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Structural Change and Energy Productivity in Türkiye

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ABSTRACT

This paper examines the relationship between structural change and aggregate energy productivity in Türkiye from 1978 to 2019. Using a three-sector model the research quantifies sectoral labor and energy productivities relative to the United States, serving as a benchmark. The findings reveal that while Türkiye initially exhibited higher energy productivity than the U.S. across all sectors, this advantage diminished significantly over the study period. Only the manufacturing sector experienced positive energy productivity growth in Türkiye. Declines in agriculture and services were substantial, emerging as key drivers of the aggregate energy productivity gap between the two countries. A decomposition analysis highlights the dominant role of within-sector energy productivity changes, particularly the negative contribution of services in Türkiye, in explaining the overall decline in aggregate energy productivity. The study underscores the need for sector-specific policies targeting energy productivity improvements, particularly in services, to meet its target of a 35% absolute reduction in emission by 2030. The findings contribute to the literature by providing, for the first time, estimates of relative sectoral energy productivities for Türkiye, offering valuable insights for policymakers focused on enhancing national energy productivity.

Keywords: Energy Productivity, Structural Change, Sectoral Productivity Differences, Türkiye
JEL Classifications: O11, O41, O57, Q43

1. INTRODUCTION

The increasing interconnectedness of global economies and the growing urgency of climate change mitigation efforts have brought the issue of energy productivity to the forefront of economic policy debates. Understanding the dynamics of energy productivity, particularly within the context of structural change, is crucial for charting a sustainable development path. Structural change, characterized by shifts in resource allocation across sectors, has profound implications for a nation's overall energy consumption and productivity.

This research investigates the complex interplay between structural change and aggregate energy productivity in Türkiye, a country experiencing rapid economic development and aiming to balance economic growth with environmental sustainability. Türkiye's experience with structural change, marked by a substantial shift in employment from agriculture to services over the past four decades, mirrors broader global trends. However, Türkiye's aggregate energy productivity growth has lagged, and its energy intensity remains relatively high despite lower per capita energy consumption than many OECD and EU countries. This divergence, coupled with Türkiye's ambitious target of achieving a 35% absolute reduction in emissions by 2030 (compared to business-as-usual projections), raises critical questions about the productivity of energy use across sectors and the effectiveness of existing energy policies. Specifically, are the observed trends in energy productivity primarily driven by technological differences within sectors, or do changes in the composition of economic activity play a more significant role? Furthermore, which sectors are the primary drivers of energy productivity change, and what policy interventions could enhance energy productivity and contribute to achieving Türkiye's emissions reduction goals?

This study addresses these questions by employing a calibrated three-sector general equilibrium model, adapted from Duarte and Restuccia (2010) and extended by Marcolino (2021), to analyze

Türkiye's structural change between 1978 and 2019. The model incorporates non-homothetic preferences and Leontief production technologies with sector-specific labor and energy productivity parameters. We quantify sectoral energy productivities relative to the United States, which serves as a benchmark representing a technologically advanced economy. A key contribution of this research is the first-time calculation of relative sectoral energy productivities for Türkiye, providing a novel perspective on the country's energy productivity performance compared to a leading global economy. Additionally, the application of a calibrated multi-sectoral model enables us to analyze the impact of structural changes and conduct counterfactual policy experiments. Moreover, we use a detailed sector-specific decomposition analysis of the aggregate energy productivity gap, which is another important contribution of this research.

Our analysis proceeds in several stages. We first calibrate the model to U.S. data to establish a benchmark and then use this calibrated model to estimate Türkiye's initial (1978) relative productivity levels. We analyze these relative productivities across sectors, highlighting key differences and comparing trends in energy productivity. We employ a shift-share analysis to decompose the growth of aggregate energy productivity in Türkiye and the U.S., providing insights into the relative contributions of within-sector changes and between-sector reallocation effects.

We further decompose the aggregate energy productivity gap between Türkiye and the U.S. to quantify the impact of sectoral productivity differences and structural change. Finally, we conduct counterfactual experiments to assess the influence of sectoral energy productivity growth on aggregate energy productivity levels, specifically by aligning U.S. sectoral growth rates with those observed in Türkiye. This comprehensive quantitative approach allows us to disentangle the complex interactions between sectoral productivity, structural change, and aggregate energy productivity.

By focusing on Türkiye, we identify key drivers of its energy productivity trends and offer insights for policymakers seeking to balance economic growth with energy intensity and environmental sustainability. This study contributes to the growing literature on structural change and energy productivity by providing a novel perspective on the Turkish experience and informing the design of more effective energy policies. The remainder of the paper is organized as follows: Section 2 presents the data and key stylized facts about structural change and energy productivity in Türkiye. Section 3 outlines the three-sector general equilibrium model and describes the calibration procedure. Section 4 reports the quantitative results, including the model's fit to the Turkish economy, an analysis of relative productivity levels, a more detailed statistical evaluation of model performance, and a discussion of initial conditions in 1978. Section 5 investigates the determinants of aggregate energy productivity through decomposition and counterfactual analyses. Finally, Section 6 concludes with policy implications and directions for future research. Additional data details and results for the benchmark economy are provided in the Appendix.

