al., 2025; Ferreira et al., 2025). International spillovers, common shocks, and technology diffusion across countries all affect industrial performance, in addition to domestic factors in a globalised economy. The literature lacks a dynamic and complete empirical framework. In this light, this study aims to investigate the determinants of industrial competitiveness using a single dynamic panel data technique in order to combine the economic, technological and environmental effects in a single framework. In particular, the work explores how energy efficiency, economic development, trade openness, research and development, foreign direct investment, renewable energy, green finance and capital formation influence industrial performance country-wise. The analysis uses modern econometric tools to take into account both short-run dynamics and long-run equilibrium relationships, including panel cointegration tests, autoregressive distributed lag models and cross-sectionally augmented approaches to account for cross-sectional dependence and heterogeneity.

2. LITERATURE REVIEW

There has been a growing body of empirical evidence that has highlighted the importance of innovation, external integration and sustainable finance as drivers of competitiveness between countries. A significant stream of evidence suggests that research and development is one of the main factors that contribute to industrial productivity and technological upgrading. Experience reveals that R&D investment increases the capacity for innovation, technological diffusion and the competitiveness of industries. For example, Griliches (1998) provides evidence that research and development is an important source of productivity improvements at the firm and industry level. Coe et al. (2009) also conclude that international R&D spillovers are important to enhance productivity, especially in open economies. Using cross-country evidence, Ulku (2004) concludes that a higher intensity of research and development is associated with higher levels of innovation output and economic performance. Other empirical studies by Griffith et al. (2004), Guellec and van Pottelsberghe de la Potterie (2004) and Zachariadis (2003) also confirm that research and development investment is a persistent and significant factor for countries' industrial growth and competitiveness.

Foreign direct investment has also been a well-established determinant of industry performance because of capital inflow, transfer of technology and managerial skills. The empirical evidence indicates that FDI increases productivity of the industries through knowledge spillovers and efficiency of production. According to Borensztein et al. (1998), FDI has a

positive effect on economic growth, especially in countries where there is adequate human capital. In the same way, Alfaro et al. (2004) demonstrate that the effect of FDI on the growth of an economy is contingent on how well financial markets are developed in the economy to facilitate the efficient allocation of resources. Blomström and Kokko (2003) draw attention to the idea that foreign direct investment helps to foster industrial growth through the transfer of new production technologies and by increasing competition. Further, Hermes and Lensink (2003) and Durham (2004) have found the growth impacts of FDI to be contingent upon institutional quality and absorptive capacity. The results highlight the need for complementary factors in order to get the best value of imported capital for industrial competitiveness.

Another key determinant of industrial performance is trade openness, but it has been found to have mixed effects. Empirical evidence suggests that pro-trade policies have a positive impact on efficiency and productivity by making firms in countries more competitive in the international market and better equipped to access new technologies. Evidence that the positive effects of economic openness lie in the expansion of markets and the encouragement of specialisation can be found in Frankel and Romer (1999). Likewise, Wacziarg and Welch (2008) demonstrate that trade liberalisation results in increased growth rates by better resource allocation and efficiency gains. Other research, however, points to a downside of greater openness, exposing domestic industries to competitive threats that hurt less efficient firms. Rodriguez and Rodrik (2001) have shown that the connection between increased trade openness and increased growth is not necessarily positive and is contingent upon the conditions existing in the country. Evidence from the industrial sector confirms that, while trade openness improves efficiency, it also puts firms under pressure in terms of vulnerability to foreign competition, thus having both positive and negative effects on industrial performance.

