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Original Research Article

Impact of Expenditures on Potable Water, Food Production, and Renewable Energy on Economic Growth and Sustainability in Saudi Arabia

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ABSTRACT

Many countries have implemented significant reforms in industrial diversification within crucial sectors, impacting various areas. However, the full extent of these impacts remains empirically unclear. This study investigates the effects of Saudi government expenditures on potable water, food production, and renewable energy infrastructure on economic growth, social welfare, public health, and environmental sustainability. Using panel fixed-effects quarterly data from 2000 to 2023 analyzed through an Autoregressive Distributed Lag model. The study finds that potable water and food production expenditures significantly improve social welfare and public health. Specifically, water expenditure contributes to a 1.2% increase in social welfare and a 2.8% increase in public health. Food expenditure leads to a 0.8% improvement in social welfare and a 3.7% improvement in public health. Investment in renewable energy enhances economic growth, public health, and environmental sustainability. Additionally, combining investments in renewable energy with spending on potable water and food production further amplifies these positive effects. These findings underscore the need for the Saudi government to prioritize investments in potable water and renewable energy to boost health, welfare, and sustainability while also implementing targeted social programs.

KEYWORDS

Industrial diversification, expenditure, welfare, economic growth, health, environmental sustainability.

INTRODUCTION

In Saudi Arabia's transition toward a more sustainable and diversified economy, expenditure on industries related to potable water, food production, and renewable energy infrastructure has become a central priority [1]. This strategic focus addresses critical challenges and opportunities across various sectors. Investment in potable water industries is crucial for enhancing public health and ensuring equitable access to clean water, supporting economic stability and social welfare [2]. Advancing food production industries is essential for achieving food security, improving nutritional standards, and fostering economic growth

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through agricultural innovation. Meanwhile, expanding renewable energy infrastructure industries is pivotal for reducing reliance on fossil fuels, mitigating environmental impacts, and promoting long-term sustainability. Examining these expenditures allows for assessing their combined effects on economic growth, social welfare, public health, and environmental sustainability, providing insights into the broader implications of Saudi Arabia's transition strategy [3].

The extensive literature on industrial diversification underscores its vital role in driving economic resilience [1], enhancing productivity, and fostering sustainable development [4], [5]. Numerous studies have demonstrated that diversifying industrial activities can reduce dependency on single sectors and enhance economic growth [7], mitigate economic, social, and environmental risks [8], and create more stable employment opportunities [6]. This diversification is also linked to innovation, as it fosters the development of new technologies and industries, leading to broader economic growth. Furthermore, research highlights the importance of diversification in promoting social welfare and environmental sustainability, enabling economies to adapt to changing global conditions and prioritize sustainable practices.

However, existing literature on the nexus between water, food, and renewable energy has largely focused on their impact on a specific aggregate, such as economic growth, public health [10], social welfare, and environmental sustainability [2], [9]. For instance, studies by Rasul [11], Kurian [12], and Ferraz et al. [1] concentrate exclusively on the environmental sustainability impacts of these sectors. Despite the growing recognition of industrial diversification's benefits, no study has comprehensively explored the combined effects of all three industries—water, food, and renewable energy—across multiple domains. This oversight leaves a significant gap in understanding their collective influence more holistically.

Our study empirically examines the impact of advancements in potable water, food production, and renewable energy investment on economic growth, social welfare, public health, and environmental sustainability. The empirical examination analyzes panel fixed-effects data from 2000 to 2023 using an Autoregressive Distributed Lag model. This approach allows us to capture these sectors' long-term and short-term effects on multiple dimensions of development, providing a comprehensive understanding of their collective influence on Saudi Arabia's transition toward sustainable growth. Our study formulates two main research hypotheses to guide our analysis, focusing on the individual and combined impacts of investments in potable water, food production, and renewable energy infrastructure on economic growth, social welfare, public health, and environmental sustainability.

H1: Investments in potable water, food production, and renewable energy infrastructure significantly and positively impact economic growth, social welfare, public health, and environmental sustainability in Saudi Arabia.

H2: The combined effects of investments in potable water, food production, and renewable energy infrastructure amplify their impact on economic growth, social welfare, public health, and environmental sustainability, producing synergistic benefits across these domains.

Our findings show varied impacts of different government expenditure variables. Expenditures on potable water significantly improve social welfare and public health, highlighting the crucial role of clean water in enhancing quality of life and health outcomes. Conversely, expenditure on food production positively affects social welfare and public health but does not influence economic growth or environmental sustainability, indicating its role in food security rather than broader economic development. Technological innovations in renewable energy significantly affect economic growth, public health, and environmental sustainability, though it does not directly impact social welfare [22]. Additionally, incorporating interaction terms reveals that combined expenditures on potable water and renewable energy produce stronger positive effects across all dependent variables, especially economic growth and public health. Similarly, the interaction between food production and renewable energy demonstrates enhanced benefits, particularly for public health.

Following these results, the Saudi government should prioritize increasing investments in potable water infrastructure to improve public health and social welfare, addressing critical water scarcity issues. Expanding renewable energy investments aligns with Vision 2030 goals and supports economic growth and environmental sustainability. While combining these investments can maximize benefits, targeted social programs are also necessary to address immediate social welfare needs alongside long-term infrastructure development.

The structure of the paper is as follows: Section 2 provides a review of the literature, Section 3 presents an analysis of the data, and Section 4 outlines the empirical methodology, including the statistical techniques and models utilized. Section 5 presents and discusses the results, assesses the robustness of our findings through alternative specifications, examines the policy implications, and offers recommendations for policymakers. Finally, Section 6 concludes the paper.

LITERATURE REVIEW

Providing potable water, sufficient food, and energy has emerged as one of the significant challenges facing many countries, especially in light of rapid population growth. These elements are interdependent and crucial in supporting various other sectors. For instance, ensuring an adequate food supply inevitably increases the demand for water and diverse energy sources, underscoring the interconnected relationship between these three essential resources.

Government spending across various sectors is a key driver of economic growth, social welfare, public health, and environmental sustainability. Notably, expenditures to provide potable water, enhance food production, and transition to renewable energy sources have become focal points of government priorities [9].