2. LITERATURE REVIEW

2.1. Energy Productivity and Structural Change

The literature on energy productivity presents a comprehensive analysis of the drivers and mechanisms shaping productivity improvements across economies. The empirical evidence predominantly suggests that within-sector productivity gains, rather than intersectoral shifts, are the primary drivers of aggregate energy productivity improvements. Atalla and Bean's (2017) decomposition analysis of 39 countries demonstrates that sectoral productivity improvements outweighed the effects of economic reallocation. This finding aligns with Fisher-Vanden et al.'s (2006) analysis of China, which revealed that firm-level productivity changes, driven by R&D expenditures and rising energy prices, contributed more significantly to declining energy intensity than sectoral shifts. Similarly, Voigt et al.'s (2014) decomposition analysis found productivity effects dominated energy intensity developments in most industrial countries.

The dominance of within-sector improvements is further supported by convergence studies across different contexts. Mulder and de Groot (2012) found that aggregate convergence of energy intensity across OECD countries was almost exclusively driven by within-sector energy intensity convergence. In the U.S. context, both Levinson (2021) and Marcolino (2021) identified intra-industry efficiency improvements as the main contributor to energy intensity decline. While recent work by Leimbach et al. (2023) and Stefanski (2013) acknowledges structural change's role through economic transitions from agriculture to services, technological advancement within sectors remains the primary driver of productivity gains. This perspective is enriched by Haas and Kempa's (2018) directed technical change model, which explains how energy price growth and sectoral productivity differentials determine whether structural or efficiency effects dominate.

The convergence of energy productivity across economies presents a nuanced picture. Mulder and de Groot (2012) find that aggregate convergence across OECD countries is primarily driven by within-sector convergence, while Grodzicki (2024) demonstrates slow but significant convergence among EU countries due to policy harmonization. Malanima (2021), however, contends that convergence is more pronounced in high-income economies, with persistent disparities in lower-income nations. Stefanski (2013) highlights the impact of persistent energy price shocks, which can permanently alter industrial composition and reduce reliance on energy-intensive sectors.

Innovation and international technology diffusion emerge as crucial mechanisms for energy productivity improvements. Sun et al. (2021), utilizing stochastic frontier analysis across 24 countries, finds that both domestic and foreign innovation enhance energy productivity, with foreign knowledge exerting a stronger influence. Jain and Goswami (2021) emphasize the role of R&D investments in facilitating technology transfer, enabling developing countries to access cleaner energy solutions. Zhao et al. (2022) further demonstrate how policy-driven incentives for renewable energy innovation reduce energy inequality across regions. Kalantzis and Niczyporuk (2022) extend this analysis by establishing a positive relationship between energy productivity investments and labor productivity.

The broader implications of structural change on energy systems reveal additional complexities. Malanima (2024) and Zhao et al. (2022) show that transitions toward service-based economies help reduce regional disparities in energy productivity. This finding complements Rauf et al.'s (2018) analysis of heterogeneous effects on CO2 emissions across countries and Acaravcı and Öztürk's (2010) investigation of dynamic relationships between energy consumption and economic growth in European countries. Liu et al.'s (2023) study of Southern European economies further confirms that higher energy productivity reduces CO_2 emissions, while Li et al. (2022) establish a nonlinear relationship between economic fluctuations and energy intensity.

International trade emerges as a significant channel influencing energy productivity through multiple mechanisms. Nieto et al. (2023) demonstrate that trade openness facilitates access to energy-efficient technologies, while Jain and Goswami (2021) observe that more globally integrated South Asian economies experience greater declines in energy intensity. Li and Lin (2017) highlight FDI's role in promoting energy-efficient industries through technology transfer. However, Rauf et al. (2018) caution that trade liberalization can sometimes lead to the relocation of energy-intensive industries to developing countries, potentially offsetting global productivity gains.

Urbanization and structural change present complex implications for energy productivity. Malanima (2024) finds that while early European urbanization increased energy intensity, recent transitions toward service-based urban centers have reduced per capita energy consumption. This contrasts with Zhao et al.'s (2022) findings that rapid urbanization in China has increased regional disparities, with industrial cities showing higher energy intensity than service-oriented centers. These patterns interact with broader structural changes, as evidenced by Liu et al.'s (2022) study of Southern European economies confirming that higher energy productivity reduces CO2 emissions, and Li et al. (2022) establishment of nonlinear relationships between economic fluctuations and energy intensity.

Recent contributions further illuminate the policy dimensions of energy productivity evolution. The IEA (2024) emphasizes emerging markets' role in driving improvements, while Haas and Kempa's (2018) directed technical change model explains how energy price growth and sectoral productivity differentials influence productivity outcomes. Malanima's (2021) historical analysis demonstrates the dominant role of technological improvements in energy conversion productivity since the Industrial Revolution, while Li and Lin (2017) explore how capital allocation efficiency shapes energy productivity in China. Together, these studies underscore the complex interplay between technological advancement, structural change, international trade, and policy interventions in shaping energy productivity trends, suggesting the need for integrated approaches to energy productivity improvement that account for both global and local contexts.