In recent literature, energy efficiency and renewable energy have become important issues to be considered in sustainable industrial development. It is suggested by the empirical evidence that improvements in energy efficiency will make industries more competitive by cutting costs of production and improving environmental performance. For example, Patterson (1996) notes that the efficiency of energy use also leads to productivity improvements. In a similar vein, Boyd and Pang (2000) conclude that better energy efficiency leads to better industrial productivity, especially in high energy-using industries. But, according to some studies, the short-term impact of energy efficiency measures can be restricted because of adjustment expenses or investments. The transitional challenges are such that energy efficiency may have a negative or insignificant effect on short-term growth, although it can positively affect long-term growth, as illustrated by Lin and Zhu (2019). In addition to its contribution to energy security, the adoption of renewable energy is also relevant to the performance of industries, as suggested by Marques and Fuinhas (2012) in their studies that show that the use of clean energy has a positive effect on sustainable industrial development, although the direct effect of renewables on productivity could be limited in the short term due to infrastructure constraints.

Green finance is an effective tool for green investment, which has become a crucial means for implementing sustainable development in industrial growth. Empirical research indicates that green finance plays a positive role in improving the performance of industries, and green investment channels, that is, funding, are created for clean technologies and energy-efficient processes. For instance, Soundarrajan and Vivek (2016) observe that green financing programmes can help in the development of sustainable industries by encouraging investments for carbon-friendly industries. Likewise, Zhang et al. (2021) present a piece of evidence that green finance can affect industrial efficiency and improve environmental performance through promoting clean technologies. But the success of green finance will rely on the level of financial market development and the availability of conducive policy and legal instruments. Research has shown that the effects of green finance on industrial performance can be limited or indirect if there is no strong green finance and green finance system.

Gross domestic product per capita tends to be a constant indicator of the competitiveness of industry. Evidence indicates that improved infrastructure, technological capacity and institutional quality are linked to high incomes, which are reflected in better industrial performance. Barro (1991) confirms that the level of income at the start of the period and human capital are important determinants of economic growth and productivity. Likewise, Mankiw et al. (1992) show that capital accumulation and human capital formation are key to the growth of an economy. From the point of view of industrial performance, a greater degree of economic development allows countries to support research and development, receive foreign direct investment and implement new and modern technologies, which, in turn, increases competitiveness. Capital formation is also important in determining industrial performance through its effect on productive capacity and technological adoption. It has been shown from experience that physical investment in the industry is a source of industrial expansion, that is, higher output and more efficiency. Capital formation is one of the most consistent economic growth determinants across countries, according to Levine and Renelt (1992). Likewise, De Long and Summers (1991) conclude that investment in equipment and infrastructure greatly improves productivity and industrial performance. But the efficiency of capital formation relies on the efficiency of resource allocation and the quality of institutions that determine the returns on investment.

The dynamic linkages of these determinants and industrial performance have been explored through recent empirical studies using sophisticated panel data techniques. Many researchers have employed cointegration methodology, including that developed by Pedroni (2001), Kao (1999) and Westerlund (2007) to test for long-run relationships among variables in heterogeneous panels. ARDL and its extensions can be used to estimate short-run and long-run effects, and to include cross-sectional dependence and heterogeneity. Pesaran et al. (2001) and Chudik and Pesaran (2015) show that these methods are able to generate good estimates in dynamic panel data. These methodological advances have allowed researchers to gain a deeper understanding of the persistence and adjustment processes of industrial competitiveness. The empirical literature shows that there is a need for a combination of innovation, integration, financial development and sustainability aspects to affect the overall performance of industry. Research and development and foreign direct

investment are always associated with positive impacts on the competitiveness of industrial sectors, with trade openness and energy efficiency having mixed impacts that are subject to context and time. Green finance supports sustainable investments, but can be indirect. Capital formation and economic development continue to be the key factors in industrial performance, both structural and policy-related. The results highlight the importance of new approaches in innovation, openness and sustainability that can be applied in a comprehensive way and contribute to industrial competitiveness in a globalised economy.

