PUBLISHED BY
VOPROSY EKONOMIKI N. P.

Russian Journal of Economics 11 (2025) 93–122
DOI 10.32609/j.ruje.11.142815
Publication date: 25 March 2025

Russian Journal of Economics

www.rujec.org

Renewable energy and industrial innovation: Catalysts for economic and trade growth

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Abstract

Modernizing and diversifying industries have become essential in recent years, particularly with the shift toward new energy sources to boost the global economy. Despite widespread initiatives, the economic impact of these reforms remains uncertain. This study examines the effects of Saudi Arabia's renewable energy and industrial innovation efforts on key economic variables, aligning with the UN Sustainable Development Goal 8 (SDG 8), which emphasizes inclusive and sustainable economic growth, full and productive employment, and decent work for all. Using an ARDL model, we analyze data from 95 firms operating in the renewable energy sector from 2000 to 2023. The findings reveal that renewable energy investments significantly enhance long-term economic growth, trade balance, and FDI inflows, though their impact on employment and foreign assets is weaker. Industrial innovation also promotes growth and trade, but less so than renewable energy, with sales growth driving foreign asset accumulation. In the short term, both sectors have limited effects on employment and foreign assets. However, when combined, renewable energy investments and industrial innovation amplify their positive influence on GDP and trade, underscoring the need for long-term strategies to sustain economic growth.

Keywords: SDG 8, renewable energy, industrial innovation, environmental sustainability, economic growth.
JEL classification: I31, I38, L60.

1. Introduction

Countries across the globe are placing greater emphasis on environmental sustainability, driven by the urgent need to address climate change and the depletion of natural resources. Renewable energy sources, such as solar and wind, and industrial innovation are critical tools in this transition (Elum and Momodu, 2017;

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Sovacool et al., 2021; Mohan et al., 2024). These efforts aim not only to reduce carbon emissions but also to foster sustainable development. As part of its Vision 2030 initiative, Saudi Arabia is taking significant strides in these areas by investing heavily in renewable energy projects and promoting technological advancements in industry. The country plans to generate 50% of its electricity from renewable sources by 2030, shifting away from its traditional reliance on fossil fuels (Tlili, 2015; Salam and Khan, 2018).

While renewable energy and industrial innovation are widely acknowledged for their environmental benefits, their economic impacts remain unclear and continue to be the subject of ongoing debate (Mathiesen et al., 2011; Wüstenhagen and Menichetti, 2012; Burke and Stephens, 2018). Although these sectors are often seen as key drivers of economic diversification, job creation, and technological advancement, empirical studies yield mixed findings regarding their economic outcomes. Lall and Narula (2004) argue that the total economic impact of these sectors remains inadequately understood despite the apparent potential of renewable energy investments to stimulate industrial growth, improve productivity, expand trade, and attract foreign direct investment (FDI). Notably, these efforts align with the UN Sustainable Development Goal 8 (SDG 8), which promotes sustained, inclusive, and sustainable economic growth alongside full and productive employment and decent work for all. The ongoing debates in the empirical literature underscore the need for further research to understand how sustainability efforts can effectively contribute to long-term economic growth and competitiveness. Moore and Manring (2009) demonstrate that sustainability-oriented strategies in small and medium-sized enterprises (SMEs) promote environmental stewardship and drive value creation and competitive advantages. Their study highlights how aligning sustainability initiatives with strategic business objectives fosters innovation and operational efficiencies, essential for long-term economic viability. Building on this, Adanma and Ogunbiyi (2024) emphasize the critical role of global environmental policies in shaping sustainable development trajectories. Their comparative analysis reveals that nations adopting comprehensive and inclusive environmental frameworks tend to experience more robust and sustained economic growth. These findings suggest that integrating sustainability efforts into broader economic and policy frameworks enhances global competitiveness. Together, these studies underscore the need for further empirical research to explore the most effective mechanisms and strategies for leveraging sustainability to achieve long-term economic growth and competitiveness. This issue is particularly relevant for Saudi Arabia, as it advances its Vision 2030 initiative. The challenge lies in accurately assessing and incorporating the broader economic impacts of these sectors into national development strategies, a gap that we have aimed to fill in our current study.

Specifically, unlike previous research, which often relies on aggregated or national-level data, our study utilizes detailed firm-level data to provide a more precise analysis of these impacts. Specifically, we explore a diverse set of proxies for renewable energy investment, including R&D expenditure, renewable energy expenditure, revenue from renewable energy, and installed renewable energy capacity. Similarly, we use three distinct proxies for industrial innovation: the number of patents or intellectual property rights filed by firms, investments in physical innovative assets such as machinery and infrastructure, and sales from new products. These variables allow us to assess their effects on five key global economic indicators: GDP growth rate, trade balance, foreign direct investment, employment rate, and foreign assets. To analyze these relationships, we employ an ARDL model with fixed effects using panel data from firms operating in renewable energy and industrial innovation sectors, covering the period from 2010 to 2023. The ARDL model allows for analyzing both short- and long-term relationships between firm-level variables and key economic indicators. It is beneficial with panel data, as it can handle different integration orders ($I(0)$ or $I(1)$) of the variables without requiring them to be all stationary. This flexibility is crucial for capturing dynamic effects across time (2010–2023) and firms.

This research aims to investigate how investments in renewable energy and industrial innovation contribute to sustained economic growth and competitiveness. Additionally, it seeks to examine the potential synergy between renewable energy investments and industrial innovation in fostering productivity and enhancing international competitiveness.

This research builds on existing studies, such as Molyneaux et al. (2016), which emphasize the transformative role of renewable energy investments in strengthening economic growth, trade balance, and FDI inflows. It also incorporates insights from Filatotchev and Piesse (2009), who highlight the link between sales growth and foreign asset accumulation, underscoring the importance of exporting innovative products for firms' foreign holdings. Furthermore, the research explores the combined effects of renewable energy and industrial innovation, as suggested by Ahmed et al. (2022), to assess their collective influence on economic performance. Aligned with the findings of Dumitriu (2020), this study also examines the critical role of private sector involvement in fostering long-term economic competitiveness through investments in innovative and sustainable industries. By addressing these themes, the research contributes to a deeper understanding of how renewable energy and industrial innovation support economic resilience and align with global development goals.

The remainder of the paper is structured as follows: In the next section, we review the literature on the economic impacts of renewable energy and industrial innovation. Section 3 focuses on data analysis, detailing the sources, variables, and statistical techniques employed. Section 4 explains our empirical methodology, outlining the model specification, estimation techniques, and robustness checks. Section 5 presents the results and a thorough interpretation of the findings. Section 6 discusses the policy implications of these results, offering recommendations. Finally, Section 7 concludes.

2. Literature review

The existing literature broadly explores two interconnected themes: the relationship between renewable energy investment and macroeconomic outcomes and the role of industrial innovation in driving economic performance. These studies collectively highlight how the performance of companies, particularly in renewable energy and innovation, contributes to national economic data, addressing key variables such as GDP, trade, and employment. Drawing on foundational theories, the endogenous growth theory developed by Romer (1990) posits that technological innovation, including advancements in renewable energy, is a critical driver of long-term economic growth. Although this model primarily focuses on general innovation, it provides a basis for understanding how clean energy technologies can enhance productivity and support economic growth. Schumpeter's "creative destruction" theory (1934) further underscores this by illustrating how innovation disrupts existing industries, fostering the emergence of new sectors that enhance economic dynamism. This concept is particularly relevant as investments in renewable energy replace traditional fossil fuel industries, reshaping national economic landscapes.

The OLI model introduced by Dunning (1988) adds another layer by linking innovation with FDI. This model suggests that countries prioritizing renewable energy attract foreign capital and expertise, boosting trade and investment. Porter and van der Linde's work on environmental innovation (1995) aligns with this perspective, arguing that investments in green technologies enhance resource efficiency and competitiveness, thereby benefiting macroeconomic variables like GDP and trade. Empirical studies further validate these theoretical insights. For example, Aghion et al. (2016) found that investments in green technologies improved trade performance by enabling the development and export of renewable energy solutions, although their study leaves the impacts on GDP and employment less explored. Research by Ahmed et al. (2022) emphasized the role of renewable energy investments in enhancing export opportunities and trade openness, while Li and Ge (2023) demonstrated a significant positive relationship between renewable energy investments and GDP growth, providing robust empirical support for earlier theoretical propositions.

Similarly, industrial innovation has significantly impacted macroeconomic outcomes such as productivity, competitiveness, trade, employment, and FDI. Schumpeter's concept of "creative destruction" highlights the transformative power of innovation in creating new sectors and driving economic growth. Building on this, research by Griliches (1979) established a strong empirical link between R&D expenditures and productivity growth, showing that innovative firms achieve higher output with lower input. Barro and Sala-i-Martin (1995) extended these ideas within the framework of endogenous growth theory, demonstrating how technological progress fosters sustained economic growth. Studies by Coe and Helpman (1995) and Lipsey (2001) further explored how innovation influenced international trade and FDI, highlighting competitive advantages for countries with strong technological capabilities. Aghion et al. (2001) examined the nuanced relationship between innovation and employment, showing how technological progress creates jobs in high-tech sectors while disrupting traditional industries. More recent studies, such as those by Bloom et al. (2019) and Bas et al. (2021), have used advanced econometric techniques to analyze firm-level data, confirming that industrial innovation enhances productivity, trade, and employment, contributing to higher GDP growth.

Despite this extensive literature, the interplay between company-level performance and national macroeconomic outcomes remains underexplored. Specifically, how investments by firms in renewable energy and industrial innovation translate into measurable national economic impacts warrants further investigation. Our research addresses this gap by examining whether advancements by companies in renewable energy and innovation affect GDP, trade, employment, and FDI at the macroeconomic level. Based on the theoretical and empirical foundations discussed, the following hypotheses are proposed:

H1: Investments in renewable energy at the company level positively influence national GDP growth.

