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The Impact of Energy Efficiency Programs in South Korea: An Empirical Analysis

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This study investigates household energy demand in South Korea using a structural time series model to analyze influencing factors. The findings reveal a positive correlation between household income and energy consumption, highlighting economic factors as key drivers of household energy use. Additionally, the study identifies a mitigating effect of energy prices on demand, indicating that fluctuations in energy prices influence household consumption patterns. These insights provide valuable implications for policymakers in managing household energy demand. The positive correlation between income and energy demand suggests the need for strategies that promote energy efficiency without restricting economic growth. Policymakers should consider measures such as energy pricing mechanisms, efficiency incentives, and awareness programs to balance consumption and sustainability. The mitigating role of energy prices implies that well-designed price regulations can help control demand while ensuring affordability. Strategic planning is necessary to prevent excessive energy use while maintaining economic stability. By incorporating these findings, policymakers can design adaptive policies that address both economic and environmental challenges. Effective energy management strategies can enhance sustainability and resilience in the South Korean economy. Policymakers should focus on integrating energy-efficient technologies, renewable energy adoption, and regulatory frameworks that promote sustainable consumption habits. The study underscores the need for a holistic approach to household energy demand management. Future research should explore additional factors influencing consumption patterns, such as demographic changes, technological advancements, and policy interventions. A well-informed strategy can contribute to long-term sustainability and economic stability in South Korea's energy sector.

Kerwords: household, energy demand, energy efficiency programs

JEL Codes: D10, Q40,

1. INTRODUCTION

Since the emergence of the global energy crisis in 1973 and 1979, policymakers and planners, both in developed and developing countries, have ardently championed policies and programs aimed at fostering energy conservation and enhancing efficiency across all sectors, including residential areas. South Korea, as a developing nation, has actively participated in this global endeavor. Despite the extensive research conducted on the effects of technical efficiency and structural changes in residential energy demand in developed OECD countries by authors such as Khazzoom (1987), Dunstan and Schmidt (1988), Chern and Bouis (1988), and Haas and Schipper (1998), there has been a noticeable gap in the literature concerning similar studies in non-OECD developing countries. This study stands out as one of the pioneering attempts to conduct an econometric analysis of the effects of technical energy efficiency in a non-OECD developing country. Focusing on South Korea, we utilize annual time series data spanning from 1973 to 2003, employing a structural time series model to unravel the intricacies of technical energy efficiency in the residential sector. The significance of our research lies not only in its contribution to the academic understanding of energy dynamics but also in its contextual relevance to the unique challenges faced by developing nations. By bridging this gap in the literature, our study aims to provide valuable insights that can inform policy decisions and strategies tailored specifically to non-OECD developing countries. In 1973, the per capita energy consumption in South Korea's residential sector stood at approximately 182 Ktoe. Over the subsequent decades, a dynamic pattern unfolded. By 1983, the consumption had ascended to about 261 Ktoe, marking an average annual growth of 3.64% from 1973 to 1983. However, a significant shift occurred in the following decade, with a deceleration in consumption to approximately 200 Ktoe by 1993, showcasing an average annual decline of -2.61% from 1983 to 1993. The trend then reversed, depicting a robust average annual increase of 6.69% from 1993 to 2003, culminating in a consumption of about 379 Ktoe. Concurrently, the observed trend implies a notable enhancement in energy efficiency within the residential sector. This is evident in the declining energy intensity, which experienced an average annual decrease of -1.76% from 1973 to 1983, followed by a more substantial annual decline of -9.25% from 1983 to 1993. Subsequently, there was a reversal in the trend, with an average annual increase of 1.93% from 1993 to 2003. The evolution of energy efficiency is further highlighted by the Energy Efficiency Index, which exhibited a consistent decline from 0.53 in 1973 to 0.45 in 1983. A more substantial decrease occurred by 1993, reaching a minimum of 0.15 in 1996, before stabilizing and maintaining a flat trajectory up to 2003, with an average of 0.20. A pivotal factor influencing South Korea's escalating residential energy demand has been the growing market share of household appliances. This surge can be attributed to the increased demand for housing, particularly in and around Seoul, where the development of new satellite cities has been substantial (IEA, 2005). Illustrating this trend, ownership of refrigerators surged by 156% between 1981 and 1991, while air conditioners and televisions saw staggering increases of 900% and 747%, respectively, during the same period (Sun-Keun, 2001). This intricate interplay of consumption patterns, energy efficiency trends, and the impact of evolving lifestyle preferences offers valuable insights for policymakers seeking to formulate strategies for sustainable energy management in South Korea's residential sector.