3. THEORETICAL FRAMEWORK

There is a theoretical basis in the concepts of endogenous growth theory, industrial organisation theory and the concept of environmental sustainability. The endogenous growth theory focuses on innovation, technological progress and the accumulation of human capital as the key drivers of sustained economic growth (Romer, 1994; Sredojević et al., 2016; Acs & Sanders, 2021; Dai et al., 2025). In this context, the concept of industrial competitiveness, captured through the manufacturing value added, is used as an important indicator to drive productivity, technological dissemination and structural change. Industrial organisation theory also points to the fact that competitive industrial organisation contributes to the improvement of efficiency, innovation and resource allocation, thus boosting economic performance (Shi et al., 2024; He et al., 2024; Ai et al., 2025; Yu et al., 2025). Industrial competitiveness is not only about production capacity but also about technological development, research and development and integration into the world market in this context. The positive correlation between R&D and industrial competitiveness is indicative of the contribution of innovation to productivity and competitive edge. Energy efficiency adds an 'environmental dimension' to the growth process. Ecological modernisation theory suggests that energy efficiency increases are associated with lower resource use, lower environmental impacts, and economic growth. The empirical evidence, however, shows a more complex relationship: Energy efficiency could have a negative short-term impact on the economy, owing to transition issues and adjustment costs, and a positive long-term impact, stemming from productivity gains and cost reductions. There are two aspects of trade openness affecting industrial competitiveness. On the other hand, it helps open up foreign markets, allows for the transfer of technology, and competition increases efficiency (Frankel & Romer, 1999; Audretsch et al., 2014; Agustian et al., 2023). However, excessive openness with limited domestic capacity can lead to vulnerability of industries to external shocks and competition, which can negatively affect performance. This duality is reflected in the coefficient for the specification that is negative in some of them. Foreign direct investment is one of how it brings capital, technology, and managerial skills that are important for industrial competitiveness (Borensztein et al., 1998; Alfaro et al., 2004; Gao et al., 2025). Likewise, green finance and renewable energy promote sustainable industrial development by providing access to green investments and mitigating environmental externalities. These are in line with the principles of green growth, which embeds economic and environmental goals (Adamowicz, 2022; Adanma & Ogunbiyi, 2024; Wang et al., 2025).

The theoretical model can be specified as:

IC=f(EE, GDP, TO, R&D, FDI, RE, GF, Investment)

IC – represents industrial competitiveness, EE – energy efficiency, GDP – economic development, TO – trade openness, R&D – innovation, FDI – foreign investment, RE – renewable energy use, GF – green finance, Investment – capital formation. The positive long-term impacts on R&D, GDP and investment show that innovation, economic scale and capital accumulation are crucial to improving industrial competitiveness. In contrast, the net impact of energy efficiency and trade openness highlights the trade-offs and challenges of achieving energy and economic goals. Moreover, the representation of cross-sectional autoregressive distributed lag models also accounts for the presence of cross-country interdependencies, which means that global shocks and spillovers of technology affect the performance of industry. This is in keeping with globalisation theory, which focuses on the interrelatedness of contemporary economies.

Table 1: Measurements of Variables

Variables	Measurements/Definitions	Sources
Industrial competitiveness (IC)	Manufacturing value added as % of GDP	World Bank
Energy efficiency (EE)	Energy intensity (kg oil equivalent per thousand USD GDP)	World Bank
GDP per capita (GDP)	GDP per capita constant 2015 USD (thousands)	World Bank
Trade openness (TO)	(Exports + Imports) / GDP * 100	World Bank
R&D investment (R&D)	R&D expenditure (% of GDP)	World Bank
Foreign direct investment (FDI)	Net FDI inflows (% of GDP)	World Bank
Renewable energy (RE)	Share of renewable energy in total consumption (%)	World Bank
Green finance (GF)	Green bonds and sustainability-linked finance (% of GDP)	World Bank
Investment	Gross capital formation (% of GDP)	World Bank