Numerous studies have explored the intricate relationships between spending on water, food, and renewable energy and their collective impact on achieving economic growth, social welfare, public health, and environmental sustainability. For instance, Kurian [12] emphasized the importance of integrating water, food, and energy systems by reviewing existing research, arguing that effective implementation of the water-energy-food nexus must be grounded in robust scientific evidence. Kurian also highlighted that successfully applying this nexus approach requires a comprehensive institutional framework that considers the role of governance in shaping behaviors related to environmental resource management [12]. While Kurian [12] emphasizes the integration of water, food, and energy systems, focusing on governance and institutional frameworks, our study provides a distinct contribution by empirically analyzing the impact of sectoral investments across multiple dimensions of development. Specifically, we apply an Autoregressive Distributed Lag (ARDL) model to capture the short- and long-term effects of potable water, food production, and renewable energy investments on economic growth, social welfare, public health, and environmental sustainability. Our study builds on existing work that has utilized the ARDL model to examine the impacts of individual sectors on economic growth and sustainability. However, we distinguish ourselves by employing this model to analyze the combined effects of three critical sectors—potable water, food production, and renewable energy infrastructure—on a range of development outcomes, including economic growth, social welfare, public health, and environmental sustainability, within the specific context of Saudi Arabia's transition towards a more diversified economy. While previous studies have used the ARDL model to focus on one or two sectors in isolation or have applied it in different regional contexts, our approach takes a more holistic view by incorporating all three sectors together. Such an approach enables us to capture the synergistic effects that may arise from combined investments, providing a more nuanced understanding of how these sectors interact to drive sustainable development. Furthermore, we analyze both the short-term and long-term dynamics of these interactions, providing valuable insights into the temporal aspects of policy impacts. This integrated methodology, focusing on a unique and timely national context, offers a novel contribution by highlighting these sectors' specific, combined role in supporting Saudi Arabia's Vision 2030 objectives, which sets it apart from existing literature that typically examines sectoral impacts separately or in different national settings.

Building on this foundation, Ferraz et al. [1] examined the nexus from a broader perspective by exploring the relationship between economic complexity, diversification, industrial policies, and sustainable development. Their review of 374 scientific articles from 1988 to 2020 identified three major research areas: industrial policies about climate change and green growth, the intersection of economic complexity with inequality and environmental sustainability, and the role of economic diversification. Ferraz and colleagues proposed that mutual learning between these research areas is crucial for advancing sustainable development. While Ferraz et al. provided a comprehensive review of 374 scientific articles to identify major research areas—industrial policies addressing climate change and green growth, the intersection of economic complexity with inequality and environmental sustainability, and the role of economic diversification—our work diverges by applying an Autoregressive Distributed Lag (ARDL) model to empirically examine the direct and synergistic effects of investments in potable water, food production, and renewable energy infrastructure across economic growth, social welfare, public health, and environmental sustainability.

Further contributing to this discourse, Mirzabaev et al. [6] investigated the nexus between water, energy, and food security, specifically promoting bioenergy innovations. Their research underscored the potential of bioenergy to foster sustainable development by reducing poverty, improving health, empowering women, and enhancing environmental sustainability. However, they also cautioned about the complex interconnections between bioenergy, food security, water, and land use, which may lead to trade-offs and unintended negative externalities, particularly for the environment. Similarly, Ringler et al. [13] explored the interplay between water, energy, land, and food, emphasizing improving resource use efficiency. They argued that the strong interconnections between these sectors necessitate careful management to balance trade-offs and ensure that human welfare, environmental impacts, and sustainable development goals are simultaneously addressed.

Expanding on these ideas, Molajou et al. [14] discussed the growing global demand for potable water, energy, and food, driven by population growth, economic expansion, international trade, urbanization, and food diversity. They identified a critical gap in government-integrated and systematic policies and strategies, threatening these resources' ability to meet increasing demand. Abdullahi et al. also stressed that urban expansion and increased energy consumption have a significant impact on food production and exports in Nigeria [26]. To address this challenge, Molajou and colleagues advocated for developing broader management strategies, including innovative approaches to modeling the water-food-energy nexus. This is what Ghosh et al. tried to do by studying the interconnections between food, energy, and water based on data from the UN's Food and Agriculture Organization during the period between 1961 and 2023, as the study recommended the need to develop effective and strong strategies to manage the interconnections and trade-offs between natural resources [23].

In a related study, Caruso et al. [2] examined the relationship between renewable energy consumption and social and health factors in 12 European countries using a panel regression model from 1990 to 2015. Their findings emphasized the need for stringent policies on renewable energy consumption, highlighting its positive impact on social factors and a causal relationship between renewable energy use and health outcomes. Moreover, the study identified a bidirectional causal relationship between GDP and renewable energy consumption and the role of increased renewable energy use in reducing carbon dioxide emissions, contributing to sustainable growth. These results are similar to those of Yuzbashkandi in his study on the dynamic relationship between urbanization, energy efficiency, renewable energies, economic growth, and ecological footprint in the MENA countries [24]. In contrast, conventional energy consumption leads to environmental pollution and increased greenhouse gas emissions, as explained by Saidmamatov in a study that included five Central Asian countries between 1992 and 2020 using Panel models [25].

Brears [15] added to this conversation by focusing on managing the water-food-energy nexus to support the transition to a green economy. He argued that efficient resource use and sectoral integration are crucial for this transition. However, Brears pointed out that the governance of water, food, and energy sectors remains largely isolated, neglecting the nexus between them, leading to policy failures and challenges in alleviating the pressures on these interconnected resources.

Moving beyond the water-food-energy nexus, economic diversification has also been recognized as a key strategy for achieving economic growth, enhancing social welfare, improving public health, and promoting environmental sustainability. Jing et al. [16] explored this by examining the role of the nexus in promoting economic diversification across 173 European regions between 2004 and 2012. Their research revealed significant regional differences, with the likelihood of developing new industrial specializations positively linked to the relationship between new and existing industries. However, this relationship weakened as innovation capacity in the region increased, highlighting the role of innovation in enhancing economic resilience and diversification.

Dan et al. [3] provided further insights by studying 243 cities in China and finding that industrial diversification is crucial in improving regional economic resilience, particularly in more economically developed cities. According to their study, industrial diversification depends on several external factors, including financing, technological innovation, and human capital, which are critical for economic growth.

Grillitsch & Asheim [7] addressed the role of place-based innovation policy in achieving industrial diversification. They argued that new industrial innovation policies are designed to promote economic growth by encouraging structural change in regions towards higher-value economic activities [17]. This positive structural change is central to smart specialization strategies, which foster economic growth by creating new pathways for economic diversification [7].