H2: Innovation activities at the firm level enhance national trade performance and competitiveness.

H3: Performance of companies in renewable energy and innovation fosters employment growth and increases FDI inflows.

These hypotheses provide a clear direction for the research, offering insights into how corporate performance in key sectors drives macroeconomic outcomes.

Table 1 summarizes studies discussed in this literature review, focusing on two key areas of analysis: the impact of renewable energy and industrial innovation on key economic variables. Building on the insights from the broader literature, which highlights the transformative potential of renewable energy and industrial innovation across various economic contexts, it is essential to focus on how these dynamics apply to specific national strategies. Given its ambitious Vision 2030 and substantial investments in these sectors, Saudi Arabia provides a compelling case study. The literature suggests that Saudi Arabia's strategic investments in renewable energy and industrial innovation will likely strengthen its economic growth, improve trade performance, and enhance its global leadership. These efforts also align closely with the UN SDG 8. Saudi Arabia advances its domestic development goals and contributes to broader global economic and social

Table 1
Summary of studies on renewable energy, industrial innovation, and key economic variables.

Study	Purpose	Results
Renewable energy impact		
Romer (1990)	Explored general innovation as a driver for long-term economic growth	Technological advancements can improve productivity and lead to sustained economic growth
Schumpeter (1934)	Analyzed the concept of 'creative destruction' and its role in economic dynamism	Innovation in clean energy reshapes economic landscapes by replacing traditional industries
Dunning (1988)	Linked innovation capacity with FDI	Countries investing in renewable energy attract more foreign capital and expertise
Porter and van der Linde (1995)	Argued for environmental innovation's dual impact on sustainability and economic performance	Renewable energy investments enhance resource efficiency, fostering growth in GDP and trade
Aghion et al. (2016)	Explored renewable energy's impact on trade performance	Countries investing in green technologies enjoy enhanced trade balances
Ahmed et al. (2022)	Examined green innovation's role in trade performance	Positive relationship found between renewable energy investments and trade openness
Li and Ge (2023)	Analyzed renewable energy investments' impact on GDP growth	Significant positive correlation with economic growth
Aydin and Degirmenci (2024)	Focused on renewable energy's contribution to sustainability and economic metrics	Investments contribute significantly to sustainability and long-term economic growth
Bashir et al. (2024)	Explored renewable energy's role in economic resilience and productivity	Higher productivity and resilience were observed in countries investing in renewable energy

(continued on next page)

Table 1 *(continued)*

Study	Purpose	Results
Industrial innovation impact		
Schumpeter (1934)	Analyzed 'creative destruction' and its role in economic growth	Innovation creates new sectors, enhancing economic dynamism
Griliches (1979)	Studied the link between R&D and productivity growth	R&D investments lead to higher output with lower input
Barro and Sala-i-Martin (1995)	Integrated innovation into economic growth models	Technological progress boosts productivity and economic output
Coe and Helpman (1995)	Explored technological progress's spillover effects on trade	Countries investing in innovation gain competitive advantage globally
Lipsey (2001)	Examined the link between innovation and FDI	High levels of innovation attract foreign investment and boost growth
Aghion et al. (2001)	Studied the impact of innovation on employment in the EU	Innovation creates jobs in high-tech industries but may reduce traditional employment
Bloom et al. (2019)	Analyzed innovation's effects on productivity and economic growth	Firms investing in R&D and patenting experience significant productivity growth
Bas et al. (2021)	Investigated innovation's macroeconomic impacts	Innovation enhances competitiveness, leading to higher GDP, trade, and employment growth

Source: Compiled by the author.

sustainability initiatives. The studies reviewed provide a robust foundation for understanding the potential impacts of these investments, underscoring their importance in achieving Saudi Arabia's Vision 2030 development goals.

3. Data analysis

Assessing the benefits of environmental sustainability practices through investment in renewable energy and industrial innovation involves examining various key proxies to understand their impact on economic and social outcomes. These proxies include R&D expenditures, revenue from renewable energy, installed renewable energy capacity, the number of patents filed, revenue growth, and capital expenditure. Investment in renewable energy and industrial innovation is essential for fostering sustainable economic growth and international competitiveness. By investing in research and development, firms can enhance technological advancements and improve the efficiency of renewable energy production. Increased revenue from renewable energy signals the sector's growing contribution to the economy, while expanded installed capacity demonstrates a country's commitment to reducing reliance on fossil fuels and increasing clean energy sources. Additionally, the number of patents filed reflects innovation in industrial sectors, directly impacting revenue growth and firm expansion. Capital expenditure on new technologies further supports this innovation-driven growth. These factors contribute positively to a nation's economic growth by boosting trade, attracting FDI, increasing employment opportunities, and enhancing foreign assets. Moreover, such practices lead to broader social welfare improvements, such as better environmental outcomes, improved public health, and long-term sustainability, all essential for achieving economic diversification and social equity goals.

Fig. 1 summarizes this process and highlights the global structure of this study, illustrating the interconnected pathways through which investment in renewable energy and industrial innovation drive economic and social outcomes. It visually maps out the relationships between key proxies such as R&D expenditures, renewable energy revenue, installed capacity, patents filed, revenue growth, and capital expenditure. It also captures how these elements influence broader economic indicators, including GDP growth, trade, FDI, employment, and foreign assets. Additionally, the methodology outlined in Fig. 1 aligns with the requirements of the UN SDG 8. By emphasizing the pathways through which renewable energy and industrial innovation contribute to sustained economic growth, productive employment, and improved trade performance, our study integrates the core principles of SDG 8 into its analytical framework.

This study examines various economic and firm-specific variables. The dependent variables include GDP per capita growth rate (*GDP*), trade balance as a percentage of GDP (*TRADE*), foreign direct investment inflows as a percentage of GDP (*FDI*), employment rate (*EMP*), and foreign assets as a percentage of GDP (*FA*). These metrics reflect a country's economic performance and international engagement. The independent variables focus on renewable energy and industrial innovation such as firms' R&D expenditure in renewable energy (*R&D*),

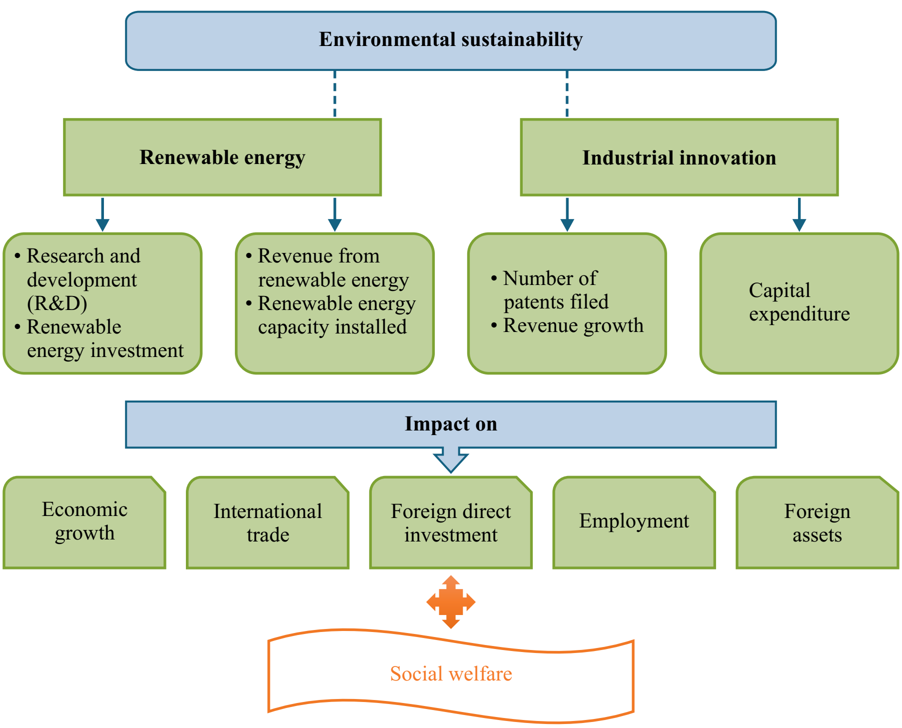

Fig. 1. Benefits of renewable energy and industrial innovation.

Source: Compiled by the author.

capital invested in renewable energy projects (*REI*), percentage of revenue from renewable energy (*REVRE*), and renewable energy capacity installed (*INST*). Industrial innovation is measured through the number of patents filed (*PAT*), capital expenditure (*CEXP*), and revenue growth from new products (*SALE*). Control variables include firm size (*FS*), industry concentration ratio (*CR*), and government support (*GS*) through grants or subsidies. Data is sourced from firm financial and industry reports, with macroeconomic variables from the World Bank's World Development Indicators (WDI). Appendix Table A1 provides a detailed summary of these variables.

The descriptive statistics in Appendix Table A2 provide insights into the dependent and independent variables. The mean GDP per capita growth rate is 2.25%, ranging from –3.51 to 5.67%, indicating variability in economic growth. Trade balance has a mean of 2.64%, and foreign direct investment averages 0.35% of GDP, both showing substantial fluctuations. Employment rate and foreign assets exhibit significant variation, with employment rates ranging from 8.97 to 31.08%. For renewable energy, research and development expenditure averages 5.13% of total firm investment, while renewable energy investment averages 11.67%. Revenue from renewable energy and renewable energy capacity installed also display wide ranges. Industrial innovation variables like the number of patents, capital expenditure, and revenue growth from new products all show considerable variation, reflecting the diverse innovation activities across firms. Control variables, such as firm size, concentration ratio, and government support, demonstrate variability, influencing the firms' capacity for growth and innovation. We also assessed the stationarity of the model variables using the augmented Dickey–Fuller (ADF) tests. As shown in the last column of Appendix Table A2, the variables are non-stationary in their original levels but achieve stationarity after first differencing, with varying significance levels.