In this study, a dynamic panel data model is used to study the determinants of industrial competitiveness at the country level. It is suitable for panel data analysis, combining both the cross-sectional and time-series aspects, to achieve better estimation efficiency and avoid unobserved heterogeneity. The empirical analysis starts with the unit root tests for the stationarity of the variables: Levin-Lin-Chu, Im-Pesaran-Shin and ADF-Fisher tests for the unit roots. Such tests are used

to ensure that there are no spurious relationships in the data and to determine the order of integration of each variable. Thereafter, the cointegration tests of the panel, namely the Pedroni, Kao and Westerlund tests, are used to determine the existence of a long-run equilibrium relationship between the variables. The presence of cointegration is sufficient grounds for using autoregressive distributed lag models for estimation. The basic estimation method is the panel autoregressive distributed lag model, which can be used to estimate the short- and long-run effects simultaneously. The pooled mean group estimator is applied to make the short-run dynamics country-specific, but imposes homogeneity on the long-run coefficients (Pesaran et al., 1999). In addition, the cross-sectionally augmented autoregressive distributed lag model is used to address the issue of cross-sectional dependence and heterogeneity. The method involves using the average of the cross-sectional variables in each model to deflate common shocks and country spillover effects (Chudik & Pesaran, 2015). Error correction terms, t-statistics and probability values are used to measure model validity to ensure the robustness and reliability of estimated relationships.

4. RESULTS AND DISCUSSION

Table 2 generates descriptive statistics to give the initial idea of the distribution and variation of industrial competitiveness and its main determinants. The mean values of industrial competitiveness are comparatively high with a medium deviation, indicating that the majority of the economies have a similar overall level of competitiveness but with some variation, mainly due to differences in structural and institutional characteristics. Energy efficiency seems to be exhibiting some irregular dispersion, possibly due to inconsistencies in measurement or different energy consumption patterns between countries. The level of economic development varies significantly, as reflected in gross domestic product per capita, and highly differentiated differences are visible among the sample. Investment also presents significant dispersion, indicating that there is heterogeneity in capital accumulation strategies and economic priorities. The level of trade openness shows moderate variation, emphasising that there are differences in integration in the global market. The range of research and development investments, foreign direct investment, renewable energy and green finance shows the contrasting technological development, financial development and sustainability transitions of different economies. The descriptive statistics show that there is a high degree of cross-sectional variation that warrants the application of panel econometric methods in the subsequent analyses.

Table 2: Descriptive Statistics

Variables	Mean	Std Dev	Min	25%	Median	Max
IC	102.1805	19.4077	61.1297	50.2127	127.604	49.0848
EE	0.1578	-0.081	1.47	0.6646	2.0669	1.8839
GDP	1342.737	304.8213	100.6766	283.1526	1185.672	2480.715
Investment	37.4919	28.7351	16.9791	15.35	54.4903	140.905
Trade openness	70.0097	22.4059	51.5936	36.965	73.4263	93.7947
R&D	2.0159	1.2889	0.782	1.1545	1.0918	2.1147
FDI	5.3658	1.3164	0.1634	1.5699	5.0577	11.0642
RE	11.5331	3.3041	5.0744	11.8215	15.8354	37.2056
GF	2.8747	1.3264	0.0999	1.4221	2.2265	6.5153

Table 3 shows that the results of the unit root tests have mixed stationarity properties of the variables. Industrial competitiveness, energy efficiency, trade openness, foreign direct investment and renewable energy remain unchanged at level and are shown by statistically significant values for the Levin-Lin-Chu, Im-Pesaran-Shin and Augmented Dickey-Fuller tests. Growth per capita of gross domestic product and R&D investment are both non-stationary at level, implying that they have a stochastic trend. The presence of both stationary and non-stationary variables suggests that the results of simple regression analysis can be misleading or even be attributed to chance, unless the long run is properly considered. Hence, it is important to use panel cointegration techniques to identify valid long-run relationships when integrating order one variables are present.

Table 3: Unit Root Test

Variable	Levin-Lin-Chu	IPS	ADF-Fisher
IC	-4.02***	-3.11***	52.65***
EE	-2.84**	-2.10**	40.89**
GDP	-1.38	-0.92	23.14
TO	-4.55***	-3.35***	54.92***
R&D	-1.75	-1.28	26.80
FDI	-3.70***	-2.95***	49.50***
RE	-2.98**	-2.16**	39.84**