2.2. Energy Productivity and Sectoral Energy Dynamics in Türkiye

Türkiye's energy productivity dynamics are shaped by gradual improvements in energy productivity rather than structural change. While energy intensity declined by 26% between 1991 and 2019 (Rüstemoğlu, 2024), this trend has been closely tied to economic fluctuations (OECD, 2019; IEA, 2021). The reduction in energy intensity stems primarily from sectoral energy productivity improvements rather than significant shifts in economic structure (Tunç et al., 2009; Akyürek, 2020). Limited structural shifts suggest that Türkiye's transition towards a modern economy has not yet yielded broad energy productivity gains (Lise, 2006; Akyürek, 2020). Furthermore, Türkiye's heavy reliance on fossil fuels presents a formidable challenge to decarbonization efforts, despite policy initiatives promoting energy productivity (OECD, 2019; IEA, 2021; Acaroğlu et al., 2023). Economic growth remains a key driver of energy demand and emissions, with Türkiye struggling to decouple economic expansion from resource consumption (Soytaş and Sarı, 2007; Ozturk et al., 2013; OECD, 2019; Akyürek, 2020; IEA, 2021; Rüstemoğlu, 2024, Daştan and Eygü, 2024). Additionally, trade openness, especially in energy-intensive industries, exacerbates emissions (Korkmaz, 2024).

The manufacturing sector plays a crucial role in Türkiye's energy productivity landscape, accounting for 32% of final energy consumption and exhibiting substantial energy-saving potential of 4.6 Mtoe (Akyürek, 2020; IEA, 2021). Studies confirm that sectoral energy intensity improvements, rather than structural change, have driven energy productivity gains. Key industries such as cement, iron, and steel remain significant consumers, necessitating targeted policies to promote energy-efficient technologies and enhance capacity utilization (Tunç et al., 2009; Akyürek, 2020; Korkmaz, 2024). Despite moderate progress in manufacturing productivity following the 2007 Energy Efficiency Law (Akbostancı et al., 2018), Türkiye's industrial transition underscores the urgency of integrating sectoral policies with broader decarbonization strategies while sustaining economic growth (OECD, 2019; IEA, 2021).

The literature on energy productivity in Türkiye reveals contrasting dynamics across sectors, with manufacturing and industrial sectors receiving primary attention while service and agricultural sectors remain relatively understudied. While the service sector in many countries exhibits declining energy intensity, Türkiye's service sector experienced a 35% increase from 2000 to 2014, primarily due to a fossil fuel-dependent electricity mix and rising per capita electricity consumption (Wang et al., 2023). This divergence underscores the varied influence of economic and technological factors on energy use, with Türkiye's economic and population growth further driving energy demand (OECD, 2019; Rüstemoğlu, 2021). The agricultural sector similarly demonstrates increasing energy intensity, with a 168.7% rise between 1980-2003, largely attributed to mechanization rather than structural modernization (Lise, 2006; OECD, 2019).

In response to these sectoral challenges, Türkiye has implemented a comprehensive framework aimed at facilitating structural change while enhancing energy productivity. The National Energy

Efficiency Action Plan (NEEAP) 2017-2023, featuring 55 specific actions (IEA, 2021), represents a concrete step toward reducing primary energy consumption while promoting sectoral change. Marra et al. (2024) emphasize how R&D-driven technological change facilitates the transition toward a more energy-efficient service-based economy, while Acaroğlu et al. (2023) advocate for cost-effective domestic opportunities through energy diversification. The high reliance on imported fossil fuels has exposed Türkiye to vulnerabilities in energy supply security and contributed to foreign trade deficits (Acar et al., 2018; OECD, 2019), making structural change toward renewable energy sources increasingly critical. Despite significant growth in renewable electricity generation, reaching 44% of total power generation in 2019 (IEA, 2021), achieving substantial energy productivity improvements requires broader sectoral integration of renewables and smart technologies (Wang et al., 2023; Ozcan et al., 2020). Daştan and Eygü (2024) underscore that future structural change must balance renewable energy adoption with economic growth, while Aşıcı (2015) proposes redirecting fossil fuel subsidies toward renewable energy production to accelerate this transition.

The Environmental Kuznets Curve (EKC) hypothesis has been extensively studied in the Turkish context, yielding mixed empirical evidence that reflects the complex relationship between economic growth and environmental degradation. Several studies, including Ozturk and Acaravci (2013) Bölük and Mert (2015), Genç et al. (2022), Acaroğlu et al. (2023), Daştan and Eygü (2024), confirm the presence of an inverted U-shaped relationship, suggesting that environmental degradation initially rises with economic growth but declines once a certain income threshold is surpassed. Using ARDL and VECM approaches, these studies identify key turning points, with Acaroğlu et al. (2023) estimating thresholds ranging from \$13,571 to \$18,704 for CO_2 emissions and \$11,821 to \$15,476 for ecological footprint. However, alternative studies such as Lise (2006), Akbostancı et al. (2009), Aşıcı (2015), Karasoy (2019) and Xu et al. (2022) find no support for the EKC hypothesis, particularly when employing longer time series and focusing on carbon emissions rather than broader ecological indicators. Methodological choices and the selection of environmental indicators significantly influence these divergent findings, as studies utilizing ecological footprint measures tend to offer stronger empirical support for the EKC hypothesis compared to those using CO_2 emissions (Acaroğlu et al., 2023; Daştan and Eygü, 2024).