The analysis of the variables' correlation in Appendix Table A3 highlights several significant relationships between renewable energy, industrial innovation, and economic performance. Renewable energy R&D expenditure shows a positive association with GDP (0.42), indicating its critical role in fostering economic growth. Renewable energy investment is strongly linked to firm revenues from renewable projects (0.64), emphasizing the financial benefits of targeted investments in renewables. In industrial innovation, patent activity correlates positively with GDP (0.52), reflecting the contribution of innovation to economic expansion. Revenue growth from new products is strongly associated with renewable energy-related revenues (0.71), highlighting the importance of innovation-driven sales strategies. Additionally, capital expenditure demonstrates a moderate positive relationship with employment (0.42), suggesting that investments in infrastructure and physical assets support job creation. The positive relationship between renewable energy R&D and GDP aligns with the SDG 8 objective of fostering innovation-driven growth. Similarly, the strong link between renewable energy investment and firm revenues underscores the potential for renewable projects to enhance productivity and competitiveness, a cornerstone of economic development under SDG 8. Patent activity and its association with GDP highlight the role of technological innovation in driving growth, while the connection between capital expenditure and employment supports the creation of decent work opportunities.

4. Empirical methodology

Our empirical analysis employs an ARDL (Autoregressive Distributed Lag) model with panel fixed-effects data from 2000 to 2023 to assess the impact of firms' renewable energy investments and industrial innovation on key economic outcomes: GDP growth, trade balance, foreign direct investment inflows, employment rate, and foreign assets. The choice of the ARDL model is justified by its flexibility in handling variables that are integrated into different orders, i.e., $I(0)$ and $I(1)$, without requiring pre-differencing. This approach is beneficial in our study, where the relationships between renewable energy investments, innovation, and economic outcomes may evolve differently (Marques et al., 2019; Sun et al., 2022). The ARDL framework also captures both short-term and long-term equilibrium relationships, making it well-suited to model the dynamic interplay between industrial innovation and macroeconomic variables. Furthermore, the panel fixed-effects structure helps control for unobserved heterogeneity across firms, ensuring more robust and unbiased results. The global ARDL model thus offers a comprehensive approach to understanding the multifaceted impacts of renewable energy and innovation on economic growth and trade outcomes.

$$Y_t = \alpha + \sum_{j=1}^{p} \beta_j Y_{i,t-j} + \sum_{k=0}^{q_1} \gamma_k X_{1,i,t-k} + \sum_{l=0}^{q_2} \delta_l X_{2,i,t-l} + \varepsilon_{i,t}, \quad (1)$$

where: Y_t — dependent variable at time t; $X_{1,i,t}$ — first independent variables (vector of renewable energy variables for firm i) at time t; $X_{2,i,t}$ — second independent variables (vector of industrial innovation variables for firm i) at time t; α — firm-specific intercept (captures unobserved heterogeneity across firms); β_j — coefficients of the lagged dependent variable $Y_{i,t-j}$; γ_k — coefficients of the lagged independent variable $X_{1,i,t-k}$ (renewable energy); δ_l — coefficients of the lagged independent variable $X_{2,i,t-l}$ (industrial innovation); p, q_1, q_2 — number of lags for the dependent and independent variables; $\varepsilon_{i,t}$ — error term for firm i at time t.

$Y \equiv [GDP; TRADE; FDI; EMP; FA]$;
$X_1 \equiv [\text{R\&D}; REI; REVRE; INST]$;
$X_2 \equiv [PAT; CEXP; SALE]$.

The corresponding error correction model (ECM) captures both short-term dynamics and long-term relationships. It includes the error correction term (ECT) for panel data:

$$\Delta Y_t = \alpha + \sum_{j=1}^{p} \beta_j \Delta Y_{i,t-j} + \sum_{k=0}^{q_1} \gamma_k \Delta X_{1,i,t-k} + \sum_{l=0}^{q_2} \delta_l \Delta X_{2,i,t-l} + \\ + \phi(Y_{t-1} - \vartheta_0 - \vartheta_1 X_{1,i,t-k} - \vartheta_2 X_{2,i,t-l}) + \varepsilon_{i,t}, \quad (2)$$

where: ΔY_t — first difference of the dependent variable (change in the global economy metric); $\Delta X_{1,i,t-k}$ and $\Delta X_{2,i,t-l}$ — first differences of the independent variables (changes in renewable energy and industrial innovation for firm i); ϕ — coefficient of the ECT that measures the speed of adjustment to the long-run equilibrium; $(Y_{t-1} - \vartheta_0 - \vartheta_1 X_{1,i,t-k} - \vartheta_2 X_{2,i,t-l})$ — ECM term.

The coefficients on the first differences (ΔY_t; $\Delta X_{1,i,t-k}$ and $\Delta X_{2,i,t-l}$) represent the short-term effects of lagged values of both the dependent and independent variables. The long-run coefficients ϑ_1 (renewable energy share) and ϑ_2 (industrial innovation) represent the long-run equilibrium relationships. The ECT ϕ indicates the speed at which deviations from the long-run equilibrium are corrected in the next period.

We assessed the robustness of our model using several diagnostic tests, including the LM test (χ^2), White test, Jarque–Bera test, and RESET test. The LM test (χ^2) confirmed the absence of serial correlation in the residuals, ensuring the model's error terms are not autocorrelated. The White test showed no evidence of heteroscedasticity, indicating that the variance of the residuals is constant across observations. The Jarque–Bera test validated the normality of the residuals, suggesting that the distribution of errors is approximately normal. Finally, the RESET test confirmed that the model is correctly specified, with no omitted variables or functional form misspecification. All tests returned satisfactory results, supporting the reliability and robustness of our model.

Our empirical approach consists of four stages. First, we regress Equation (2) to assess both the short-term and long-term effects of renewable energy investment and industrial innovation variables on economic performance. We capture how each variable influences key macroeconomic indicators over different time horizons. Control variables are included in the long-term analysis to capture persistent relationships and structural factors that influence the dependent variables over time. These variables account for external influences and ensure the robustness of the long-term estimates, aligning with theoretical expectations about the factors driving economic performance. In the short-term analysis, the focus is on capturing immediate and dynamic responses to changes in independent variables, where the impact of control variables may be less pronounced or statistically insignificant. Moreover, excluding control variables in the short-term analysis helps avoid overloading the results tables with excessive information, ensuring clarity and a more focused interpretation of the primary short-term dynamics under investigation.

In the second stage, we examine the joint effect of renewable energy investment and industrial innovation by introducing interaction terms into the model. We expect that combining these two categories will have a more pronounced impact on macroeconomic aggregates, as the synergy between renewable energy advancement and industrial innovation could potentially amplify their contribution to economic growth. In this stage, we moved from an ARDL model to a GMM fixed effects panel data estimation (Equation (3)) to better handle the inclusion of interaction terms and account for potential endogeneity issues. While the ARDL model is effective for time-series analysis, it may not adequately capture the complexities of panel data, particularly when interactions are involved.

$$Y_t = \alpha + \beta_1 Y_{i,t-1} + \alpha_1 X_{1,i,t} \times X_{2,i,t} + \pi_i + \varepsilon_{i,t}, \tag{3}$$

where π_i represents the firms' fixed effects; the remaining variables are defined in Equation (2).

The third stage involves using instrumental variables to address any potential endogeneity issues that may arise. Although the ARDL model we employ is robust in handling endogeneity, introducing instrumental variables further strengthens our results by mitigating any lingering concerns regarding bias or simultaneity in the relationships between the variables. We introduced two instrumental variables into our regressions to address potential endogeneity concerns and account for simultaneous causality between renewable energy investment, industrial innovation, and the dependent variables. The first variable is the historical average of renewable energy investment in each firm's sector (*H_AVR*), which influences current investments and innovation while remaining largely unaffected by contemporary economic conditions. The second variable represents government innovation policies or support measures, proxied by the budget allocated to innovative and environmentally friendly projects (*GOV*). This variable promotes renewable energy and industrial innovation, acting as an exogenous factor that helps isolate causal relationships within our regression analysis.

Finally, we conduct a robustness check of our primary findings in the fourth stage. We will replace the original key variables with alternative measures and use different estimators to ensure our results are not sensitive to the specific variables or estimation methods initially selected. This approach helps validate the consistency and reliability of our conclusions across various modeling frameworks.

The 95 companies selected for this study include prominent players in Saudi Arabia's renewable energy and industrial innovation sectors, each with substantial potential to influence macroeconomic aggregates like GDP, employment, and exports. The study focuses on companies that operate on a large scale, invest heavily in renewable energy and R&D, and drive national economic growth. For instance, Saudi Aramco, SABIC, and ACWA Power stand out as significant contributors to the Saudi economy, with the ability to directly impact GDP.

Saudi Aramco, the world's largest oil producer, drives national oil revenues and invests in renewable energy projects, helping diversify the economy and secure long-term growth. SABIC, a leader in the petrochemical sector, fosters industrial innovation and boosts exports. Its technological advancements and high-value products contribute considerably to Saudi Arabia's trade balance and employment levels. ACWA Power, a leading renewable energy developer, supports Saudi Arabia's energy transition goals and increases its renewable energy exports, particularly in solar and wind energy. This company's efforts to diversify the economy and strengthen the country's global position in energy markets enhance Saudi Arabia's trade and investment prospects.

In addition to these large companies, medium-sized firms like Desert Technologies and Taqnia Energy contribute to renewable energy and industrial innovation. Desert Technologies helps develop solar power solutions for domestic and export purposes, while Taqnia Energy focuses on energy solutions that promote industrial innovation and contribute to the diversification of the economy.