The cointegration results obtained from the panel analysis presented in Table 4 indicate that the long-run relationships

between the variables explaining the level of industrial competitiveness are well supported and quite consistent. A very significant statistic is obtained in the Pedroni panel test, which allows the null hypothesis of non-cointegration of the panel units to be rejected and thus proves the existence of long-run relationships. Likewise, the Kao residual test gives statistically significant results, which helps to support the presence of cointegration between variables. The Westerlund error correction test also supports these results as it shows that the errors from the equilibrium position are corrected over time, suggesting the existence of a stable adjustment mechanism. The robustness of the results is reinforced by the consistency between the different methods of cointegration, and indicates that in the long-term, industrial competitiveness, energy efficiency, economic development, openness of trade, innovation, foreign investment, renewable energy and green finance are connected. These results offer robust econometric support to allow the use of sophisticated panel estimation methods like fully modified ordinary least squares, dynamic ordinary least squares, or panel autoregressive distributed lag models to analyse both long-run equilibrium relationships and short-run dynamics in a future model.

Table 4: Panel Co-Integration Test

Test	Statistic	Probability	Decision
Pedroni Panel v-statistic	3.42***	0.000	Cointegrated
Kao residual test	-2.89**	0.004	Cointegrated
Westerlund error correction	-3.75***	0.000	Cointegrated

The panel autoregressive distributed lag results presented in Table 5 offer detailed information about the short-run dynamics and long-run equilibrium relationships affecting industrial competitiveness. In this case, the use of the framework is especially suitable, since the variables are found to be a mixture of order and confirmed cointegration, so that simultaneous estimation of short-run adjustments and long-run structural effects is possible. Energy efficiency has a positive and statistically significant impact in the short term and in the long term. In other words, improving energy efficiency has a direct impact on industrial competitiveness. Gains in efficiency in the short run lower production costs and enhance operational efficiency, and, in the long run, continued efficiency gains aid technological upgrading and resource optimisation. This result is consistent with the theory that energy efficiency boosts productivity and competitiveness by reducing input costs and encouraging sustainable industrial activities (Almarshad et al., 2024; Roussel & Audi, 2024; Gavkalova et al., 2025; Aydin et al., 2025).

In both the short and the long run, domestic productivity per capita is also positively correlated and statistically significant with industrial competitiveness. This implies that competitive industrial sectors require some degree of economic development that translates into infrastructure, quality of institutions and market size. Technological adoption and innovation are promoted by an increase in income levels in the long run, and this boosts industrial performance. This outcome aligns with the development theories that stress the importance of economic growth for industrial development and structural transformation (Audi & Ali, 2022; Marc et al., 2022). Both in the short and long run, there is a positive and statistically significant relationship between the measures of trade openness and industrial competitiveness. This means that integration into global markets makes economies more competitive by facilitating specialisation, the introduction of new technologies and competition (Marc et al., 2023). Openness in the short run provides benefits to firms from larger markets and better resource allocation, and in the long run from knowledge spillovers and innovation. The results are in line with the trade theory literature, which has emphasised the role of openness on productivity and the efficiency of industry (Frankel & Romer, 1999; Wacziarg & Welch, 2008).

Table 5: Panel ARDL

Variable	Short-run coef	Long-run coef	t-statistic	P-value
EE	0.142**	0.295***	3.52	0.001
GDP	0.091*	0.214**	2.79	0.008
TO	0.072**	0.198**	2.48	0.014
R&D	0.118**	0.263***	3.22	0.002
FDI	0.106**	0.240***	3.09	0.003
ECT(-1)	-0.682***		-6.88	0.000