Recent empirical investigations have expanded the EKC analysis in Türkiye by incorporating additional macroeconomic and structural factors that shape the environmental-economic nexus. Genç et al. (2022) introduce output volatility as a determinant, demonstrating that economic fluctuations reduce CO_2 emissions in both the short and long run. Conversely, trade openness has been linked to higher emissions, as evidenced by Halicioglu (2009) and Acaroğlu et al. (2023), highlighting the environmental costs of Türkiye's export structure, which remains reliant on energy-intensive industries. Furthermore, Çetin et al. (2018) emphasizes the role of financial development and energy consumption in shaping Türkiye's emissions trajectory, with coal dependence exacerbating environmental degradation while renewable energy investments mitigate it. Despite the ongoing debate over the EKC hypothesis, a clear consensus emerges: Türkiye's current development trajectory alone is unlikely to induce automatic environmental improvements. Instead, proactive environmental policies, including stricter emissions regulations, investments in cleaner technologies, and economic diversification, are essential to achieving sustainable growth while mitigating environmental degradation (Aşıcı, 2015; Acaroğlu et al., 2023; Daştan and Eygü, 2024).

Our study contributes to the existing literature by focusing specifically on the relationship between structural change and energy productivity in Türkiye, using a calibrated multi-sectoral model. Our research provides new insights into the sectoral drivers of energy productivity and explores the impact of productivity changes and structural shifts on aggregate energy performance. The explicit calculation of relative sectoral energy productivities offers a novel perspective on Türkiye's energy landscape, particularly in comparison to the U.S. benchmark. Moreover, the counterfactual experiments conducted in this study allow us to isolate the specific contributions of individual sectors to changes in aggregate energy productivity, providing valuable information for policymakers seeking to enhance energy productivity in Türkiye.

Despite the growing body of research on energy in Türkiye, there remains a gap in the literature regarding the detailed analysis of the relationship between structural change and relative sectoral energy productivity. Existing studies have primarily focused on aggregate trends or individual sectors, without a comprehensive assessment of the interplay between sectoral dynamics and aggregate energy performance. Moreover, while many studies have examined energy intensity and CO_2 emissions, fewer have directly addressed the issue of energy productivity, especially at the sectoral level. Finally, detailed sector-specific decomposition and counterfactual analyses of aggregate energy productivity in Türkiye are limited in the existing literature.

This study addresses these gaps by using a detailed sector-specific decomposition and counterfactual analyses. Our analysis provides a novel perspective on Türkiye's energy landscape by comparing sectoral energy productivities to those of the U.S., offering a benchmark against a technologically advanced economy. The counterfactual experiments and the quantitative assessment of the energy productivity gap further contribute to a deeper understanding of the challenges and opportunities facing Türkiye in enhancing its energy productivity and promoting sustainable economic growth. This paper's findings have important implications for policymakers seeking to design effective sector-specific policies aimed at improving energy productivity and facilitating Türkiye's progress toward its emission reduction targets.

3. METHODS

3.1. Data and Facts

This section describes the data used in the analysis and presents stylized facts concerning structural change and energy productivity in Türkiye. The data employed in this study are primarily drawn from three sources: (1) the United Nations National Accounts Main Aggregates Database for sectoral value-added data (both at constant 2015 prices and current prices); (2) the Turkish Statistical Institute (TurkStat) for sectoral employment data; and (3) the International Energy Agency (IEA) World Energy Balances database for sectoral energy consumption data. A more detailed account of the data sources, construction of variables, and associated limitations is provided in the Data Appendix A.

A central focus of this study is energy productivity. At the aggregate level, energy productivity (θ^e) is defined as the ratio of gross value-added (Y) to total energy use (E):

$$\theta^e = \frac{Y}{E} \tag{1}$$

To understand the sectoral contributions to aggregate energy productivity, we employ the following decomposition:

$$\frac{Y}{E} = \sum_{i \in \{a,m,s\}} \frac{Y_i}{E_i} \frac{E_i}{E} \tag{2}$$

where i represents the three sectors (agriculture, manufacturing, and services), Y_i and E_i denote sector-specific output and energy use, respectively. The term $\frac{Y_i}{E_i}$ represents sectoral energy productivity, indicating the output produced per unit of energy consumed in each sector. The term $\frac{E_i}{E}$ represents the energy share of each sector. This decomposition reveals each sector's relative contribution to overall energy productivity.