The performance of these companies significantly affects macroeconomic aggregates. Investments by Saudi Aramco and SABIC in R&D and renewable energy innovations drive technological advancements, increase productivity, and foster economic growth. Their export activities—from oil and petrochemicals to renewable energy technologies—directly impact Saudi Arabia's trade balance, improving its competitiveness in global markets. These firms also create jobs across various sectors, supporting national employment growth. Their contributions to FDI through partnerships and international ventures strengthen the country's economic resilience.

The study focuses on companies with the capacity to influence national economic performance. Their operations and investments significantly impact macroeconomic outcomes, spanning key areas such as GDP, employment, and exports. These companies represent a large portion of Saudi Arabia's industrial output, and their performance can substantially affect key economic indicators, supporting the hypothesis that their actions influence national economic outcomes.

From our sample of 95 Saudi companies, we identified the 30 most impactful firms, highlighted in Table 2, based on their substantial contributions to national economic indicators and their influence on key macroeconomic aggregates. These firms drive economic performance in Saudi Arabia through extensive operations, innovative practices, and sizable investments. Their inclusion ensures the study highlights their critical role in advancing economic objectives at the national level.

Table 2
Sample of Saudi companies in renewable energy and production innovation.

	Company name	Sector of work	Focus area
1	Saudi Aramco	Energy	Oil, renewable energy, innovation
2	SABIC	Petrochemicals	Industrial innovation, exports
3	ACWA Power	Renewable energy	Solar and wind energy development
4	Desert Technologies	Renewable energy	Solar energy solutions
5	Taqnia Energy	Renewable energy, technology	Energy innovation
6	King Abdullah City for Atomic and Renewable Energy (KACARE)	Renewable energy	Policy development, R&D
7	First National Operation and Maintenance Company (NOMAC)	Energy	Renewable energy operations
8	ALJ Renewable Energy	Renewable energy	Solar and wind projects
9	National Industrialization Company (Tasnee)	Petrochemicals	Industrial innovation
10	Advanced Petrochemical Company	Petrochemicals	R&D in sustainable materials
11	Red Sea Farms	Agriculture, technology	Agri-tech, solar-powered greenhouses
12	Alfanar Company	Renewable energy, construction	Energy infrastructure projects
13	Modern Industrial Investment Holding Group	Manufacturing	Industrial R&D
14	NEOM	Urban development, energy	Renewable energy infrastructure
15	Ma'aden	Mining, industrial innovation	Sustainable mining practices
16	Almarai	Agriculture, food production	Sustainable agri-food solutions
17	Juffali Solar	Renewable energy	Solar power systems
18	E. A. Juffali & Brothers	Industrial innovation	Technology solutions
19	Al-Babtain Power & Telecommunication Co.	Energy infrastructure	Transmission and renewable energy systems
20	Advanced Electronics Company	Technology, defense	Energy efficiency solutions
21	Zamil Industrial Investment Co.	Manufacturing	Energy-efficient products
22	National Grid SA	Energy infrastructure	Renewable grid integration
23	Binzagr Factory for Insulation Materials	Manufacturing	Sustainable building materials
24	Saudi Electricity Company	Utilities	Green energy transition
25	Arabian Cement Company	Manufacturing, innovation	Energy-efficient cement production
26	Sipchem	Chemicals, petrochemicals	Green chemicals
27	Petro Rabigh	Chemicals, petrochemicals	Energy-efficient processing
28	Al Gihaz Holding	Energy, construction	Renewable energy projects
29	Elm Company	Technology	Smart solutions in energy
30	Saudi Investment Recycling Company	Recycling	Renewable materials innovation

Source: Compiled by the author.

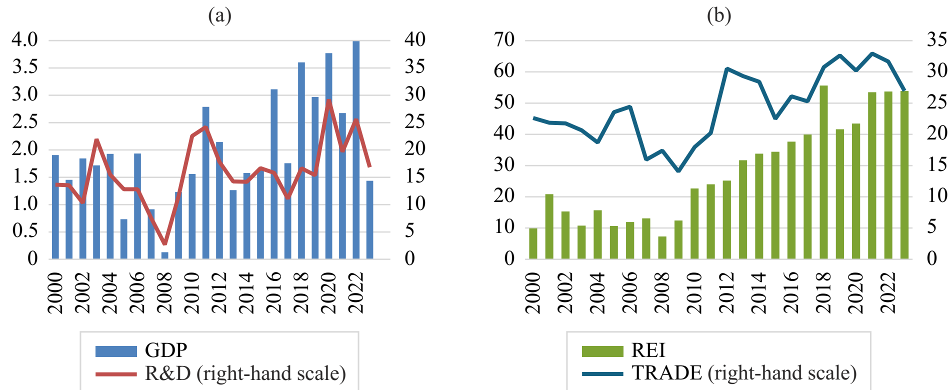

Fig. 2. Macroeconomic indicators and firms' capital expenditure in renewable energy, 2000–2023 (%).

Source: Author's calculations.

5. Results and discussion

We aim to visualize the evolution of selected economic indicators with renewable energy investment variables. Fig. 2 provides a clear depiction of these relationships. On the left, we illustrate the association between Saudi firms' aggregate R&D expenditures in renewable energy and the GDP growth rate, showcasing how increased investment in innovation correlates with economic expansion. On the right, we plot the association between the trade balance and Saudi firms' investments in renewable energy (aggregate values). In both cases, the right axis represents the macroeconomic indicators (GDP growth and trade balance), while the left axis corresponds to renewable energy investment variables, offering a comparative view of their interdependencies.

We observe a generally positive association between R&D expenditure and the GDP growth rate across most of the analyzed period, except for 2015–2018 when this relationship appears weaker. The notable sharp decline in both variables during 2007–2008 can be attributed to the global financial crisis, which significantly impacted worldwide economic activity and investment capacity. This decline highlights the sensitivity of innovation investment and economic growth to external financial shocks, underscoring the critical need for resilient economic policies that protect R&D expenditure during downturns. The positive association outside crisis periods reinforces the argument that sustained R&D investment helps foster long-term economic growth. The graph on the right illustrates a weaker association between renewable energy investment and the trade balance compared to the stronger link between GDP and R&D expenditure. Despite this, a positive relationship exists between *REI* and *TRADE*, indicating that renewable energy investments improve Saudi Arabia's trade position. As firms invest in renewable energy, they are better positioned to enhance their export capabilities, positively impacting the trade balance. The data highlights the role of renewable energy investment in supporting Saudi firms' international competitiveness and export growth, reinforcing the broader economic benefits of transitioning to renewable energy.

Fig. 3 shows the evolution of the GDP growth rate alongside capital expenditure, a proxy for industrial innovation through investments in physical assets

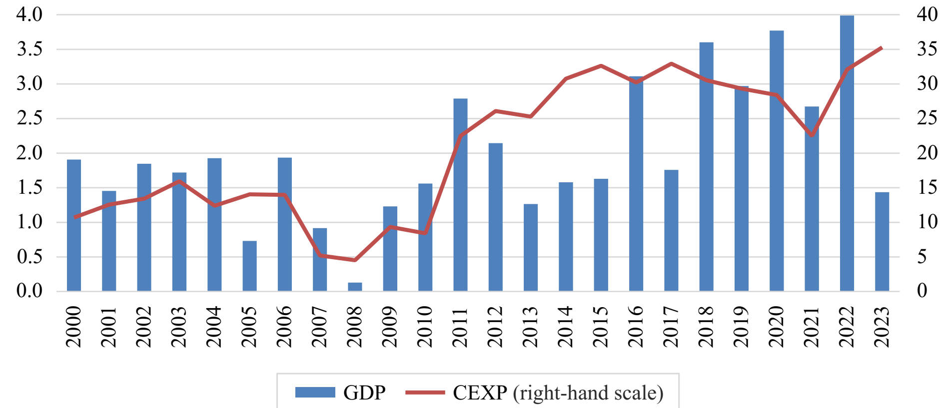

Fig. 3. GDP growth rate and firms' expenditure in innovative industrial projects, 2000–2023 (%).
Source: Author's calculations.

like machinery, equipment, and infrastructure for innovative projects. From 2000 to 2011, there is a clear positive association between these two variables, suggesting that higher investments in industrial innovation contributed to sustained economic growth during this period. However, from 2011 to 2018, their paths diverged, indicating that other factors may have influenced economic growth during this time. Notably, *CEXP* shows two sharp declines: first during the global financial crisis and later during the coronavirus pandemic, both disrupted industrial innovation investments and overall economic performance. These declines highlight the vulnerability of capital-intensive sectors to global economic shocks, emphasizing the need for robust policies that support innovation investments even in times of crisis to ensure stable long-term growth.

Fig. 4 displays two scatter plots examining potential relationships involving R&D expenditure. The first plot reveals a lack of clear association between foreign assets and R&D expenditure, as the data points are widely dispersed without forming any discernible pattern or trend. Similarly, the second plot indicates no evident relationship between the employment rate and R&D expenditure, with data points scattered randomly, suggesting an absence of correlation. These findings suggest that R&D expenditure does not appear to be directly influenced, nor is it significantly influenced by foreign assets or employment rates within the observed dataset.