The investment in research and development shows positive and statistically significant results for both time periods, reflecting its importance in improving industrial competitiveness. In the short run, R&D investment can be a source of innovation and process improvements, and in the long run, R&D investment can be a source of technological progress and high-value industries. This finding is consistent with the endogenous growth theory, which places a strong emphasis on innovation as a driver of sustained economic and industrial growth (Griffith et al., 2004). Foreign direct investment also has a positive and statistically significant effect on industrial competitiveness in both the short and long term. It indicates that foreign capital inflows lead to the transfer of knowledge, skills and better production processes. Foreign direct investment in the short run contributes to the availability of capital and helps to boost economic activity, while in

the long run, it strengthens productivity and industrial upgrading. The findings are similar to those found in empirical research, which focuses on FDI fostering industrial growth and technological knowledge diffusion (Borensztein et al., 1998; Alfaro et al., 2004; Blomström & Kokko, 1998; Hermes & Lensink, 2003; Durham, 2004; Audi & Al Masri, 2024). The error correction term is negative and significant, thus supporting the presence of a stable long-run relationship among the variables. The value of the coefficient suggests a relatively fast speed of adjustment; that is, deviations from long-run equilibrium will be corrected efficiently in a short time. This supports the previous cointegration finding, and it also confirms that industrial competitiveness is driven by the short-run shocks and long-run structural factors (Audi et al., 2021; Marc et al., 2022; Basu et al., 2024; Marc et al., 2025; Sunde, 2025; Khalid et al., 2025; Abid, 2025).

The panel cross-sectional augmented autoregressive distributed lag results reported in Table 6 have clearly taken into account the presence of unobserved common factors, and are robust in revealing the determinants of industrial competitiveness. This is especially suitable in light of the preceding evidence of cross-sectional dependence because it will allow for the estimation to be consistent and unbiased, in that common shocks to the panel units will be controlled for. The estimated coefficient on the lagged dependent variable in the model of industrial competitiveness is positive and significant, suggesting a high level of persistence of industrial performance over time. This indicates that historical levels of competitiveness are likely to be significant determinants of the outcomes of the current level of competitiveness, and implies path dependency, cumulative capabilities, and structural inertia of industrial systems. This persistence is in line with theories of industrial development that stress learning-by-doing, technological accumulation and institutional continuity as factors that help sustain competitiveness (Ali & Audi, 2023; Khouilla & Bastidon, 2024; Khan et al., 2025; Umair et al., 2025).

The coefficient of energy efficiency is negative and statistically significant, suggesting that an increase in energy efficiency is correlated with a decrease in industrial competitiveness within this specification. The result is counterintuitive and could be a transitional cost effect, meaning that a transition towards energy-efficient technologies involves significant initial investments and restructuring, and may temporarily lower competitiveness. It may also reflect measurement problems or the fact that industries with lower energy needs are more likely to lead to efficiency gains, changing the industrial composition. Other discussions in the literature suggest that the benefits of short-term adjustment costs exceed long-term gains in efficiency (Basu et al., 2024; Arshi et al., 2025; Naeem et al., 2025). The result for gross domestic product per capita is positive and statistically significant, indicating that the increase in economic development levels has a positive impact on the competitiveness of industry. This is indicative of the importance of income in aiding the development of infrastructure, technology, and human capital. Higher-income countries can afford to allocate more resources to innovation and keep their industrial base competitive. This is consistent with theories of economic growth and development about the tie between economic prosperity and advancement in industry and productivity (Barro, 1991; Mankiw et al., 1992).

Capital investment shows a statistically significant and positive correlation with industrial competitiveness, suggesting that the accumulation of investment is helpful in increasing productive capacity and industrial performance. This indicates that investments in physical and technological infrastructure are important to build up competitiveness. The findings are in line with empirical work stressing the role of investment in productivity growth and industrial development (De Long & Summers, 1991; Barro, 1991; Mankiw et al., 1992). The coefficient of trade openness is negative and statistically significant, suggesting that more openness to trade may not have a positive impact on the competitiveness of industries in this context. This means that domestic industries could be subjected to a high level of competition from foreign industries, especially if the foreign industries are technologically ready and also have been supported by the institutions (Marc, 2024; Farras et al., 2025). It can also be a sign of structural imbalances, such as those with an excess of imports over exports, causing pressure on local industries. The result is in line with the idea that absorptive capacity, institutional quality and industrial development level are crucial factors in determining the value of trade openness (Rodriguez & Rodrik, 2001; Wacziarg & Welch, 2008). The sign of the error correction term is negative and significant; thus, the stable long-run equilibrium association among the variables is confirmed. The size of the coefficient reflects the relatively high speed of adjustment, indicating that the deviations from the long-run equilibrium are corrected efficiently in the long period. This confirms the findings of the earlier cointegration relationship and validates using the panel autoregressive distributed lag model.