In a complementary study, Jang et al. [4] focused on product diversification at the factory level, using a study of 20,000 electronics factories in Taiwan between 1992 and 1999. They found that Taiwanese electronics factories could leverage production skills, technological knowledge, and management experience to enhance productivity growth. However, Pallares & Adkisson [18] offered a contrasting perspective, arguing that economic diversification does not positively impact employment growth, unlike exports, which they found to be positively correlated with employment growth.

Margarethe & Harry [5] explored the degree and scope of international diversification by U.S. companies, linking it to industrial globalization and foreign competition. Their study of U.S. companies between 1987 and 1999 provided further evidence of diversification strategies' complex and varied impacts on economic outcomes.

Finally, Sarkodie et al. [20] stressed that there is no single path to achieving environmental sustainability, especially in light of population growth that has led to increased energy consumption and greenhouse gas emissions. Food and energy consumption supports economic and social development, and food and water waste will increase the environmental footprint [20]. Menegaki & Tiwari attempted to estimate the relationship between food production and water and energy use for 21 countries worldwide using multiple models between 1990 and 2000. The study showed varying degrees of elasticity between food production, water and energy use, greenhouse gas emissions, and the demand for labor and machinery [21].

Our study makes a distinct contribution by examining the combined effects of investments in potable water, food production, and renewable energy infrastructure on multiple dimensions of development, including economic growth, social welfare, public health, and environmental sustainability, within the specific context of Saudi Arabia. Unlike previous studies focusing on industrial diversification in specific regional, industrial, or national contexts, our research integrates three key sectors pivotal to Saudi Arabia's economic diversification and sustainability goals. While previous studies have explored sectoral impacts on economic resilience or diversification, our study takes a holistic approach by analyzing the synergies between these sectors, providing insights into their collective influence on long-term sustainable growth, a focus not addressed in the existing literature.

DATA ANALYSIS

While many countries have made substantial strides in industrial diversification within key sectors, the empirical evidence on the full extent of these impacts remains limited. This study explores the effects of Saudi government expenditures on potable water, food production, and renewable energy infrastructure on economic growth, social welfare, public health, and environmental sustainability. However, due to the scarcity of publicly available data on these variables, the study has had to rely on internal data from various ministries in Saudi Arabia. These data are compiled quarterly, providing a more granular view of the government's expenditure impacts across these critical areas.

Figure 1 highlights the strategic industrial priorities essential for driving sustainable economic growth and improving the quality of life in a country. Priorities like renewable energy, food production, potable water, education, healthcare, biotechnology, digital infrastructure, and advanced manufacturing are pivotal for fostering long-term resilience and prosperity. These sectors address critical needs, from ensuring food and water security to advancing healthcare and technological innovation. Industrial priorities in Saudi Arabia are reflected in the government's substantial investment in vital sectors, underscoring the country's commitment to economic diversification and sustainability. Our analysis focuses on the impact of expenditures in renewable energy (REEXP), food production (FEXP), and potable water (WEXP), areas where Saudi Arabia has significantly increased its budget over the past two decades. This shift aligns with Vision 2030, the kingdom's strategic framework aimed at reducing its dependence on oil by fostering growth in these critical sectors. The increased investment in renewable energy is evident in the development of large-scale projects like the King Salman Renewable Energy Initiative, while food production has been bolstered by initiatives to achieve greater food security. Similarly, potable water infrastructure has seen significant upgrades, reflecting the kingdom's efforts to address water scarcity and improve public health.

Figure 1. Strategic industrial priorities

The study examines the impact of these expenditures on four variables proxying economic growth (GDPG), social welfare (SW), public health (PH), and environmental sustainability (ES). The description of these variables is reported in Table 1 in the appendices. Before conducting the empirical analysis, data visually illustrates the joint evolution of the main variables of interest. Specifically, Figure 2 shows the relationship between renewable energy expenditure and real GDP growth rate on the left and between renewable energy expenditure and environmental sustainability on the right from Q1 2000 to Q4 2023. Figure 3 displays the association between food production expenditure and social welfare, measured by the Human Development Index, as well as the link between food production expenditure and public health, measured by the Life Expectancy Index. Finally, Figure 4 depicts the connections between potable water expenditure and both social welfare and public health. In these figures, the right axis represents the expenditure variables, while the left axis is used for GDP growth rate, environmental sustainability, social welfare, and public health.

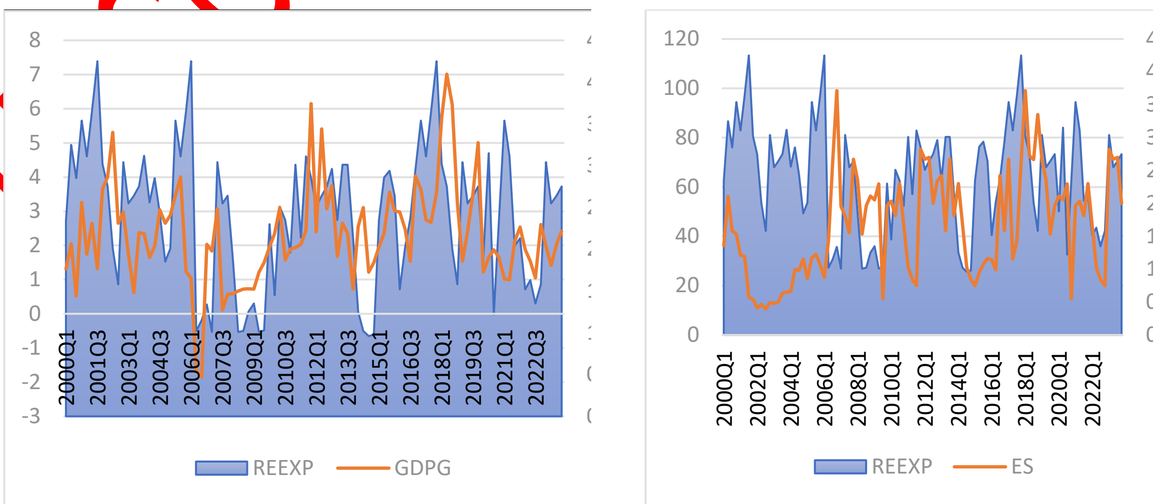

Figure 2. Renewable energy expenditure, GDP growth rate, and environmental sustainability

A clear positive correlation exists between renewable energy expenditure and economic growth in Saudi Arabia, as evidenced by parallel increases in both variables during several periods: 2000-2002, 2003-2006, 2010-2012, and 2016-2018. Similarly, both variables experienced parallel declines during 2002-2003 and 2011-2013. However, the relationship between renewable energy expenditure and environmental sustainability is less consistent. In the early analysis period (2000-2006), the positive association is weaker, though there are periods, such as 2006-2008 and 2017-2018, where a stronger positive correlation is observed. This suggests that while renewable energy investment in Saudi Arabia has generally supported economic growth, its impact on environmental sustainability has varied.