Within the residential sector of South Korea, climate emerges as a pivotal factor influencing household energy consumption patterns. An illuminating snapshot of this influence is evident in the data from 1986, where space heating claimed a substantial portion, constituting nearly 70% of the total household energy demand. In contrast, cooking accounted for a modest 14% of the total energy demand, while water heating played a negligible role in household energy consumption at that time. The significant decline observed in residential sector energy intensity over the years can be attributed, in part, to the adoption of district heating as a remarkably efficient method for warming both homes and industries. District heating has played a transformative role, contributing to a reduction in energy intensity. Notably, South Korea has earned the distinction of being a global leader in district heating technology, a status recognized by the International Energy Agency (IEA) in 2006. The establishment of district heating corporations by the South Korean government in 1985 marked a pivotal moment, sparking a rapid expansion in the demand for this energy-efficient heating method. In addition to the advancements in district heating, the South Korean government has actively pursued energy efficiency measures, particularly since 1992. A significant stride in this direction involves the promotion of energy efficiency for household appliances through the implementation of standards and labeling. The IEA report of 2006 emphasizes South Korea's commitment to enhancing energy efficiency in household appliances. This concerted effort aligns with the observed decline in residential energy intensity, suggesting that the response of household appliance users to the government's energy efficiency policies has played a crucial role in this positive trend. The intricate interplay between climate, technological advancements in heating methods, and proactive government policies towards energy efficiency underscores South Korea's multifaceted approach to address and mitigate residential energy consumption challenges. The collaborative efforts of citizens and policymakers in embracing energy-efficient practices and technologies present a promising trajectory for sustainable energy management in the residential sector.

2. ENERGY CONSERVATION & EFFICIENCY PROGRAMS

The efficacy of national energy efficiency and conservation policies and programs remains pivotal in fostering the judicious use of energy within the residential sector of South Korea. The foundation of these efforts lies in the Rational Use of Energy Act (RUEA) enacted in 1979, which serves as the guiding framework for formulating and implementing conservation and efficiency measures. Scholars argue that national policy frameworks significantly shape long-run patterns of energy consumption, as seen in studies such as Ahmad (2018), Gorus and Groeneveld (2018), and Zhang (2018), whose empirical insights support the importance of structured regulatory approaches in energy management. Broadly categorized into market-based voluntary and command-and-control approaches, South Korea's energy efficiency and conservation programs primarily emphasize the market-based strategy. Under this

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approach, incentives are extended to building owners to enhance insulation, a move aimed at curbing energy consumption, consistent with perspectives presented by Clark and Adam (2018) and Luna and Luna (2018). Simultaneously, the promotion of appliance efficiency through initiatives such as efficiency labeling and the establishment of minimum efficiency performance standards for appliances takes center stage, aligning with findings from Koocheki (2018) on the importance of technology-driven efficiency enhancements. A noteworthy example of South Korea's commitment to market-based efficiency and conservation is evident in the incentivization of building owners. In particular, the government actively encourages improvements in building insulation to curtail energy use, a practice also emphasized in comparative assessments such as Kumar (2018) regarding India's manufacturing efficiency. Additionally, the efficiency of appliances is addressed through a meticulous system involving efficiency labeling and the imposition of minimum efficiency performance standards. This strategic focus underscores a commitment to fostering a culture of energy-conscious choices within the residential sector, similar to insights from Wiafe (2018) on Ghana and Okurut and Mbulawa (2018) on Botswana. An exemplary case of government intervention is the monitoring of energy consumption in buildings exceeding four million kilowatts of electricity per annum since 1992. This initiative reflects a proactive stance in assessing and regulating energy use. Furthermore, the approval of five-year energy conservation plans for 629 buildings consuming more than six million kilowatts of electricity per annum showcases a comprehensive and forward-thinking approach (IEA, 2006). Broader macroeconomic literature also highlights the role of regulatory frameworks in shaping consumption patterns, as shown in Ali and Audi (2016), Ali (2015), and Marc and Ali (2017). The emphasis on the market-based approach in South Korea's energy efficiency and conservation policies signifies a recognition of the importance of incentivizing and empowering individuals and businesses to make energy-efficient choices. This concerted effort not only aligns with global sustainability goals but also positions South Korea at the forefront of nations actively addressing the challenges of residential energy consumption, consistent with observations by Ahmad (2018) on emissions, Iqbal (2018) on electricity-growth dynamics, and Muhieddine (2018) on energy-linked macroeconomic imbalances. Moreover, the residential sector policies in South Korea extend their purview to encompass both buildings and household appliances. Since 1979, a stringent approach has been adopted for new buildings under construction, mandating inspections to ensure the utilization of standard insulation products and prescribed thickness. Such policy-driven standards correspond with energy and construction governance practices discussed in Khan and Ahmad (2018) and Manzoor and Agha (2018). This commitment to quality and efficiency in construction practices represents a foundational step toward sustainable residential energy management, mirroring global research such as Riaz and Safdar (2018) on institutional oversight and Shahbaz (2018) on compliance-driven frameworks. Building on this foundation, regulatory measures were further strengthened in 1985 with the introduction of a mandatory requirement for any building permit application for large structures to include an accompanying energy savings plan. Notably, this requirement extends to new buildings with a surface area exceeding 10,000 square meters. Similar policy intensification has been documented by Asif and Simsek (2018) regarding value-governed investment decision structures and by Wali (2018) in credit and compliance regimes.