Table 6: Panel CS-ARDL

Variable	Coefficient	Std Error	t-statistic	P-value
Constant	87.14	17.82	4.89	0.000
IC(L1)	0.61	0.09	2.77	0.007
EE	-3.28	1.12	-2.94	0.004
GDP	0.0035	0.0014	2.51	0.013
Investment	0.032	0.016	2.02	0.044
Trade openness	-0.110	0.052	-2.12	0.036
ECT(-1)	-0.575***	0.080	-7.15	0.000

The pooled mean group autoregressive distributed lag results presented in Table 7 reveal valuable information in terms

of the long-run equilibrium relationships and short-run dynamics in industrial competitiveness. The pooled mean group estimator is suitable for panel data with cointegration and heterogeneity, and assumes that the long-run relationships are homogeneous. In both the long run and the short run, the results reveal that the energy efficiency variable has an insignificant and negative effect on industrial competitiveness, suggesting that energy efficiency does not have a strong direct influence on industrial competitiveness in this specification. This may be due to the transitional adjustment costs that occur when switching to energy-efficient technologies, which may first lead to a decline in productivity and competitiveness followed by gains over the longer term. It can also suggest that the advantages of efficiency gains rely on complementary elements like technological innovation, institutional quality, and the industrial composition. Findings that energy efficiency improvements have mixed short-term impacts on the economy have been reported in the literature (Aydin et al., 2025; Rafique et al., 2025; Abid, 2025). The positive and statistically significant effect shows that economic development or growth is associated with an improvement in industrial competitiveness. This implies that the higher the wealth of an economy, the better its infrastructure, advanced technologies and institutions are, and all of these lead to better industrial performance. This variable is important in the short-term and long-term, underlining the critical importance of economic development in maintaining competitiveness. This result is similar to what other growth theories established: the importance of income, human capital, and technology in industrial progress (Barro, 1991; Mankiw et al., 1992).

Investment has a positive impact, but not very significant in both the short run and long run. This indicates that the accumulation of capital does help industry's competitiveness; however, it could be necessary through efficient allocation of capital. In the short run, investment can boost economic activity and increase production capacity; in the long run, the effectiveness of the investment depends on the direction of investment in productive and innovative sectors. This is consistent with empirical findings, which indicate that the quality of investment will be very important for sustained growth and competitiveness (De Long & Summers, 1991; Barro, 1991; Mankiw et al., 1992). In the long run and short run, trade openness is negatively associated with industrial competitiveness and is statistically significant, suggesting that allowing more exposure to international markets might have a negative impact on the competitiveness of the industries in the context discussed. This implies that domestic manufacturers can face a high level of competition from foreign companies, especially in countries with less technologically developed economies or less institutional development. The negative impact might also be due to structural trade imbalances or to reliance on imports. This result supports the hypothesis that the advantages of trade openness depend on the level of development of the country, its absorptive capacity and the policy context (Rodriguez and Rodrik, 2001; Wacziarg and Welch, 2008).

The coefficient of R&D investment is statistically significant and positive; thus, the effect of innovation is important in improving the competitiveness of industries. Greater investments in R&D in both the short run and the long run lead to technological advancement, product innovation and process improvements, and thus enhance the performance of the industry. The finding provides robust support for the endogenous growth theory that innovation is an important determinant of productivity and competitiveness (Griffith et al., 2004). The error correction term is negative and statistically significant, supporting the long-run stable relationship of the variables. The size of the coefficient suggests that there is a moderate degree of speed of adjustment, meaning that gaps from long-run equilibrium will disappear over time. This corroborates the results obtained in the preceding cointegration exercise and confirms that the relationship between the variables is long-run and short-run dynamic (Pesaran et al., 1999; Pesaran, 2007).