The PPP-adjusted aggregate output, denoted by Y, is sourced from the Penn World Tables (PWT) version 10.01 for its initial 1978 value. Subsequent values are derived by applying the growth rates of constant-price value added in local currency units, obtained from the United Nations National Accounts Statistics, Main Aggregates and Detailed Tables. This approach rests on the assumption that the growth of value added in constant local prices accurately reflects changes in quantities. At the sectoral level, energy productivity is calculated analogously, using sectoral value-added and energy consumption data. Higher energy productivity, both at the aggregate and sectoral levels, signifies a more efficient use of energy resources in the production process.

To facilitate cross-country comparisons of energy productivity, value-added data should ideally be converted to a common currency using purchasing power parities (PPPs). PPP adjustments account for differences in price levels across countries, enabling a more accurate comparison of real output. However, due to the unavailability of PPP-adjusted sectoral value-added data, our analysis relies on growth rates of value-added expressed in constant local currency units, following the methodology of Marcolino (2021).

A key aspect of structural change is labor reallocation across sectors, impacting energy productivity due to varying sectoral energy intensities. In developed economies, GDP growth typically surpasses energy consumption growth. This decoupling is less pronounced in developing countries like Türkiye. For instance, while U.S. GDP tripled (1978-2019), its energy consumption rose only 16%, yielding a 2.5-fold increase in aggregate energy productivity. Conversely, Türkiye's six-fold GDP growth coincided with a 5.6-fold increase in energy consumption, causing a 6% decline in aggregate energy productivity. Thus, Türkiye's energy intensity increased. These differences motivate further sectoral analysis.

These contrasting trends motivate a deeper investigation into the underlying sectoral dynamics and the specific factors contributing to Türkiye's lagging energy productivity performance. To this end, we examine the evolution of sectoral energy shares and productivity levels in Türkiye, providing a detailed account of the structural changes that have occurred over the past four decades.

Figure 1 illustrates the labor reallocation trends in Türkiye from 1978 to 2019, revealing a pronounced shift away from agriculture and towards services, consistent with the stylized facts of structural change. The agricultural employment share declined dramatically from approximately 50% to 18%, while the service sector's share increased from around 28% to 57%. The manufacturing sector's share exhibited some fluctuations over this period, remaining relatively stable between 22% and 27%. This reallocation of labor has implications for aggregate energy productivity, given the different energy intensities of these sectors.

Figure 2 depicts the evolution of Türkiye's aggregate energy productivity relative to the U.S. from 1978 to 2019. The downward trend indicates a declining energy productivity relative to the U.S. benchmark, from approximately 4.15 times the U.S. level in 1978 to about 1.61 times in 2019. This declining relative performance motivates a deeper investigation into the underlying sectoral dynamics.

Figure 3 shows the sectoral energy shares in Türkiye over the same period. Manufacturing consistently held the largest share, although it experienced a decline from around 62% in 1998 to below 48% by 2019. The service sector's energy share exhibited a steady upward trend, starting around 40% and gradually converging with manufacturing's share. Agriculture's energy share remained relatively small and stable, hovering around 5%. These trends reveal a shift in the composition of energy demand, with services becoming increasingly important energy consumers.

Figure 4 presents the normalized sectoral energy productivity growth in Türkiye from 1978 to 2019 (with 1978 as the base year). The graph highlights the manufacturing sector's success in increasing its energy productivity, reaching approximately 1.4 by 2019, signifying a 40% improvement. In contrast, both agriculture and services experienced declines in energy productivity. Agriculture's energy productivity fell significantly to 0.38, while services declined to 0.69. This indicates that these sectors became less efficient in their energy use over time.

Figure 5 displays the sectoral energy productivity levels in Türkiye from 1978 to 2019, measured in billions of constant 2015 Turkish Lira per unit of energy (ktoe). Similar to the normalized values in Figure 4, the graph emphasizes the positive growth in