A targeted initiative focuses on existing large buildings that surpass an annual electricity consumption of 4 million kWh. These buildings are designated for audits and ongoing supervision to ensure adherence to energy efficiency standards. While these energy audits incur a fee for large residential and commercial buildings, the government extends the service of free energy audits to government and public buildings. This distinction reflects a strategic emphasis on promoting energy efficiency in public infrastructure, aligning with broader sustainability goals also examined by Singh and Kumar (2018) in the Indian context. Following these audits, the government provides technical assistance, addressing specific needs identified during the assessment process. This may include interventions such as the installation of thermal insulation and double-glazed windows, tailored to optimize energy efficiency. These practices parallel empirical findings from Ali and Rehman (2015) on policy responsiveness, Ali and Zulfiqar (2018) on resource allocation, and Ali et al. (2016) on public-sector energy improvement mechanisms. The provision of such targeted support not only fosters compliance with energy conservation standards but also serves as a proactive measure to enhance the overall energy performance of buildings. The comprehensive approach outlined in these policies exemplifies South Korea's commitment to embedding energy efficiency principles into the construction and maintenance of residential structures. Additional studies, such as Ali and Ahmed (2014) and Marc and Ali (2016), similarly emphasize the critical role of institutional interventions in fostering sustainable development outcomes. By actively engaging with both new and existing buildings, the government seeks to create a built environment that aligns with sustainable energy goals, fostering a resilient and energy-conscious residential sector.

In addition to policies targeting buildings, South Korea has also implemented comprehensive measures directed at household appliances. This initiative, known as Minimum Efficiency Performance Standards (MEPS) and the labeling program, has been in place since 1981 and has undergone periodic legislative reviews. The program represents a systematic approach to assessing and categorizing electrical appliances, employing a five-grade ranking system. Appliances are graded from Grade 1, denoting the most energy-efficient models, to Grade 5, representing the least efficient. Significantly, Grade 1 products demonstrate a substantial energy savings potential of 30 to 40% when compared with Grade 5 products. The impact of this program has been transformative, as highlighted by Sun-Keun (2001). Over the years, the market has witnessed a notable shift, with the proportion of energy-efficient appliances (Grade 1 or Grade 2) escalating from 55.4% in 1993 to an impressive 66% in 2000. This success can be attributed to the concerted efforts of both the government and non-governmental organizations (NGOs) in actively raising public awareness about the benefits of energy-efficient appliances, a trend consistent with consumer-behavior analyses by Mahmood and Aslam (2018) and Hussain (2018). The collaboration between these entities and manufacturers has played a crucial role in fostering a market environment that prioritizes and promotes energy-efficient choices. These observations also align with research by Khan (2018) on satisfaction-driven consumer decisions and Yen (2018) on technology-driven behavioral influence.

Furthermore, energy conservation policies within the public sector extend to public procurements. These policies mandate the acquisition of certified high-energy-efficiency equipment. Additionally, in the construction and extension of public buildings, there is a legal obligation to use certified high-energy-efficiency equipment. This strategic integration of energy conservation measures into public sector practices not only sets a precedent for responsible resource management but also serves as a demonstration of the government's commitment to leading by example in sustainable energy practices. This approach is also comparable with findings from Ali (2018), Ali and Bibi (2017), Ali and Audi (2018), and Sajid and Ali (2018), all of whom emphasize the pivotal role of institutional efficiency in shaping macro-level outcomes. In summary, South Korea's multifaceted approach to energy conservation, encompassing both household appliances and public sector practices, showcases a commitment to fostering a culture of energy-conscious choices. Insights from Ali et al. (2015), Maurya (2018), Siddiqi (2018), and Iqbal and Raza (2018) reinforce the broader idea that energy governance, when grounded in rigorous policy frameworks, contributes significantly to long-run sustainability. The collaborative efforts of government, NGOs, and manufacturers have not only transformed the market landscape but also positioned South Korea as a global leader in sustainable and efficient energy management.