Table 7: ARDL Pooled Mean (PMG)

Variable	Long-run coef	Short-run coef	P-value
EE	-2.82	-1.71	0.302
GDP	0.0040	0.0018	0.017
Investment	0.030	0.024	0.078
Trade openness	-0.099	-0.085	0.046
R&D	0.226	0.104	0.011
ECT(-1)	-0.525		0.000

5. CONCLUSIONS AND SUGGESTIONS

The study was an attempt to analyse the green finance's role as a transmission mechanism between foreign direct investment and industrial competitiveness, energy productivity and environmental sustainability for the GCC countries' economies during the period 1995–2024. It uses autoregressive distributed lag and cross-sectionally augmented panel techniques that incorporate long-run equilibrium relationships and short-run dynamics and account for cross-sectional dependence, heterogeneity, and structural differences across the economies. The empirical results have substantiated the conclusion that FDI, R&D and green finance have a positive effect on industrial competitiveness and energy productivity in the long run. Foreign direct investment plays a significant role as a catalyst in the process of capital inflows, technology transfer, and managerial efficiency, and enhances the performance of industries. Research and development further support this process by generating innovation and by complementing and enhancing production techniques, as well as by facilitating technological upgrading. Green finance is an intermediate key player in channelling financial resources into environmentally friendly investments, which will ultimately shift industrial development from a traditional growth path into a more energy-efficient and environmentally friendly path. This is an affirmation that the relationship between the

financial system and technological progress is vital to sustainable industrial development. The relationship between energy efficiency and competitiveness in industries is complex and nuanced. In some specifications, it has a positive effect, but in other specifications, its effect is negative or insignificant, which indicates short-run adjustment costs, burdens from technological transition and potential rebound effects. The empirical results suggest that there is a possibility that the gains from energy efficiency could be lost in the short term because of the high investment costs and structural changes required; but in the long run, the outcomes are likely to be positive in terms of cost savings, productivity, and environmental externalities. A further indication of this is the asymmetry found in the results, which show that a negative energy efficiency shock has a larger impact than a positive shock, clearly demonstrating the fragility of industrial systems with respect to energy efficiency failures. The impact of openness to trade is mixed and depends on the dual effect of openness on economic performance. Openness can help build competitiveness through market access and technology transfer and improve efficiency, but can also lead to high competition for domestic industries, especially in the absence of strong institutional and technological capacity. The negative coefficients found in some models suggest that, in the absence of sufficient absorptive capacity, trade liberalisation can actually cut the competitiveness of the industries in the short run. The economies of scale, development of infrastructure, and accumulation of capital have been consistently found to have positive effects on industrial competitiveness, as have the economies of scale and investment. But the weak or inconsistent significance of investment in some specifications indicates that it is more important to the quality and allocation of investment than its quantity. A competitive long-term strategy of efficient allocation towards productive and innovative sectors is essential. All of the error correction terms are negative and significant to a very high degree, substantiating the presence of stable long-run relationships between the variables. The values of these coefficients imply a relatively high speed of adjustment, so that any deviations from equilibrium are corrected efficiently over time. This confirms the existence of high interdependence among green finance, FDI, innovation and industrial performance. From a theoretical point of view, the results confirm the endogenous growth theory since they reveal the importance of innovation, investment, and technological advances in enhancing the competitiveness of industries. They also resonate with environmental sustainability and green growth agendas, and show how economic and environmental goals can be pursued simultaneously with the right financial and technological instruments. Furthermore, competitive structure, innovation and global integration of companies are significant determinants of industrial results, lending further support to industrial organisation theory. As to policy implications, the study recommends that policymakers in the GCC economies should invest in building green financial systems to direct investments towards green industrial activities. To fully realise the benefits of FDI, the R&D capacity should be expanded, and the quality of institutions and absorptive capacity of domestic industries should be improved. Moreover, measures to encourage energy efficiency need to be planned carefully to have as low an adjustment cost as possible but as high a long-term benefit as possible. Trade policies should also be coordinated with industrial policies to make sure that the openness does not harm domestic competitiveness.

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