Turning to the regression results for Equation (2), presented in Appendix Table A4, we find a favorable long-term impact of renewable energy investment on key macroeconomic indicators. Specifically, the estimated coefficients for renewable energy investment are positive and statistically significant, indicating a robust relationship with economic growth rate, trade balance, and FDI inflows. These findings suggest that renewable energy investments enhance economic performance and attract foreign capital. However, the impact on employment rate and foreign assets is comparatively weaker, as reflected by smaller coefficient values and marginal statistical significance (at the 1% level). These findings align with Bermejo Carbonell and Werner (2018), who also find that while renewable energy investments strongly contribute to macroeconomic growth and trade openness, their effects on labor markets and asset accumulation tend to be more gradual and less pronounced, particularly in the early stages of investment. While renewable energy investments stimulate

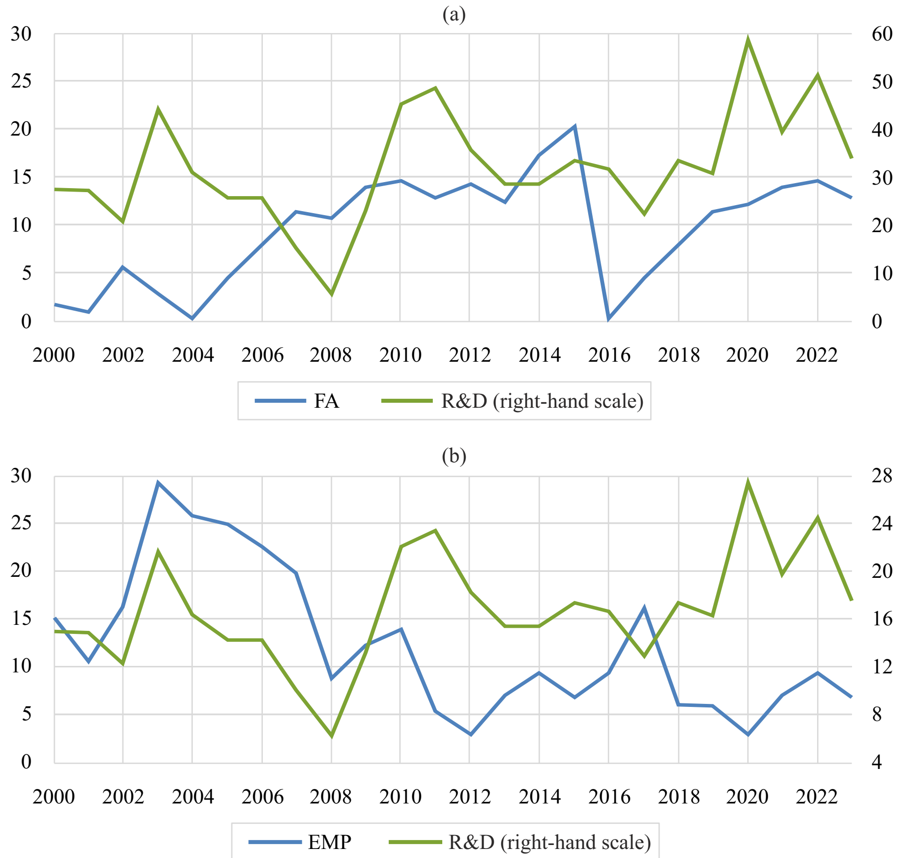

Fig. 4. Foreign assets (a) and employment rate / R&D expenditure (b), 2000–2023.

Note: FA—foreign assets (% of GDP); *EMP*—employment rate (%); R&D—R&D expenditure in renewable energy (%).
Source: Author's calculations.

growth and trade, their effect on employment and foreign asset accumulation is less pronounced, possibly due to factors such as the capital-intensive nature of renewable energy projects or lagged employment effects (Aydin and Degirmenci, 2024). These results highlight the role of renewable energy investments in driving sustainable economic growth and fostering trade, aligning directly with the goals of the UN SDG 8. Such efforts support the creation of productive employment opportunities while contributing to long-term economic resilience.

The long-term effects of industrial innovation, as measured by the number of patents filed, capital expenditure on innovative projects, and sales growth, demonstrate significant positive contributions to economic growth, trade balance, and FDI inflows. However, these effects are relatively weaker when compared to the influence of renewable energy investments. This disparity can be attributed to the differing nature of the two sectors. Renewable energy investments, such as those in solar photovoltaic (PV) systems, wind turbines, and advanced biomass technologies, yield more immediate economic benefits due to their direct impact on energy production, cost efficiency, and resource utilization. For instance, solar PV systems leverage Saudi Arabia's abundant sunlight to provide a reliable and cost-effective energy source, while wind farms in regions like Al-Jouf and Tabuk capitalize on optimal wind speeds to generate electricity. Biomass innovations, such as waste-to-energy technologies, address environmental challenges while creating additional revenue streams.

In contrast, industrial innovation often requires longer development cycles, substantial infrastructure support, and significant market adaptation before achieving notable macroeconomic impacts. This is consistent with findings by Doytch and Narayan (2016), who highlight that while industrial innovation fosters growth and enhances a nation's competitive edge, its benefits tend to be gradual. Such innovations include AI-driven energy management systems that optimize energy distribution, modular battery storage solutions addressing renewable energy intermittency, and 3D-printed components that reduce production lead times and costs. While these innovations improve operational efficiency and long-term sustainability, their immediate impact on attracting foreign capital and enhancing trade performance is limited by factors such as high initial costs, technological complexity, and the need for specialized workforce training.

Given the gradual nature of industrial innovation's impact, policy recommendations should focus on fostering synergy between renewable energy investments and industrial innovation. This includes providing financial incentives for R&D in emerging technologies, enhancing collaboration between academic institutions and industries, and implementing training programs to build a technologically adept workforce. Additionally, export-oriented policies for innovative products and international partnerships can help bridge the gap between the developmental phases of industrial innovation and their economic realization, ensuring long-term competitiveness and resilience.

The effects of industrial innovation variables are notably weaker for employment rate and foreign assets. Specifically, the number of patents filed shows no significant relationship with either employment rate or foreign assets. Similarly, capital expenditure on innovative industrial projects is only weakly significant for the employment rate and remains insignificant for foreign assets (Pan et al., 2019; Li and Ge, 2023). An interesting result is found with the *SALE* variable, which is strongly statistically significant for foreign assets. Rising sales of renewable energy and innovative products may increase exports, thereby contributing to firms' accumulation of foreign assets. Filatotchev and Piesse (2009) provide key insights into the relationship between innovation and international market expansion. They argue that as firms increase sales of innovative products, they gain a competitive edge that enables them to penetrate global markets more effectively. The access to a more enhanced market boosts export revenues and strengthens the firm's foreign asset holdings, contributing to a more diversified and resilient international presence. These results highlight the contribution of industrial innovation to economic growth and international trade, in alignment with the UN SDG 8. As innovation drives exports and strengthens foreign asset holdings, it supports sustainable economic development, job creation, and global economic integration.

When examining the short-term estimates, we observe that both renewable energy investment and industrial innovation variables exert a relatively weaker influence on economic growth and trade balance than their long-term effects. The immediate benefits of investments in renewable energy and innovative industries may be limited, with their full economic impact emerging only over an extended period. In the renewable energy sector, companies are often engaged in developing and deploying technologies such as solar, wind, and battery storage systems, which require substantial upfront capital investment, technological infrastructure, and time to scale. In terms of industrial innovation, companies are implementing advancements in automation, artificial intelligence, and green manufacturing technologies. However, these innovations take time to optimize, leading to gradual improvements in productivity and competitiveness. Therefore, the immediate economic benefits — such as GDP growth and trade balance improvements — are often slower to materialize.

Countries adopting strategies focused on renewable energy and industrial innovation must exercise patience, as favorable economic outcomes will likely emerge in the long term. The delay in these effects is largely attributed to the capital-intensive nature of these sectors and the time required for the widespread adoption of new technologies and infrastructure. Partridge and Olfert (2011) also emphasize the importance of a long-term, forward-looking approach to economic development, arguing that regions concentrating on innovation and renewable energy should prioritize sustained investment and policy consistency. They acknowledge that short-term fluctuations are inevitable, but continued support for these sectors fosters economic resilience, higher productivity, and a stronger competitive position in global markets.

Additionally, the short-term results reveal that the coefficients for employment rate and foreign assets are generally statistically insignificant, suggesting that immediate changes in employment or foreign asset accumulation due to investments in renewable energy and industrial innovation are minimal. This finding underscores the gradual transformation in these sectors, where the workforce may need time to adapt to new technologies and industries, and foreign assets may accumulate slowly as the global competitiveness of these sectors grows.

One particularly notable finding in the short-term analysis is the error correction term behavior. The ECT is negative and statistically significant, a critical indicator of the model's dynamic adjustment process. Specifically, the negative sign and significance of the ECT demonstrate that any short-term deviation from the long-term equilibrium is corrected rapidly. In other words, when the economy experiences a shock or disturbance in the short run, it quickly returns to its long-term path of growth and stability. The magnitude of the ECT suggests the speed at which this adjustment occurs, with a larger (in absolute terms) negative value indicating a faster return to equilibrium. This finding supports the notion that the economic systems under study — particularly in the context of renewable energy and industrial innovation — are resilient and capable of correcting short-term imbalances efficiently (Molyneaux et al., 2016). While the immediate impacts of investments in renewable energy and industrial innovation may be muted, the significant error correction mechanism suggests that these sectors contribute to a stable and sustainable path toward long-term economic growth and development.

Appendix Table A5 presents the results of the GMM estimation using a fixed-effects panel data approach, incorporating interaction terms between four variables representing renewable energy investment (*R&D*, *REI*, *REVRE*, and *INST*) and two variables representing industrial innovation (*PAT* and *CEXP*). Compared to the standalone effects reported in Appendix Table A4, the analysis demonstrates a significantly stronger impact of the interactions between renewable energy investment and industrial innovation on GDP growth rate and trade balance. However, the influence on FDI is relatively less pronounced. Azam and Haseeb (2021) examined the case of BRICS. They reached similar conclusions, indicating that the combined effects of renewable energy and industrial innovation create synergistic benefits for economic growth and trade performance but are less influential in directly attracting foreign capital. Their study highlights that while innovation and energy investments drive competitiveness and long-term sustainability, FDI inflows may depend more on macroeconomic stability, market size, and institutional frameworks rather than solely on technological and energy advancements.