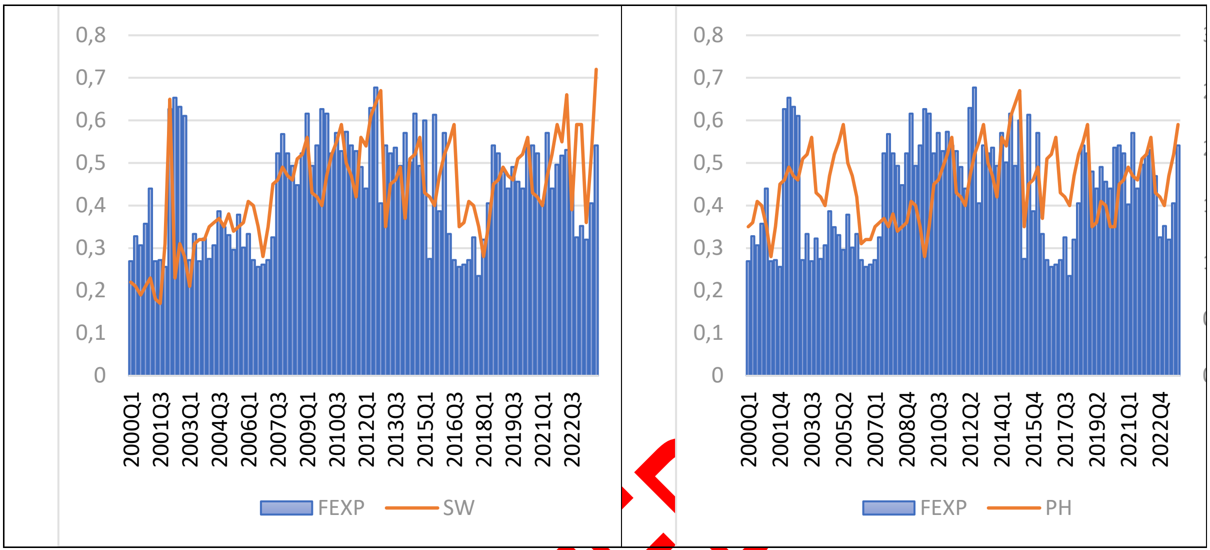

Figure 3. Food production expenditure, social welfare, and public health

Figure 3 illustrates a consistent relationship between food production expenditure and social welfare. Throughout much of the analysis period, increases in food production expenditure are accompanied by improvements in social welfare, and similar patterns are observed during periods of decline. However, the association between food production expenditure and public health, shown in the right graph, is less clear over most of the analysis period. Despite this, there are instances, such as in 2019, where food production expenditure and public health exhibit similar trends, suggesting that while the overall relationship may be ambiguous, specific periods show notable alignment.

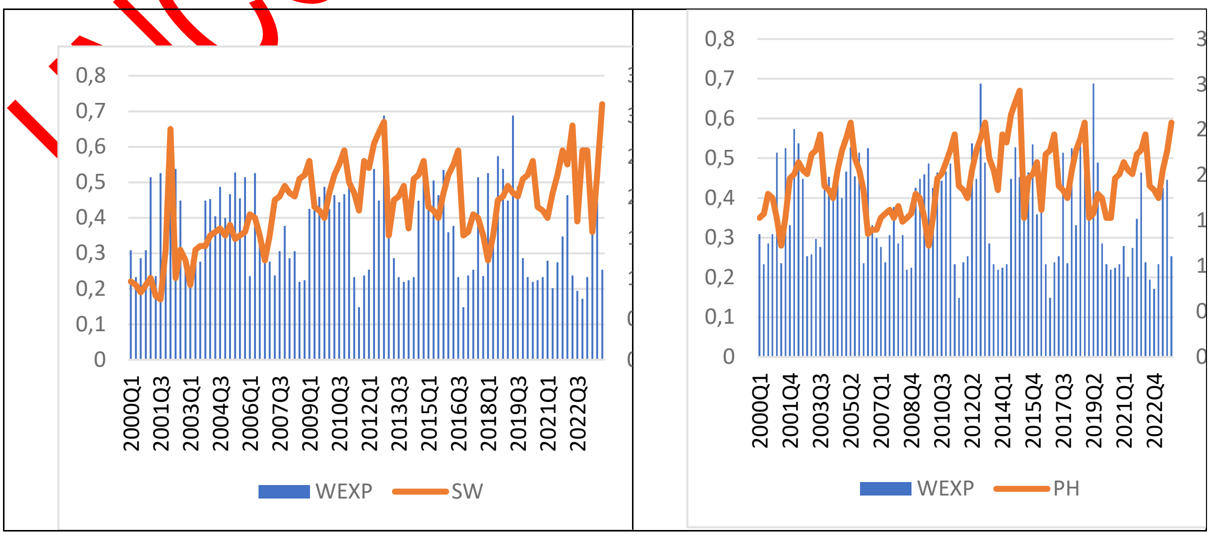

Figure 4. Potable water expenditure, social welfare, and public health

Figure 4 demonstrates that increases in potable water expenditure are associated with improvements in social welfare during specific periods, such as 2001-2002, 2004-2006, 2011-2012, and 2018-2020. These periods reflect when enhanced investment in potable water likely contributed to better health outcomes and overall quality of life. Conversely, declines in potable water expenditure correspond with reductions in social welfare, notably between 2016 and 2018, highlighting the negative impact of reduced investment in water infrastructure on community well-being. However, no clear association is observed between these variables during other periods, especially toward the end of the analysis timeframe. On the right side of Figure 4, the relationship between water expenditure and public health generally shows a positive correlation, as expected. Adequate water supply supports better community health, potentially increasing life expectancy.