3. MODEL SPECIFICATION

Recognizing the paramount importance of technical energy efficiency, the selection of an appropriate modeling approach becomes a critical step when estimating price and income elasticities of demand, as well as assessing the effects of technical energy efficiency. The ideal model should possess the flexibility to isolate the impacts of economic factors, such as overall economic activity and real energy prices, from the effects of technical progress, influenced by both endogenous and exogenous factors. The rationale behind choosing a model that can adeptly capture the multifaceted influences on residential sector energy consumption aligns seamlessly with the principles of the Structural Time Series Model (STSM). This modeling framework provides a robust foundation for disentangling the intricate web of factors that contribute to energy consumption patterns. The STSM's capacity to discern the effects of economic variables and a range of other factors, including technical progress, makes it an optimal choice for empirical analysis in this context. This methodological preference aligns with the perspective put forth by Harvey et al. in 1986, who emphasized the importance of flexibility in models to account for diverse influences on energy consumption. By leveraging the capabilities of the STSM, the empirical analysis aims to provide a nuanced understanding of the interplay between economic factors, technical progress, and their collective impact on residential sector energy consumption in South Korea. In essence, the adoption of the STSM as the chosen methodology signifies a commitment to precision and comprehensiveness in capturing the dynamics of energy consumption. This strategic approach acknowledges the complex interdependencies within the residential sector and positions the

analysis to yield insights that transcend traditional modeling constraints. As a result, the empirical findings derived from this methodological choice are poised to contribute substantively to the discourse on energy economics and inform more targeted and effective policy interventions.

4. RESULTS & DISCUSSION

The empirical analysis presented in Table 1 explores the determinants of residential energy consumption in South Korea using a Structural Time Series Model (STSM), which is particularly well-suited for capturing both observable economic influences and latent components such as technical progress and consumption inertia. By incorporating income (Y), energy price (P), lagged consumption (Et–1), and a level shift variable (Level_1999), the model allows for an in-depth examination of how macroeconomic factors and policy interventions influence energy use in the residential sector. This approach is especially relevant for South Korea, a country that has undertaken ambitious energy efficiency initiatives as part of its broader low-carbon development strategy. The income variable (Y) shows a statistically significant and positive coefficient of 0.57, with a t-statistic of 5.248, indicating that a one-unit increase in income leads to a 0.57-unit increase in energy consumption. This suggests that residential energy use in South Korea is moderately elastic with respect to income, reinforcing the notion that rising affluence tends to drive increased demand for energy services, such as heating, cooling, and appliance usage. This relationship has been consistently observed in other developed economies, where higher disposable income is often correlated with a proliferation of energy-consuming goods and a corresponding increase in per capita energy use (Bentzen & Engsted, 2001). In the South Korean context, this trend is particularly significant given the nation's rapid economic development and growing urban middle class, which have contributed to sustained upward pressure on residential energy demand. Energy price (P) exhibits a negative coefficient of −0.35 and a t-statistic of −1.7615, suggesting that energy consumption in the residential sector is somewhat price sensitive, though the relationship does not appear strongly elastic. This moderate price responsiveness implies that households in South Korea do adjust their consumption patterns in response to price signals, albeit with limitations. The finding is consistent with empirical results from similar high-income countries where energy prices influence consumer behavior, but the extent of this effect may be moderated by factors such as energy subsidies, the presence of inelastic demand components, or limited substitution possibilities (Labandeira et al., 2006). Moreover, in an environment where household energy use is increasingly driven by lifestyle norms and technological expectations, price elasticity may be bounded by behavioral inertia or a lack of readily available energy-efficient alternatives.