Combining renewable energy investments with industrial innovation significantly boosts Saudi Arabia's economic performance, aligning with the country's Vision 2030 goals of economic diversification and sustainability. Renewable energy investments, particularly solar, wind, and hydrogen, are critical in transforming Saudi Arabia's energy landscape. Given its abundant sunshine, the country is investing heavily in solar power, with projects such as the Mohammed bin Rashid Al Maktoum Solar Park and the King Salman Renewable Energy Initiative. Though less developed, wind energy is being explored in regions such as the Red Sea coast, while the development of green hydrogen — produced using renewable energy — is also gaining traction as a potential export industry. These investments stimulate technological advancements such as improvements in energy storage systems, smart grid technologies, and energy-efficient processes in sectors like oil refining and petrochemicals.

Industrial innovation in Saudi Arabia is largely centered on integrating cutting-edge technologies, such as artificial intelligence (AI), automation, and advanced manufacturing processes, into traditional industries like oil and gas, and emerging sectors like renewables and biotechnology. Saudi companies are implementing AI-driven solutions in energy management, predictive maintenance for industrial equipment, and automation of manufacturing lines. These innovations help increase productivity, reduce costs, and improve the global competitiveness of Saudi industries.

However, despite the positive impacts on trade balance and economic growth through exports and efficiency gains, the immediate effects on employment and foreign assets remain limited. This observation suggests that while innovation and investment may lead to long-term job creation and an increase in foreign asset accumulation, these effects take time to materialize. The current stage of industrial transformation in Saudi Arabia may not yet be sufficiently widespread or capitalized on to significantly alter labor market outcomes, contrasting with the findings of Bassanini and Duval (2006), who noted a more direct influence of innovation and capital investments on the labor market.

In the third stage of our analysis, we introduced two instrumental variables to address endogeneity and simultaneous causality between renewable energy investment, industrial innovation, and the dependent variables. The first is the historical average of renewable energy investment in each firm's sector (*H_AVR*), and the second is government innovation policies, proxied by the budget for innovative, eco-friendly projects (*GOV*), serving as an exogenous factor to isolate causal relationships in our regressions. The results of these regressions are reported in Appendix Table A6. They show that including *H_AVR* and *GOV* helps ameliorate the coefficients of all variables that act as a proxy to industrial innovation and renewable energy. By addressing endogeneity, these instrumental variables ensure that the estimated coefficients for industrial innovation and renewable energy investments more accurately reflect their true impact on GDP, trade, FDI, employment, and foreign assets. Besides, introducing these variables leads to more consistent and reliable estimates of both short-term and long-term effects, enhancing the robustness of the model's results. This approach of using instrumental variables closely aligns with the methodology employed by Wen et al. (2022), who estimated the effects of renewable energy and energy efficiency on technological innovation. They utilized panel data from 1995 to 2017 and applied the instrumental variable fixed effect technique to address potential endogeneity issues. Their findings demonstrated a significant improvement in the accuracy and reliability of the estimated coefficients when instrumental variables were introduced, compared to baseline models without such adjustments.

Additionally, we conducted robustness checks by examining alternative variables, allowing us to evaluate the stability and consistency of our results across varying conditions.[1] We have utilized the Gross National Income (GNI) per capita growth rate, the Terms of Trade index, Portfolio investment (% of GDP), Labor force participation rate, and International reserves (% of GDP) as alternatives to the GDP growth rate, FDI, Trade balance ratio, Employment rate, and External financial assets (% of GDP), respectively.

Supplementary specifications on the empirical model are performed, notably by evaluating changes in our baseline model estimates using different estimators, such as fully modified OLS and dynamic OLS. We also separated the long-run and short-run effects to determine whether the signs and significance of the coefficients remain consistent across both contexts. Furthermore, we re-ran the model with alternative specifications, including varying combinations of lag lengths for the ARDL model and additional control variables such as inflation rate, interest rates, and government expenditure. Following these exercises, the results remained consistent with the estimates in Appendix Table A4, reinforcing the reliability of our findings. The stability of the results across various robustness checks, including introducing alternative variables and alternative estimators, emphasizes the validity of the relationships identified between renewable energy investment, industrial innovation, and the dependent variables. This consistency suggests that our empirical analysis captures the proper dynamics, providing confidence that the observed effects are not merely artifacts of model specification or sampling variations.

Based on our study results, the hypotheses proposed are partially confirmed. The findings validate H1 as renewable energy investments at the company level significantly and positively influence GDP growth, demonstrating their immediate economic benefits through enhanced energy production, cost efficiency, and resource utilization. Similarly, H2 is confirmed, as industrial innovation activities, measured by patents filed, capital expenditure on innovative projects, and sales growth, enhance trade performance and competitiveness, albeit with effects that emerge more gradually. Regarding H3, the hypothesis is supported for FDI inflows, where renewable energy investments and sales growth in innovative sectors exhibit strong contributions. However, the impact of industrial innovation variables on employment growth and foreign asset accumulation remains weaker and statistically insignificant in the short term, suggesting a delayed influence. These results underline the synergy between renewable energy investments and industrial innovation,

[1] We omit these additional robustness checks to maintain the paper's focus and conciseness.

which aligns with long-term goals of economic diversification and sustainability, despite the slower pace of short-term benefits for employment and foreign assets.

6. Policy implications

The findings highlight significant policy implications regarding renewable energy investment and industrial innovation in Saudi Arabia. The positive relationship between renewable energy investment and key macroeconomic indicators, such as economic growth and trade balance, suggests that the Saudi government should prioritize and incentivize these projects to boost economic performance and attract foreign capital. Specifically, advancements in solar energy, which have vast potential in Saudi Arabia due to its abundant sunshine, are central to the country's renewable energy strategy. In addition, innovations in energy storage, such as lithium-ion batteries and the development of green hydrogen technologies, play a crucial role in addressing the intermittency issues of solar power and enhancing its reliability for large-scale use. Saudi Arabia's commitment to building the NEOM city, focusing on renewable energy, and investments in solar and wind farms are clear examples of how industrial innovation is being integrated into the country's energy transition.

However, the weaker impact on employment rates and foreign asset accumulation indicates a need to account for renewable energy projects' capital-intensive nature. Such projects typically require large upfront investments in technology, infrastructure, and machinery, with relatively less immediate need for labor compared to more traditional industries. For instance, while installing solar panels and wind turbines creates jobs, the operation and maintenance of these systems are less labor-intensive, especially as automation and smart grid technologies are increasingly integrated. As a result, while these projects can drive long-term economic growth, they may not generate significant job creation in the short term or quickly contribute to foreign asset accumulation. This capital intensity can also lead to slower employment growth because the sector's expansion is driven by investment in automation and advanced technologies, such as robotic systems and AI-driven energy management, rather than a large workforce. Acemoglu and Restrepo (2020) examine the impact of automation on employment and wages. They have found that industries with high capital intensity and significant investment in automation tend to experience slower employment growth. The authors explain that automation often replaces tasks traditionally performed by humans, leading to a reduced demand for labor in the short term. While automation enhances productivity and contributes to long-term economic growth, its immediate effect on job creation is limited.

Therefore, policymakers should consider complementary strategies, such as workforce development programs focused on renewable energy and technology sectors, alongside targeted support for industries that generate higher employment, to balance the economic benefits of renewable energy with broader social objectives like job creation and asset growth. Furthermore, fostering innovation in renewable energy technologies, such as next-generation photovoltaic cells, large-scale concentrated solar power plants, and advanced wind turbine designs tailored to Saudi Arabia's climate, could help reduce costs and increase the industry's competitiveness. This, in turn, would spur greater economic activity and job creation. Creating policies that incentivize industries with greater labor intensity, alongside renewable energy projects, could ensure that the benefits of growth are more equitably distributed, addressing both economic performance and job creation goals outlined in SDG 8.

Additionally, the role of industrial innovation is crucial, as evidenced by its significant contributions to economic growth and trade. Implementing supportive measures for innovation, such as increasing funding for R&D and creating favorable conditions for patenting, may maximize these benefits. Such measures are particularly relevant for Saudi Arabia, as it seeks to diversify its economy and reduce its reliance on oil exports under Vision 2030. While the effect of innovation on employment and foreign assets is currently limited, the strong relationship between rising sales of innovative products and foreign asset accumulation suggests that enhancing market access for these goods can facilitate export growth. Expanding exports in non-oil sectors strengthens the trade balance and enhances the nation's global competitiveness, paving the way for a more diversified and resilient economy in the future.

The analysis highlights the critical importance of adopting a long-term perspective in policy design, particularly regarding investments in renewable energy and industrial innovation. Aghion et al. (2016) emphasize that while the short-term economic benefits of investments in green technologies may appear modest, the long-term returns are substantial. Their research highlights how investments in renewable energy and innovation enhance energy efficiency and drive long-term productivity gains, positioning economies for sustained growth. The long-term benefits of these innovations—such as enhanced productivity, new market creation, and greater competitiveness on the global stage—can significantly strengthen the economy. Therefore, patience and strategic foresight are essential in policy planning, as these investments in renewable energy and innovation are foundational to achieving sustained economic growth, diversification, and resilience, particularly for economies like Saudi Arabia's, which aim is to transition away from oil dependency. Policymakers should remain committed to these initiatives, recognizing that the long-term payoff will far outweigh any short-term limitations. Moreover, the rapid correction of short-term deviations from long-term equilibrium, as indicated by the statistically significant and negative ECM term, highlights the resilience of the economic environment. This resilience suggests that short-term shocks do not derail overall growth as the economy swiftly adjusts to its long-term trajectory. Such a robust adjustment mechanism underscores the importance of implementing policies that foster sustainable practices and promote innovation. By focusing on long-term stability, these policies can help ensure that the economy remains adaptable and well-positioned to weather future disruptions while maintaining consistent growth.