The descriptive statistics reported in Table 2 show significant variability across economic and social indicators. The GDP growth rate averages 1.73%, with fluctuations ranging from -1.85% to 5.41%. Social welfare and public health scores, averaging 0.63 and 0.42, respectively, indicate moderate levels with some variability. Environmental sustainability averages 63.22, suggesting generally above-median levels with substantial variation. Water expenditure shows an unusual range, requiring further review. Food expenditure varies widely, reflecting significant differences—renewable energy expenditure averages 8.82, with moderate variability. Human capital is relatively stable at an average of 75.52, while labor force participation and per capita values show moderate to high variability.

METHODS

Our empirical analysis utilizes an Autoregressive Distributed Lag (ARDL) model with panel fixed-effects data from 2000 to 2023. The fixed-effects model enables us to control for unobserved individual heterogeneity and capture time-invariant characteristics within the studied sectors. This methodology is particularly well-suited for assessing both the long-term and short-term impacts of investments in potable water, food production, and renewable energy infrastructure on various outcomes, such as economic growth, social welfare, public health, and environmental sustainability. The panel data structure enhances the robustness and reliability of our results by tracking changes over time and across sectors. By focusing on within-sector variations, the fixed-effects model ensures that our findings are not influenced by unobserved, time-invariant factors, leading to more accurate estimations of the impact of these investments on Saudi Arabia's transition to sustainable growth.

The panel data consists of 42 firms operating within the Saudi renewable energy sector and firms engaged in water and food production. These firms vary in size and significantly influence the aggregate national accounts, contributing to the broader economic landscape and national development goals.

The study examines four distinct models, each represented by the following four equations. These equations are designed to assess the impact of expenditures on potable water, food production, and renewable energy infrastructure on GDP growth, social welfare (SW), public health (PH), and environmental sustainability (SE), respectively.

$$GDPG_t = \alpha + \beta * GDPG_{t-i} + \delta * WEXP_{t-i} + \partial * FEXP_{t-i} + \varphi * REEXP_{t-i} + \gamma * X_{t-i} + \varepsilon_t \qquad Eq(1)$$

$$SW_t = \alpha + \beta * GDPG_{t-i} + \delta * WEXP_{t-i} + \partial * FEXP_{t-i} + \varphi * REEXP_{t-i} + \gamma * X_{t-i} + \varepsilon_t \qquad Eq(2)$$

$$PH_t = \alpha + \beta * GDPG_{t-i} + \delta * WEXP_{t-i} + \partial * FEXP_{t-i} + \varphi * REEXP_{t-i} + \gamma * X_{t-i} + \varepsilon_t \quad Eq(3)$$

$$ES_t = \alpha + \beta * GDPG_{t-i} + \delta * WEXP_{t-i} + \partial * FEXP_{t-i} + \varphi * REEXP_{t-i} + \gamma * X_{t-i} + \varepsilon_t \quad Eq(4)$$

Where:

- GDPG: Growth rate of real GDP
- SW_t: global social welfare
- PH: Public Health
- ES: Environmental Sustainability
- WEXP: Lagged values of expenditures on potable water.
- FEXP: Lagged values of expenditures on food production.
- REEXP: Lagged values of expenditures on renewable energy infrastructure.
- Xt: Vector of classic determinants of economic growth, including human capital, physical capital, and labor force.
- Parameters' *t*' for quarters and '*i*' for lags[†]
- α: Intercept term.
- $\beta, \delta, \partial, \varphi, and\ \gamma$: Coefficients of the variables.
- ϵ_t : Error term.

We have incorporated the inflation rate as an additional control variable to mitigate potential multicollinearity among the model variables. By introducing this neutral factor, we reduce the correlation between the sectors, thereby enhancing the robustness of the model. Our empirical analysis demonstrates that the model is robust and effectively addresses the concerns identified through diagnostic testing. The Arellano-Bond Test for AR(1) indicates that there is no first-order autocorrelation in the first-differenced errors, affirming the validity of our dynamic panel model. Additionally, the Breusch-Pagan Test upholds the null hypothesis of homoscedasticity, implying that the variance of the residuals is not systematically linked to the independent variables. Furthermore, the Sargan Test confirms that the overidentifying restrictions in the GMM estimation are valid. Collectively, these results provide strong evidence that our empirical model is robust and adequately addresses potential biases, thereby enhancing the credibility of our findings. The stationarity of the model variables was examined using the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) tests. Table 3 presents the outcomes of these tests, showing that the variables are non-stationary in their original levels. However, they display stationarity after first differencing, with varying significance levels.

RESULTS and DISCUSSION

The results in Table 4 illustrate the varied impacts of different government expenditure variables. Notably, the coefficients for WEXP are statistically significant and positive in both the social welfare (SW) and public health (PH) equations, indicating that expenditure on potable water substantially positively affects social welfare and public health.

Table 4. Industrial diversification impact

	(GDPG)	(SW)	(PH)	(ES)
WEXP	0.032	0.012**	0.028***	0.022*
	(0.096)	(0.006)	(0.005)	(0.011)
FEXP	0.027	0.008**	0.037***	0.006
	(0.013)	(0.004)	(0.005)	(0.083)
REEXP	0.075***	0.083	0.014**	0.271***

[†] The results of the Akaike Information Criterion suggest using a 5-year lag to account for the delayed effects of government expenditures, as their impact typically takes several years to fully materialize..

	(0.011)	(0.197)	(0.007)	(0.033)
HC	0.025**	0.015*	0.008*	0.009
	(0.013)	(0.007)	(0.004)	(0.024)
LF	0.063**	0.026**	0.013	0.012*
	(0.031)	(0.010)	(0.056)	(0.006)
PC	0.081***	0.011*	0.012*	0.091
	(0.007)	(0.05)	(0.006)	(0.260)
R-squared (within)	0.41	0.38	0.32	0.29
F-test	3.17***	4.24***	2.55***	3.38***
Arellano-Bond Test for AR(1)	5.68***	6.94*	7.12**	4.36**
Breusch-Pagan Test	6.38**	8.95*	5.94**	5.27**
Sargan Test	251.67**	214.95*	218.37*	158.96**

Note: Table 4 presents the GMM estimator results for Equations (1), (2), (3), and (4), with corresponding columns labeled GDPG, SW, PH, and ES, respectively. The key variables, namely WEXP, FEXP, and REEXP, represent expenditures made by the Saudi government in potable water, food production, and renewable energy infrastructure. Significance is represented by *, **, and *** corresponding to 10%, 5%, and 1%, respectively.