Figure 1: Labor reallocation in Türkiye

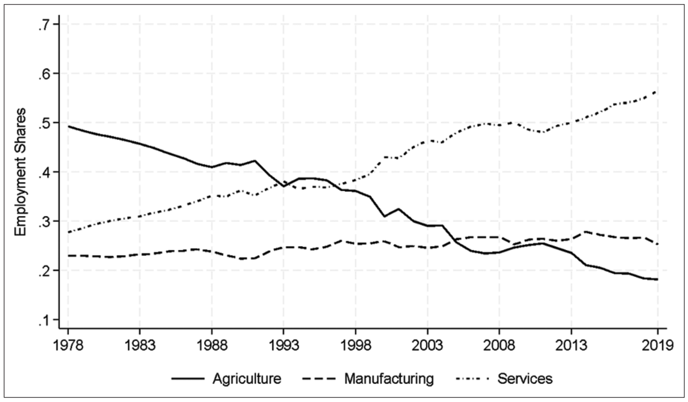


Figure 2: Relative aggregate energy productivity

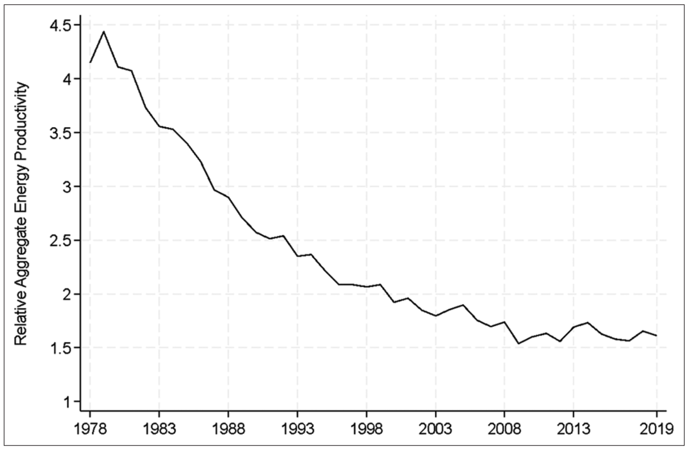
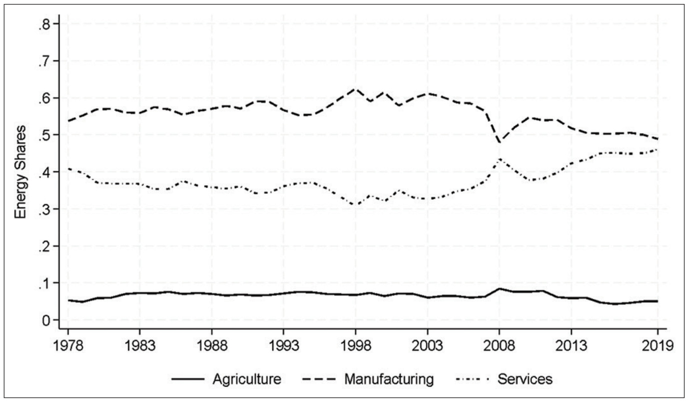


Figure 3: Sectoral energy shares in Türkiye



manufacturing energy productivity, despite a period of decline between 1986 and 2002. Conversely, both agriculture and services experienced significant declines over the period. In 1978, with the same energy input, the agricultural and services sectors were 727% and 392% more productive than manufacturing, respectively. By 2019, these figures had dropped to 128% and 143%. This divergence highlights the heterogeneous impact of structural changes on sectoral energy productivity.

Table 1 further quantifies these trends by presenting the average annual growth rates of energy productivity for each sector in Türkiye and the U.S. As shown in the table, Türkiye's manufacturing sector experienced positive energy productivity growth (0.82% annually), while agriculture and services experienced negative growth rates (−2.31% and −0.89%, respectively). In contrast, all three sectors in the U.S. exhibited positive energy productivity growth, contributing to the declining relative energy productivity of Türkiye observed in Figure 2.

Figure 4: Normalized energy productivity growth in Türkiye

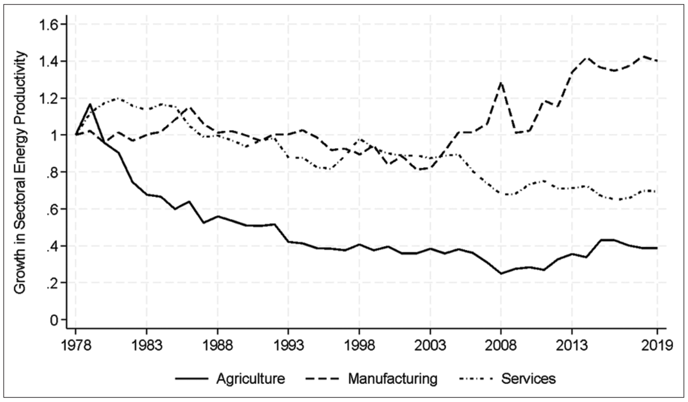


Figure 5: Sectoral energy productivities in Türkiye

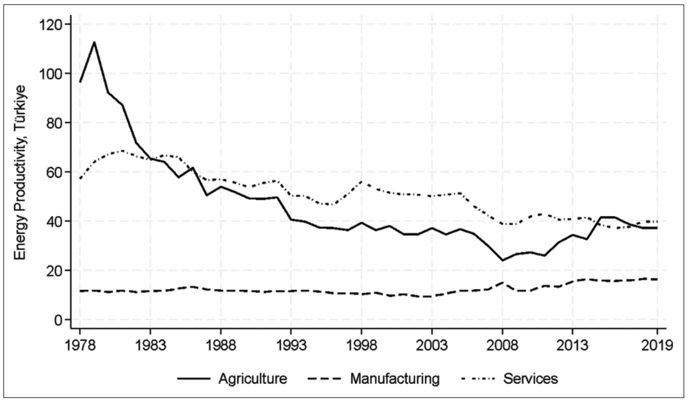


Table 1: Sectoral growth rates of energy productivity

Countries	θ_a^e	θ_m^e	θ_s^e
USA (%)	1.91	1.71	1.83
Türkiye (%)	−2.31	0.82	−0.89

These stylized facts reveal important patterns in Türkiye's energy landscape. The declining relative energy productivity, the contrasting sectoral trends, and the relatively high energy intensity of the Turkish economy, especially in the industrial sector, underscore the need for a more detailed investigation of the underlying drivers of these trends. The following sections will delve into these dynamics using the calibrated model, decomposition analysis, and counterfactual experiments.