Finally, the interaction between renewable energy investment and industrial innovation in Saudi Arabia reveals a powerful synergy that can significantly amplify economic benefits. Firms operating in the renewable energy sector, particularly in solar and wind energy, are often at the forefront of technological innovation, developing new processes, products, and systems that advance renewable energy capabilities and enhance the country's overall industrial competitiveness. Saudi Arabia's ambitious Vision 2030, focusing on transitioning to a sustainable and diversified economy, emphasizes the importance of technological innovation in energy production, including investments in green hydrogen and energy storage technologies. This complementary relationship suggests that integrating renewable energy investment with industrial innovation can boost productivity, drive export growth, and elevate global competitiveness.

Strengthen industrial innovation through increased R&D funding and targeted tax incentives to enhance technological capabilities. Investments in energy storage solutions, such as advanced battery technologies and large-scale storage systems, are critical to supporting the growth of intermittent renewable energy sources like wind and solar. Establish R&D hubs like King Abdulaziz City for Science and Technology to foster innovation in clean energy technologies and accelerate commercialization. Moreover, developing smart grid systems and automation technologies in the renewable energy sector to increase efficiency, reduce costs, and enhance energy security further establishes Saudi Arabia as a leader in renewable energy technologies.

To address limited job creation in capital-intensive sectors like renewable energy and industrial innovation, equip citizens with necessary skills through workforce development programs. Training in renewable energy technologies such as solar panel installation and maintenance, wind turbine operation, and green hydrogen production processes will be essential. Collaborate with educational institutions, private companies, and international organizations to provide specialized training programs that develop a skilled workforce capable of meeting the needs of the renewable energy and technology sectors. Saudi initiatives, such as the National Industrial Development and Logistics Program, align educational curricula with the green economy's needs, fostering high-skilled jobs that support long-term economic growth.

Encourage public—private partnerships to accelerate renewable energy and innovation initiatives. Monitor and evaluate policies to allow data-driven adjustments for effectiveness. Track the performance of renewable energy initiatives and innovations in industrial sectors and assess the social and economic impacts of job creation, training programs, and new technologies. Establish a renewable energy monitoring agency or integrate into existing bodies like the Saudi Energy Efficiency Center to provide real-time data and insights, enabling policymakers to make informed decisions.

Promote export competitiveness by improving market access for innovative and renewable energy products to stimulate economic growth. Create favorable trade policies, including trade agreements with key markets in Europe, Asia, and the Middle East, to support export growth and strengthen the Kingdom's position in the global energy market.

Integrate sustainability criteria into government procurement processes and facilitate knowledge transfer to reinforce Saudi Arabia's commitment to renewable energy, supporting the transition to a diversified and resilient economy. Prioritize purchasing energy-efficient technologies and renewable energy solutions for public infrastructure projects. Encourage international partnerships for knowledge transfer, including collaboration with leading renewable energy firms and universities worldwide, to accelerate the adoption of best practices and advanced technologies in Saudi Arabia.

7. Conclusion

The study investigates the long-term and short-term economic impacts of renewable energy investments and industrial innovation in Saudi Arabia, focusing on key macroeconomic indicators such as GDP growth, trade balance, FDI, employment rates, and foreign asset accumulation. The findings indicate that renewable energy investments significantly boost economic growth, trade balance, and FDI inflows in the long term, although their effects on employment and foreign assets are weaker. Industrial innovation also contributes to economic growth, though its impact is less pronounced than that of renewable energy investments. This study aligns with the UN SDG 8: Decent Work and Economic Growth. The findings highlight the potential of these sectors to boost GDP growth, trade balance, and FDI. While the study reveals the limitations of these sectors in terms of immediate job creation and foreign asset accumulation, it emphasizes the importance of complementary policies that can enhance the social benefits of economic growth. These efforts will help create productive employment opportunities and strengthen the global competitiveness of Saudi Arabia.

The main policy implication of the study is that Saudi Arabia should continue prioritizing renewable energy investments and industrial innovation as part of its economic diversification efforts under Vision 2030. However, the government should also consider complementary policies to address the limited job creation in capital-intensive sectors, such as developing workforce training programs for emerging industries and fostering public—private partnerships to facilitate smoother implementation of these investments.

While the study provides valuable insights, it faces certain limitations. First, the analysis focuses on macroeconomic indicators and does not fully account for the social or environmental impacts of renewable energy and industrial innovation projects. Additionally, the capital-intensive nature of these sectors may have understated the effects on employment, and the short-term results might not capture the immediate shifts in labor markets or asset holdings. Finally, the reliance on available data from firms and government reports may not fully reflect the complexities of sectoral interactions and the broader economic context.

Future research should aim to explore the social and environmental dimensions of renewable energy investments and industrial innovation, particularly their impact on job quality, income distribution, and ecological sustainability. Longitudinal studies could also investigate the evolving role of workforce development in these sectors and how the gradual transition to a low-carbon economy influences broader economic resilience. Expanding the analysis to include additional countries or regions would offer comparative insights and help refine the understanding of how renewable energy and innovation contribute to economic transformation.

Acknowledgements

The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project No. PSAU/2024/02/30964.

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Appendix A

Table A1
Variables description.

Variable	Notation	Definition	Source	Data access link
Dependent variables				
Economic growth	GDP	GDP per capita growth rate	WDI of the World Bank	https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG
Trade balance	TRADE	(Exports − Imports) / GDP	WDI	https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS
Foreign direct investment	FDI	FDI, inflows (% of GDP)	WDI	https://data.worldbank.org/indicator/BX.KLT.DINV.WD.GD.ZS
Employment rate	EMP	Proportion of a country's working-age population that is employed	WDI	https://data.worldbank.org/indicator/SL.*EMP*.TOTL.SP.ZS
Foreign assets	FA	Value of a country's external financial assets (% of GDP)	WDI	https://www.imf.org/en/Data
Independents variables				
Renewable energy				
Research and development (R&D) expenditure	R&D	Firms R&D expenditure in renewable energy (% of firm total investment)	Financial reports of firms (FRF) and industry reports (IR)	https://www.iea.org/topics/renewables
Renewable energy investment	REI	Capital invested by firms in renewable energy projects (% of firm total investment)	FRF and IR	https://www.bnef.com/
Percentage of revenue from renewable energy	REVRE	Proportion of a firm's total revenue derived from renewable energy-related activities or products	FRF and IR	https://www.statista.com/topics/2180/renewable-energy/
Renewable energy capacity installed	INST	Value of installed capacity of renewable energy systems (e.g., solar panels, wind turbines) by the firm (% of total assets)	FRF and IR	https://irena.org/Statistics
Industrial innovation				
Number of patents filed	PAT	Number of patents or intellectual property rights filed by the firm	FRF and IR	https://www.wipo.int/ipstats/en/
Capital expenditure	CEXP	Investments in physical assets like machinery, equipment, and infrastructure (% of total investment)	FRF and IR	https://www.capitaliq.com/
Revenue growth	SALE	Firm's sales from new products (% of total sales)	FRF and IR	https://www.reuters.com/markets/companies/

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Table A1 *(continued)*

Variable	Notation	Definition	Source	Data access link
Control variables				
Firm size	FS	Total assets of the firm (% of Total industry assets)	FRF and IR	https://www.bloomberg.com/markets
Concentration ratio	CR	Market share held by the top 4 firms in the industry (CR 4)	FRF and IR	https://www.statista.com/
Government support	GS	Financial support provided to a firm through grants, subsidies, or tax incentives (% of total capital)	FRF and IR	https://www.vision2030.gov.sa/en/

Source: Compiled by the author.

Table A2
Summary statistics.

Variable	Mean	Min	Max	Std. dev.	Kurtosis	Obs.	Unit root
GDP	2.25	–3.51	5.67	3.15	0.32	1870	414.6*
TRADE	2.64	0.56	12.67	2.05	76.77	1717	305.4**
FDI	0.35	–0.67	7.67	1.15	24.14	1835	166.7**
EMP	12.67	8.97	31.08	3.69	170.59	1958	113.3**
FA	1.27	0.31	11.67	2.97	89.77	1751	431.8***
R&D	5.13	2.37	26.85	4.68	10.47	2015	130.5*
REI	11.67	9.37	75.03	8.64	43.70	2007	109.7***
REVRE	10.87	12.64	81.37	5.27	105.76	1850	464.9*
INST	14.51	10.37	52.16	8.07	–1.29	1661	171.02***
PAT	7.00	3.00	81.00	2.31	11.22	1515	130.5**
CEXP	10.37	15.68	71.06	5.67	28.40	1954	245.9***
SALE	15.26	8.39	38.99	8.12	359.54	1857	466.4***
FS	4.56	1.24	16.85	3.24	10.16	1885	280.7*
CR	70.21	61.37	91.25	22.35	1.65	1892	103.5***
GS	3.24	2.64	21.37	1.08	163.81	1957	254.7***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

Table A3
Variables correlation.

Variable	GDP	TRADE	FDI	EMP	FA	R&D	REI	REVRE	INST	PAT	CEXP	SALE
GDP	1											
TRADE	0.36	1										
FDI	0.61	0.58	1									
EMP	0.56	0.41	0.29	1								
FA	0.48	0.76	0.81	0.46	1							
R&D	0.42	0.52	0.39	0.52	0.31	1						
REI	0.30	0.33	0.39	0.10	0.27	0.02	1					
REVRE	0.34	0.61	0.35	0.24	0.12	0.28	0.24	1				
INST	0.30	0.15	0.43	0.19	0.08	0.27	0.20	0.08	1			
PAT	0.52	0.34	0.45	0.31	0.21	0.12	0.27	0.29	0.35	1		
CEXP	0.41	0.23	0.50	0.42	0.08	0.08	0.32	0.18	0.20	0.33	1	
SALE	0.36	0.52	0.61	0.35	0.31	0.02	0.64	0.71	0.12	0.08	0.15	1

Source: Author's calculations.