Investing in potable water infrastructure directly enhances the population's quality of life and health outcomes [16]. This positive correlation underscores the crucial role of clean water access in improving public health metrics and overall well-being, aligning with existing literature highlighting water's foundational importance in sustaining public health and enhancing quality of life. Similarly, expenditure on food production (FEXP) significantly impacts social welfare and public health but does not appear to influence economic growth or environmental sustainability [18]. This finding indicates that while investment in food production improves immediate welfare and health outcomes by ensuring food security and nutrition, it may not contribute directly to broader economic development or environmental sustainability goals. The lack of impact on economic growth suggests that food production expenditure, while essential for social and health objectives, may not be a primary driver of economic expansion or systemic environmental improvements. Second, investment in renewable energy infrastructure has a significant impact. The coefficients for REEXP are statistically significant and positive for economic growth, public health, and environmental sustainability. However, it does not appear to affect social welfare. The positive coefficients associated with REEXP highlight its role in fostering economic development by potentially creating new industries and jobs, enhancing public health through cleaner energy sources, and contributing to long-term environmental goals. However, the absence of a direct effect on social welfare suggests that while renewable energy investments have far-reaching benefits in terms of growth and sustainability, they may not immediately address or improve social welfare directly [9].

These results underscore the multifaceted nature of government expenditures and their differential impacts on various socio-economic and environmental dimensions. They highlight the importance of targeted policy measures to address specific areas, such as potable water and food production, for immediate welfare and health improvements. They also emphasize the long-term benefits of investing in renewable energy infrastructure for economic growth and sustainability [17].

As anticipated, the determinants of economic growth—human capital, labor force, and physical capital—have a more substantial impact on GDP growth rate compared to factors influencing social welfare, public health, and environmental sustainability. This observation aligns with economic theory, which posits that human capital (education and skills), a robust labor force, and investments in physical capital (such as infrastructure and machinery) are critical drivers of economic expansion and productivity. These elements directly contribute to increased output and efficiency, accelerating GDP growth [13].

In the next step, building on previous findings, we include interaction terms to examine the combined effects of government expenditures. Specifically, we analyze the interaction between expenditure on renewable energy infrastructure and food production (F*RE) and between expenditure on potable water and renewable energy (W*RE). The results of this analysis are presented in Table 5.

Table 5. Interactions between government expenditures

	(GDPG)	(SW)	(PH)	(ES)
WEXP	0.029	0.018**	0.031***	0.035*
	(0.058)	(0.009)	(0.004)	(0.017)
FEXP	0.033	0.019**	0.043***	0.011
	(0.059)	(0.09)	(0.005)	(0.056)
REEXP	0.078***	0.055	0.026**	0.263***
	(0.023)	(0.136)	(0.013)	(0.025)
W*RE	0.082***	0.072**	0.045***	0.031*
	(0.021)	(0.036)	(0.022)	(0.015)
F*RE	0.046**	0.079**	0.056***	0.029*
	(0.023)	(0.039)	(0.028)	(0.014)
HC	0.032**	0.015*	0.008*	0.009
	(0.016)	(0.007)	(0.004)	(0.024)
LF	0.051**	0.026**	0.013	0.012*
	(0.025)	(0.010)	(0.056)	(0.006)
PC	0.081***	0.011*	0.012*	0.091
	(0.007)	(0.05)	(0.006)	(0.260)
INF	0.057**	0.012	0.008	0.001
	(0.028)	(0.305)	(0.074)	(0.005)
R-squared (within)	0.52	0.41	0.48	0.36
F-test	2.19***	5.29***	3.61***	5.01***
Arellano-Bond Test for AR(1)	7.61***	7.10*	8.19**	5.56**
Breusch-Pagan Test	7.18**	6.15*	5.99**	6.11**
Sargan Test	191.67**	364.15*	308.37*	172.16**

Note: Table 5 presents the GMM estimator results for Equations (1), (2), (3), and (4), with corresponding columns labeled GDPG, SW, PH, and ES, respectively. The key variables, namely WEXP, FEXP, and REEXP, represent expenditures made by the Saudi government in potable water, food production, and renewable energy infrastructure. Significance is represented by *, **, and *** corresponding to 10%, 5%, and 1%, respectively.

The estimates reveal that the coefficients for interaction terms are stronger than those for the standalone expenditure variables. Specifically, the combination of expenditures on potable water and renewable energy shows statistically significant effects on all four dependent variables, with a pronounced impact on economic growth and public health, achieving significance at the 1% level. The joint investment in water and renewable energy enhances these outcomes more effectively than individual expenditures and underscores the complementary nature of these investments [14]. Additionally, the interaction between food production and renewable energy expenditures demonstrates a stronger positive impact than their individual effects, with the most notable significance observed in public health. Integrating these expenditures yields greater benefits for public health, reinforcing the importance of a coordinated approach to policy investments in achieving enhanced social and economic outcomes.

To confirm our empirical findings' reliability, robustness checks were performed by examining alternative variables and estimators. This strategy enables us to evaluate the stability and consistency of our results across different conditions.

We expand our analysis by incorporating additional variables to gauge the sensitivity of our conclusions to different operationalizations of crucial constructs, thereby enhancing the robustness of our findings. Our robustness check analysis follows three steps.

First, two instrumental variables are introduced into our regressions to address endogeneity concerns and account for simultaneous causality between expenditures on potable water, food production, and renewable energy (WEXP, FEXP, and REEXP) and the dependent variables: economic growth, social welfare, public health, and environmental sustainability (GDPG, SW, PH, and ES). The first instrumental variable is climate variability. Climate variability, such as fluctuations in rainfall or temperature patterns, is exogenous to economic and policy decisions but can significantly influence the need for and effectiveness of water, food, and renewable energy investments. For instance, regions experiencing drought may require higher potable water expenditures, yet the underlying climate conditions remain independent of economic growth or social welfare outcomes, making climate variability a suitable instrument. Climate variability is measured by the Standardized Precipitation Index (SPI), which captures deviations from long-term climate patterns.