3.2. Model and Calibration

This section presents the three-sector general equilibrium model used to analyze structural change and energy productivity in Türkiye. The model, adapted from Duarte and Restuccia (2010) and extended by Marcolino (2021), incorporates non-homothetic preferences and a Leontief production technology with sector-specific labor and energy productivity parameters. We first outline the model's structure and equations, followed by a detailed description of the calibration strategy.

3.2.1. Model structure

The model economy consists of three sectors: agriculture (*a*), manufacturing (*m*), and services (*s*). Each sector produces a distinct good using labor (l_i) and energy (e_i) as inputs.

3.2.1.1. Production

Output in each sector is determined by a Leontief production function:

$$Y_i = \min\{\theta_i l_i, \theta_i^e e_i\} \forall i \in \{a,m,s\} \tag{3}$$

where θ_i and θ_i^e represent sector-specific labor and energy productivity, respectively.

3.2.1.2. Resource constraints

The economy is subject to resource constraints in each sector. For agriculture and services:

$$\mathrm{c_i = Y_i}\ \forall \mathrm{i} \in \{\mathrm{a,s}\} \tag{4}$$

Where c_i denotes consumption of good *i*. The manufacturing sector produces both a final good for consumption and an intermediate good (energy):

$$c_m + \psi \sum_{i \in \{a,m,s\}} e_i = Y_m \tag{5}$$

Where ψ is the rate at which manufacturing output is transformed into energy.

3.2.1.3. Labor market

Labor is mobile across sectors, and the total labor supply is normalized to one:

$$\sum_{i \in \{a,m,s\}} l_i = 1 \tag{6}$$

3.2.1.4. Household preferences

The representative household has non-homothetic preferences over the three goods, represented by:

$$U(c_a, c_m, c_s) = \gamma \ln(c_a - \overline{A}) + (1-\gamma) \ln\left[\beta^{\frac{1}{\eta}} c_m^{\frac{\eta-1}{\eta}} + (1-\beta)^{\frac{1}{\eta}} (c_s + \overline{c}_s)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{7}$$

The parameter $0<\gamma<1$ governs the relative weight of agricultural consumption in the overall utility, while $0 < \beta < 1$ determines the weight between manufacturing and services consumption within the composite goods represented by the CES function. The parameter $\eta > 0$ is the elasticity of substitution between the manufacturing and the services goods.

$\overline{A} > 0$ represents the subsistence level of consumption for the agricultural goods. The presence of $(c_a - \overline{A})$ implies that the household must consume at least $\overline{A}$ units of the agricultural good, implying a non-homotheticity where the household derives no utility from agricultural goods below this subsistence level and where demand is more inelastic at lower income levels.

This utility function, also incorporates another non-homotheticity by including $\overline{c_s} > 0$ for services. By adding $\overline{c_s}$ to the consumption of services, the utility function implies that services are an income-elastic good. As income rises, the household will allocate a disproportionately larger share of its expenditure to services.

The household supplies labor inelastically, with income *w* derived from this labor supply being used to purchase the three consumption goods. The household's budget constraint is:

$$p_a c_a + p_m c_m + p_s c_s = w \tag{8}$$

Where *w* represents the wage rate.

3.2.2. Equilibrium

The competitive equilibrium of the model is characterized by a set of prices $\{p_a, p_m, p_s, p_e, w\}$ and allocations $\{Y_i, l_i, e_i, c_i\}$ that satisfy the following conditions:

1. Household Optimization: Households maximize utility (7) subject to the budget constraint (8).
2. Firm Optimization: Firms in each sector maximize profits, given by $p_i Y_i$-wl_i-$p_e e_i$, subject to the production function (3).
3. Market Clearing: All markets clear, satisfying the resource constraints (4) and (5) and the labor market clearing condition (6).

3.2.3. Equilibrium prices and labor allocations

Solving the model yields equilibrium prices and labor allocations. The equilibrium price for each sector *i* reflects the unit labor cost and the unit energy cost: $p_i = \frac{1}{\theta_i} + \frac{p_e}{\theta_i^e}$. Given the manufacturing sector's role in energy production, the zero-profit condition in energy markets dictates that $p_m = \psi p_e$. Combining these conditions allows us to express the prices for manufacturing, services, and agriculture in terms of sectoral productivities and the energy conversion rate:

$$p_m = \frac{\psi \theta_m^e}{\theta_m(\psi\theta_m^e - 1)} \tag{9}$$

For agriculture and services (*i* ∈ *{a,s}*):

$$p_i = \frac{1}{\theta_i} + \frac{\theta_m^e}{\theta_i^e \theta_m [\psi \theta_m^e - 1]} \tag{10}$$