Table A4
Economic impacts of renewable energy and industrial innovation.

Variable	GDP	TRADE	FDI	EMP	FA
Estimated long-term coefficients					
R&D	0.205***	0.249***	0.186**	0.046*	0.003
	(0.054)	(0.034)	(0.093)	(0.125)	(0.102)
REI	0.243**	0.075**	0.081**	0.127*	0.031*
	(0.121)	(0.037)	(0.040)	(0.028)	(0.015)
REVRE	0.125*	0.037**	0.128**	0.015*	0.117*
	(0.063)	(0.018)	(0.064)	(0.007)	(0.058)
INST	0.091**	0.078*	0.113**	0.134*	0.109*
	(0.046)	(0.039)	(0.056)	(0.068)	(0.257)
PAT	0.097***	0.007*	0.008*	0.124	0.137
	(0.023)	(0.003)	(0.004)	(0.363)	(0.269)
CEXP	0.067**	0.081**	0.032**	0.071*	0.074
	(0.033)	(0.040)	(0.009)	(0.035)	(0.139)
SALE	0.031*	0.067**	0.105	0.138*	0.061***
	(0.015)	(0.033)	(0.364)	(0.070)	(0.015)
FS	0.293	0.341	0.123	0.033	0.412
	(0.116)	(0.170)	(0.101)	(0.267)	(0.110)
CR	–0.019***	–0.023**	–0.014**	0.095	0.205
	(0.005)	(0.011)	(0.007)	(0.148)	(0.364)
GS	0.037*	0.011*	0.067*	0.017***	0.018
	(0.018)	(0.005)	(0.033)	(0.003)	(0.249)
Estimated short-term and ECM coefficients					
ΔDep. var. (–1)	0.015*	0.017*	0.108*	0.031*	0.076*
	(0.007)	(0.008)	(0.054)	(0.015)	(0.038)
ΔR&D	0.033*	0.012*	0.064*	0.053	0.011
	(0.016)	(0.006)	(0.032)	(0.126)	(0.105)
ΔREI	0.081*	0.034*	0.025	0.021*	0.072
	(0.040)	(0.017)	(0.072)	(0.011)	(0.036)
ΔREVRE	0.041*	0.063*	0.021*	0.014	0.052*
	(0.020)	(0.031)	(0.010)	(0.097)	(0.026)
ΔINST	0.017**	0.011*	0.031*	0.087	0.021
	(0.008)	(0.005)	(0.015)	(0.293)	(0.070)
ΔPAT	0.012	0.024*	0.032*	0.058	0.141
	(0.056)	(0.012)	(0.016)	(0.129)	(0.870)
ΔCEXP	0.006**	0.039	0.022*	0.096*	0.047*
	(0.003)	(0.084)	(0.011)	(0.048)	(0.023)
ΔSALE	0.011*	0.055*	0.038	0.051	0.197
	(0.005)	(0.027)	(0.119)	(0.498)	(0.048)
ECM(–1)	–0.492***	–0.405***	–0.388***	–0.192**	–0.124**
	(0.046)	(0.052)	(0.064)	(0.096)	(0.062)
LM test (χ^2)	0.117	0.102	0.151	0.186	0.215
White test	0.148	0.109	0.157	0.237	0.261
Jarque–Bera test	0.138	0.195	0.294	0.127	0.112
RESET test	0.527	0.218	0.159	0.354	0.108

Note: Table presents the estimates from Equation (2), with the first row listing the five dependent variables: *GDP*, *TRADE*, *FDI*, *EMP*, and *FA*. Table is divided into two sections: long-term and short-term coefficient estimates. The *t*-statistics are reported in parentheses. The *p*-values for the diagnostic tests are displayed at the bottom of the table; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

Table A5
Interactions between renewable energy investment and industrial innovation.

Variable	GDP	TRADE	FDI	EMP	FA
R&D × PAT	0.356***	0.337***	0.297***	0.041*	0.082*
	(0.042)	(0.067)	(0.041)	(0.020)	(0.041)
REI × PAT	0.408***	0.235**	0.189**	0.048*	–0.101
	(0.054)	(0.117)	(0.094)	(0.024)	(0.350)
REVRE × PAT	0.321***	0.071*	0.067**	0.013	–0.009*
	(0.060)	(0.035)	(0.033)	(0.076)	(0.004)
INST × PAT	0.246***	0.047**	0.021**	0.088	0.075*
	(0.023)	(0.023)	(0.010)	(0.093)	(0.037)
R&D × CEXP	0.422***	0.351**	0.132*	0.037	0.141
	(0.071)	(0.175)	(0.066)	(0.511)	(0.273)
REI × CEXP	0.531**	0.210*	0.362**	0.051	0.007*
	(0.215)	(0.365)	(0.181)	(0.310)	(0.003)
REVRE × CEXP	0.421**	0.118***	0.025**	0.021*	0.022*
	(0.210)	(0.029)	(0.012)	(0.010)	(0.011)
INST × CEXP	0.510**	0.263**	0.121***	0.044	0.052*
	(0.255)	(0.131)	(0.030)	(0.122)	(0.026)
LM test (χ^2)	0.201	0.342	0.261	0.322	0.203
White test	0.161	0.117	0.109	0.208	0.223
Jarque–Bera test	0.108	0.133	0.201	0.139	0.232
RESET test	0.220	0.203	0.144	0.174	0.158

Note: Table presents the GMM estimator results for Equation (3), with the first row listing the five dependent variables: *GDP*, *TRADE*, *FDI*, *EMP*, and *FA*. It provides the estimated interaction terms between the four renewable energy investment variables and the two industrial innovation variables (*PAT* and *CEXP*). *p*-values for the diagnostic tests are displayed at the bottom of the table; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Author's calculations.

Table A6
Renewable energy and industrial innovation: Instrumental variables.

Variable	GDP	TRADE	FDI	EMP	FA
Estimated long-term coefficients					
R&D	0.283***	0.267***	0.201**	0.075*	0.015
	(0.046)	(0.031)	(0.100)	(0.037)	(0.082)
REI	0.279***	0.094**	0.087**	0.163*	0.052*
	(0.064)	(0.047)	(0.043)	(0.081)	(0.026)
REVRE	0.141*	0.056**	0.132*	0.037*	0.138**
	(0.070)	(0.028)	(0.066)	(0.018)	(0.069)
INST	0.098**	0.083*	0.120**	0.145*	0.139*
	(0.049)	(0.041)	(0.060)	(0.072)	(0.069)
PAT	0.105***	0.012*	0.009*	0.098	0.057
	(0.041)	(0.006)	(0.004)	(0.113)	(0.169)
CEXP	0.082**	0.093**	0.061**	0.091*	0.083
	(0.041)	(0.046)	(0.030)	(0.045)	(0.259)
SALE	0.041*	0.060**	0.138	0.153*	0.084***
	(0.020)	(0.030)	(0.244)	(0.076)	(0.026)
FS	0.104	0.141	0.093	0.133	0.212
	(0.336)	(0.260)	(0.234)	(0.267)	(0.510)
CR	–0.031**	–0.043**	–0.037**	0.061	0.105
	(0.015)	(0.021)	(0.018)	(0.228)	(0.264)

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Table A6 *(continued)*

Variable	GDP	TRADE	FDI	EMP	FA
GS	0.047*	0.031*	0.083*	0.028**	0.021*
	(0.023)	(0.015)	(0.041)	(0.014)	(0.010)
H_AVR	0.121***	0.094**	0.025**	0.061*	0.036***
	(0.037)	(0.047)	(0.012)	(0.015)	(0.010)
GOV	0.237***	0.157***	0.037*	0.012*	0.041*
	(0.054)	(0.025)	(0.018)	(0.006)	(0.020)
Estimated short-term and ECM coefficients					
ΔDep. var.(–1)	0.023**	0.021*	0.112*	0.031*	0.086*
	(0.011)	(0.010)	(0.056)	(0.015)	(0.043)
ΔR&D	0.046**	0.031*	0.081*	0.083	0.011
	(0.023)	(0.015)	(0.040)	(0.096)	(0.105)
ΔREI	0.097*	0.051*	0.038	0.042*	0.012
	(0.048)	(0.025)	(0.072)	(0.021)	(0.076)
ΔREVRE	0.051*	0.070*	0.043*	0.068	0.071*
	(0.025)	(0.035)	(0.021)	(0.087)	(0.035)
ΔINST	0.028**	0.019*	0.052*	0.087	0.021
	(0.014)	(0.009)	(0.026)	(0.293)	(0.070)
ΔPAT	0.012	0.024*	0.032*	0.158	0.091
	(0.056)	(0.012)	(0.016)	(0.169)	(0.170)
ΔCEXP	0.008**	0.067	0.046*	0.098*	0.051*
	(0.004)	(0.094)	(0.023)	(0.048)	(0.025)
ΔSALE	0.011*	0.055*	0.098	0.071	0.207***
	(0.005)	(0.027)	(0.119)	(0.498)	(0.031)
ECM(–1)	–0.492***	–0.405***	–0.388***	–0.192**	–0.124**
	(0.046)	(0.052)	(0.064)	(0.096)	(0.062)
LM test (χ^2)	0.212	0.223	0.171	0.201	0.209
White test	0.311	0.426	0.109	0.255	0.231
Jarque–Bera test	0.109	0.118	0.194	0.161	0.151
RESET test	0.114	0.264	0.264	0.154	0.166

Note: Table presents Equation (2) estimates, augmented by two instrumental variables (*H_AVR* and *GOV*). The first row lists the five dependent variables: *GDP*, *TRADE*, *FDI*, *EMP*, and *FA*. The table is divided into two sections, displaying the long-term and short-term coefficient estimates. *p*-values for the diagnostic tests are reported at the bottom of the table; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Author's calculations.