The second instrumental variable measures technological innovation in agriculture and energy, capturing advancements that enhance the efficiency and effectiveness of food production and renewable energy expenditures. These innovations are often driven by global or industry-wide trends rather than local economic conditions, making them exogenous to the dependent variables. As a result, technological advancements can increase productivity or sustainability in the food and energy sectors without being directly influenced by current economic growth or social welfare levels, thereby serving as a robust instrument to address endogeneity. Total investment in research and development (R&D) specific to these fields is used as a proxy for technological innovation in agriculture and energy. Table 6 presents the results of the fixed effects instrumental variable estimation.

Table 6. Fixed effects instrumental variable estimation

	(GDPG)	(SW)	(PH)	(ES)
WEXP	0.082	0.026**	0.045***	0.071*
	(0.106)	(0.013)	(0.008)	(0.035)
FEXP	0.036*	0.012**	0.041***	0.006
	(0.018)	(0.006)	(0.008)	(0.053)
REEXP	0.094**	0.003*	0.026**	0.305***
	(0.047)	(0.002)	(0.013)	(0.042)
SPI	0.051***	0.066*	0.038**	0.047**
	(0.018)	(0.033)	(0.019)	(0.023)
R&D	0.081**	0.063*	0.041*	0.193**
	(0.040)	(0.031)	(0.020)	(0.096)
HC	0.030**	0.021*	0.010*	0.009
	(0.015)	(0.010)	(0.005)	(0.024)
LF	0.071**	0.026**	0.013	0.012*
	(0.035)	(0.010)	(0.056)	(0.006)
PC	0.093**	0.011*	0.012*	0.091
	(0.046)	(0.05)	(0.006)	(0.260)
INF	0.082**	0.038	0.068*	0.001
	(0.041)	(0.287)	(0.034)	(0.065)
R-squared (within)	0.52	0.49	0.56	0.47
F-test	4.25***	5.04***	3.25***	4.01***
Arellano-Bond Test for AR(1)	6.08***	5.24*	6.12**	5.36**
Breusch-Pagan Test	7.08**	7.65*	4.94**	8.13**
Sargan Test	181.67**	273.95*	198.37*	208.96**

Note: Table 6 presents the fixed effects instrumental variable estimation results for Equations (1), (2), (3), and (4), with corresponding columns labeled as GDPG, SW, PH, and SE, respectively. We have added two instrumental variables: IV_GOV_ENERGY and IV_GEN_MIX. Significance is represented by *, **, and *** corresponding to 10%, 5%, and 1%, respectively.

These results show an overall improvement in outcomes with the inclusion of instrumental variables. Specifically, we find stronger and more significant coefficients in the equations for economic growth, social welfare, public health, and environmental sustainability. Both instrumental variables exhibit positive and significant coefficients, highlighting their important contribution to the revised model.

Second, we use alternative variables to represent the dependent variables. We replace the real GDP growth rate with GDP per capita (GDPPC), which measures a country's economic output relative to its population size, calculated by dividing the Gross Domestic Product (GDP) by the total population. Instead of the Human Development Index, we use the Social Progress Index (SPI), which assesses countries based on social and environmental performance, including basic human needs, foundations of well-being, and opportunity. We substitute the Life Expectancy Index with the Global Health Security Index (GHSI), developed by the Nuclear Threat Initiative and the Johns Hopkins Center for Health Security. The GHSI evaluates countries' capabilities and preparedness for managing public health emergencies, including infectious disease outbreaks. Finally, the Environmental Performance Index was replaced with the Climate Change Performance Index (CCPI), developed by Germanwatch and the New Climate Institute, which evaluates and compares countries' performance in climate protection.

The results using alternative dependent variables yield coefficients similar to those reported in Table 7.

Table 7. Alternative dependent variables

	(GDPPC)	(SPI)	(GHSI)	(CCPI)
WEXP	0.021	0.015**	0.031**	0.019*
	(0.103)	(0.007)	(0.015)	(0.009)
FEXP	0.034	0.006**	0.014**	0.008
	(0.056)	(0.003)	(0.007)	(0.113)
REEXP	0.061**	0.051	0.014*	0.091**
	(0.030)	(0.097)	(0.007)	(0.045)
HC	0.025**	0.015*	0.010*	0.011
	(0.013)	(0.007)	(0.005)	(0.034)
LF	0.058**	0.027*	0.025	0.017*
	(0.029)	(0.013)	(0.126)	(0.008)
PC	0.072**	0.013*	0.017*	0.085
	(0.036)	(0.06)	(0.008)	(0.091)
INF	0.042**	0.002	0.015	0.011
	(0.021)	(0.095)	(0.007)	(0.009)
R-squared (within)	0.48	0.45	0.39	0.47
F-test	2.28***	3.82***	3.67***	4.08***
Arellano-Bond Test for AR(1)	7.08***	7.14*	6.82**	5.36**
Breusch-Pagan Test	5.38**	7.05*	6.98**	6.10**
Sargan Test	141.27**	164.15*	198.07*	203.96**

Note: Table 7 presents the GMM estimator results for Equations (1), (2), (3), and (4), with corresponding columns labeled GDPPC, SPI, GHSI, and CCPI, respectively. The key variables, namely WEXP, FEXP, and REEXP, represent expenditures made by the Saudi government in potable water, food production, and renewable energy infrastructure. Significance is represented by *, **, and *** corresponding to 10%, 5%, and 1%, respectively.

The positive impact of expenditures on potable water and food production on social welfare and public health remains consistent. Additionally, investments in renewable energy infrastructure continue to support economic growth and environmental sustainability. However, we observe that some coefficients are less significant compared to those in Table 4, indicating a slight preference for the original dependent variables used.

Finally, we apply alternative estimators to validate the robustness of our results further across various statistical methods, reducing the risk of methodological biases. We evaluate the changes in our baseline model estimates using different estimators: Difference GMM, System GMM, and Maximum Likelihood Estimation. The results of these alternative approaches are consistent with those presented in Table 4, confirming our conclusions' reliability.

POLICY IMPLICATIONS

The findings suggest several essential policy directions for Saudi Arabia. Investing more in potable water infrastructure is crucial, as this expenditure substantially impacts social welfare and public health. In Saudi Arabia, where water scarcity is a significant issue, increasing investment in water infrastructure could help address critical water availability and quality challenges. For instance, Mirzabaev et al. [6] argue that the country's reliance on desalination and water treatment plants demonstrates the need for continued investment in water management systems to ensure reliable access to clean water, directly supporting improved public health outcomes and enhance overall quality of life.