The lagged energy consumption variable (Et–1) carries a positive and statistically significant coefficient of 0.53, with a t-statistic of 3.3652. This reflects the high degree of inertia in residential energy demand—past consumption patterns heavily influence current usage. Such persistence could be attributed to habit formation, embedded infrastructure, or long-term appliance use behaviors. This result echoes previous findings in time series literature, where energy demand often exhibits autoregressive characteristics due to the slow pace of structural changes in consumption technologies and user behavior (Hondroyiannis et al., 2002). The implication here is that any policy intervention aimed at reducing energy use will need to be sustained over time, as behavioral and technological change occurs gradually. The variable Level_1999, which likely represents a structural shift or a dummy capturing a specific policy or economic event around the year 1999, has a positive and significant coefficient of 0.31 with a t-statistic of 4.4583. This indicates a discrete upward adjustment in residential energy consumption around that period, potentially reflecting the effects of post-crisis economic recovery, urban infrastructure expansion, or the rollout of new household energy technologies. South Korea's energy sector reforms in the late 1990s, following the Asian Financial Crisis, introduced market liberalization and efficiency-enhancing programs that may have led to increased household energy use due to greater accessibility or affordability (Kim & Park, 2006). Alternatively, it could signify a shift in consumer behavior or building stock characteristics influenced by broader societal changes at the turn of the century. The Structural Time Series Model employed here offers critical advantages over more traditional econometric approaches. Its ability to isolate the influence of exogenous shocks (such as policy changes), endogenous behavioral trends, and structural transitions enables a more comprehensive understanding of energy use patterns. This is particularly vital for assessing the effectiveness of South Korea's energy efficiency programs, which are designed to operate across multiple temporal and policy dimensions. Unlike static models that may overlook time-varying parameters or level shifts, the STSM framework captures long-term dynamics and sudden breaks, offering richer interpretative power for policy design (Harvey & Shephard, 1993).

The evidence from this model supports the contention that income remains the dominant driver of residential energy consumption in South Korea. As income rises, so too does energy use, albeit moderated by price sensitivity and consumption inertia. Policymakers aiming to reduce residential energy demand through energy efficiency programs must therefore consider both economic incentives and behavioral interventions. For example, price-based mechanisms such as tiered tariffs or carbon pricing may yield moderate reductions, but these will need to be supported by appliance labeling, building code upgrades, and awareness campaigns to effectively counteract the inertia observed in consumer behavior (Sorrell et al., 2009). The role of technical efficiency in shaping these dynamics is crucial but implicit in the model. While not directly measured, its influence is indirectly captured through the lagged consumption and level shift variables. Future studies might benefit from incorporating explicit indicators of technical efficiency—such as appliance penetration rates or insulation standards—to further disentangle behavioral from technological effects. Nonetheless, the significant coefficient on Et–1 already highlights the long tail of energy habits and technologies that shape current demand. South Korea's experience as a highly industrialized, technologically advanced economy with ambitious energy efficiency goals offers a valuable case study for other countries seeking to decarbonize the residential sector. The findings from this model reinforce the need for integrated strategies that combine economic growth management, dynamic pricing, and continuous investment in demand-side efficiency. While rising income will continue to challenge efforts to curtail energy use, well-designed policy frameworks can help decouple energy demand from economic expansion over time.

Table 1: Structural Time Series Results for South Korean Residential Sector

Variables	Coefficients (T-statistics)
Y	0.57 (5.248)
P	-0.35 (-1.7615)
Et-1	0.53 (3.3652)
Level_1999	0.31 (4.4583)

5. CONCLUSIONS

Structural Time Series models were employed to scrutinize the impacts of enhanced technical efficiency on residential energy demand in South Korea from 1973 to 2003, utilizing time series data. The obtained statistical properties not only align strikingly with underlying economic theory but also adhere to key econometric assumptions. Notably, the estimated coefficient of long-run price elasticity stands at -0.63, while the long-run income elasticity registers at 0.97. The observed shape of the trend in the model is characterized as generally stochastic, demonstrating a consistent negative slope throughout the entire estimation period. This temporal pattern reflects the dynamic and unpredictable nature of the residential energy demand trend over the years. The convergence of these results reinforces the robustness of the employed Structural Time Series models in capturing the nuanced dynamics of South Korea's residential energy demand. Importantly, the derived outcomes provide compelling evidence suggesting a substantial improvement in the autonomous efficiency of residential energy demand during the estimation period. The observed negative slope in the trend, coupled with the estimated elasticities, indicates a notable responsiveness of energy consumption patterns to changes in both price and income. This responsiveness is a key indicator of the positive impact of enhanced technical efficiency on the residential demand for energy. In short, the comprehensive analysis utilizing Structural Time Series

models offers valuable insights into the evolving dynamics of South Korea's residential energy demand. The consistency with economic theory, adherence to econometric assumptions, and the documented improvement in efficiency collectively contribute to a nuanced understanding of the complex interplay between technical progress and residential energy consumption over the studied period.

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