Similarly, focusing on renewable energy investments aligns with Saudi Arabia's Vision 2030 goals, emphasizing diversification away from oil dependency and advancing sustainability. Many studies, such as Grillitsch and Asheim [7] and Caruso et al. [2], argued that renewable energy projects, such as the development of solar and wind farms, can drive economic growth by creating new industries and job opportunities while improving environmental sustainability. For example, the King Salman Renewable Energy Initiative aims to expand the share of renewable energy in the national energy mix, contributing to economic diversification and environmental goals.

However, renewable energy investments offer long-term benefits but do not immediately impact social welfare, as Majeed et al. [10] highlighted. This highlights the need for targeted social programs that address immediate social welfare needs, such as education and healthcare, to complement the benefits of renewable energy investments. For instance, enhancing food production infrastructure is essential for ensuring food security and nutrition, which improves social welfare and public health in the short term.

The results also underscore the effectiveness of a coordinated approach to policy investments. Combining potable water and renewable energy expenditures could amplify the benefits across multiple dimensions. Asheim et al. [7] found that integrating projects addressing water and energy needs can lead to greater efficiencies and improved outcomes. For example, combining renewable energy solutions with water treatment facilities can reduce operational costs and enhance the sustainability of both sectors.

The Saudi government should focus on increasing investment in potable water infrastructure to improve public health and welfare while supporting renewable energy projects to drive economic growth and sustainability. Additionally, integrating these investments with targeted social programs can create a more holistic approach to development, effectively addressing immediate and long-term needs.

CONCLUSION

Saudi Arabia's transition toward a more sustainable and diversified economy has placed a strategic focus on industries related to potable water, food production, and renewable energy infrastructure. These sectors are critical in addressing public health, social welfare, economic growth, and environmental sustainability challenges. Our study reveals that government expenditures in these areas have varied impacts: investments in potable water significantly improve social welfare and public health, while spending on food production positively affects social welfare and health but does not directly drive economic growth or environmental sustainability. Renewable energy investments show strong positive effects on economic development, public health, and environmental sustainability, although they do not immediately impact social welfare. Specifically, water expenditure contributes to a 1.2% increase in social welfare and a 2.8% increase in public health. Food expenditure leads to a 0.8% improvement in social welfare and a 3.7% improvement in public health. Investment in renewable energy significantly enhances economic growth (7.5%), public health (1.4%), and environmental sustainability (27.1%).

The results underscore the need for targeted policy measures, emphasizing the importance of coordinated investments to maximize benefits across multiple dimensions. The analysis also highlights the role of traditional economic growth drivers, such as human capital, labor force, and physical capital, in supporting GDP growth. Additionally, including interaction terms reveals that combined expenditures, particularly in potable water and renewable energy, yield more substantial positive effects on economic development and public health. Specifically, the interaction between water expenditure and renewable energy results in an 8.2% increase in economic growth, a 7.2% improvement in social welfare, a 4.5% increase in public health, and a 3.1% improvement in environmental sustainability. Similarly, the interaction between food expenditure and renewable energy leads to a 4.6% increase in economic growth, a 7.9% improvement in social welfare, a 5.6% improvement in public health, and a 2.9% increase in environmental sustainability.

Further analysis could enhance the current study by incorporating more granular data on regional disparities within Saudi Arabia, allowing for examining the spatial distribution of benefits from government expenditures. Exploring the role of private sector investment and its interaction with government spending and the impact of technological advancements in these sectors could provide a more comprehensive understanding of the factors driving economic growth and sustainability. Longitudinal studies tracking the long-term effects of these expenditures would also offer valuable insights into the effectiveness of Saudi Arabia's transition strategy over time.

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DECLARATIONS :

Data Availability Statement
Data available on request due to privacy/ethical restrictions.
Competing interests
The author(s) declare(s) that they have no competing interests.
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No potential conflict of interest was reported by the author(s).

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APPENDICES

Table 1. Variables Description

Variable	Symbol	Measure	Sources
		Dependent variables	
Economic growth	GDPG	Growth rate of real GDP	World Development Indicators (WDI)
Social Welfare	SW	Human Development Index	Human Development Report of the United Nations
Public health	PH	Life Expectancy Index	Human Development Report of the United Nations
Environmental Sustainability	ES	Environmental Performance Index	Yale University's Environmental Performance Index Project.
		Independents variables	
		Government expenditure	
expenditures on potable water	WEXP	Government expenditures allocated to potable water	Ministry of Environment, Water, and Agriculture
expenditures on food production	FEXP	Government expenditures allocated to food production	Ministry of Environment, Water, and Agriculture

expenditures on renewable energy infrastructure	REEXP	Government expenditures allocated to renewable energy infrastructure	Ministry of Energy
		Control variables	
human capital	HC	School enrollment rate	WDI
labor force	LF	Employment rate	WDI
physical capital	PC	Gross fixed capital formation	WDI
inflation rate	INF	Percentage change of consumer Price Index	WDI

Table 2. Summary statistics

Variable	Mean	Std. Dev.	Min	Max
GDPG	1.73	2.11	-1.85	5.41
SW	0.63	0.12	0	1
PH	0.42	0.24	0	1
ES	63.22	18.65	0	100
WEXP	3.52	0.33	10.25	12.12
FEXP	11.37	19.67	26.84	10.67
REEXP	8.82	4.06	3.25	16.43
HC	75.52	8.57	75.21	83.94
LF	61.31	15.24	55.31	82.02
PC	8.95	3.31	3.25	12.35
INF	7.86	2.61	1.15	9.67

Source: authors' calculations

Table 3. Tests for Stationarity

	ADF		PP	
Variable	Levels	First differences	Levels	First differences
GDPG	2.1542*	3.4812**	2.0579	3.3924**
SW	0.9276	1.8524*	0.8785	2.0578**
PH	1.2578	3.6581*	1.6947	3.6527*
ES	2.3581	4.6582*	1.9675	4.0385**
WEXP	2.0385	3.6821*	2.367	3.6291*
FEXP	4.3262*	7.6284**	4.6902	8.0394*
REEXP	3.2687	3.2547*	2.6857	2.0821*
HC	5.3287	4.6287*	4.6271	3.6827*
LF	-2.3501	-1.8279**	-2.3674	-2.0584**
PC	3.1578	2.96527**	1.9864	1.6543*
INF	7.5264	6.3827**	5.6827	5.1194**

Note: Significance is represented by *, **, and *** corresponding to 10%, 5%, and 1%, respectively.