The labor allocation across sectors is determined by the household's preferences, relative prices, and sectoral productivities. Agricultural labor, l_a, is primarily driven by the subsistence requirement for agricultural goods and agricultural labor productivity, modified by a term capturing non-homothetic preferences when $\gamma > 0$. In the simplified form where we assume the change of service sector labor is too small, it is denoted by:

$$l_a = (1-\gamma)\frac{\overline{A}}{\theta_a} + \gamma[1+p_s\overline{c}_s]\frac{1}{p_a\theta_a} \tag{11}$$

The manufacturing employment share, l_m, is influenced by the relative demand for manufacturing and services, determined by the elasticity of substitution (η) and the preference parameter (β), as well as by sectoral productivities and the energy conversion rate. Specifically, l_m is given by:

$$l_m = \frac{\left(\frac{\beta}{1-\beta}\right)\left(\frac{p_m}{p_s}\right)^{-\eta}[\theta_s(1-l_a)+\overline{c}_s] + \psi\left(\frac{\theta_a}{\theta_a^e}\right)l_a + \psi\left(\frac{\theta_s}{\theta_s^e}\right)(1-l_a)}{\theta_m - \psi\frac{\theta_m}{\theta_m^e} + \psi\frac{\theta_s}{\theta_s^e} + \theta_s\left(\frac{\beta}{1-\beta}\right)\left(\frac{p_m}{p_s}\right)^{-\eta}} \tag{12}$$

Finally, the services employment share, l_s, is determined by the remaining labor after allocating to agriculture and manufacturing: $l_s = 1-l_a-l_m$.

3.2.4. Calibration

The model is calibrated to the U.S. data from 1978 to 2019 to establish a benchmark economy. This involves determining values for the preference parameters $(\gamma, \overline{A}, \overline{c}_s, \beta, \eta)$, the energy conversion rate (ψ), and the initial productivity levels in each sector ($\theta_{i,1978}, \theta_{i,1978}^e$).

The model is calibrated to the U.S. data (1978-2019) to establish a benchmark. The preference parameters $(\gamma, \overline{A}, \overline{c}_s, \beta, \eta)$ and the energy conversion rate (ψ) are chosen to match key features of the U.S. economy. γ is set to 0.005, reflecting the declining agricultural employment share; $\overline{A}$ and $\overline{c}_s$ are set to 0.018 and 0.65, respectively, matching the initial (1978) agricultural and services employment shares; β is set to 0.17 based on the 2019 manufacturing employment share, and η is 0.15, minimizing the sum of squared deviations between model-generated and observed employment shares for manufacturing and services in the U.S.

ψ is calibrated using the relative price of manufacturing to energy, calculated from the IEA's "Nominal index for industry and households." For the U.S., initial labor productivities are normalized to one ($\theta_{i,1978} = 1$), and initial energy productivities ($\theta_{i,1978}^e$) are set to match observed labor-energy ratios ($e_{i,1978})/l_{i,1978}$). These yields $\theta_{a,1978}^e = 227$, $\theta_{m,1978}^e = 48$, and $\theta_{s,1978}^e = 98$. Subsequent productivity levels are obtained using sectoral growth rates calculated from value-added and energy use data. For Türkiye, initial relative labor and energy productivities ($\theta_{i,1978}$ and $\theta_{i,1978}^e$) are calculated using the calibrated model, along with six targets from the Turkish data in 1978: employment shares in each sector and energy shares in each sector.

The time paths of sectoral labor and energy productivity for both the U.S. and Türkiye are generated using their respective average annual growth rates, calculated from the sectoral value-added series (measured at constant 2015 prices) and sectoral energy use data. The calibration strategy ensures that the model parameters reflect the key characteristics of the U.S. and Turkish economies, enabling a robust analysis of the interactions between structural change and energy productivity in Türkiye.

3.3. Quantitative Analysis

This section assesses the quantitative performance of the calibrated model in replicating key features of the Turkish economy between 1978 and 2019. We first examine the model's ability to reproduce observed trends in sectoral employment and energy shares, as well as aggregate energy productivity. Subsequently, we analyze the relative productivity levels across sectors in Türkiye compared to the U.S. and provide a more detailed statistical evaluation of the model's overall fit. This assessment serves as a foundation for the subsequent analysis of the determinants of aggregate energy productivity and the counterfactual experiments. The model's ability to replicate salient features of the U.S. economy is presented in the Appendix B.

3.3.1. Model's fit to the Turkish economy

Figures 6 and 7 provide a visual comparison between the model's predictions and the empirical data for Türkiye. The closer the model-generated values are to the observed data, the better the model's fit. In these figures, solid lines represent the observed data, while dashed lines represent the model's generated values.

In Figure 6, the model's ability to replicate sectoral employment and energy shares is evaluated. Figure 7 assesses the model's performance in capturing aggregate energy productivity. Figure 6a and b illustrate the model's ability to reproduce the sectoral allocation of labor and energy in Türkiye from 1978 to 2019, respectively. Figure 6a demonstrates that the model closely captures the main trends in sectoral employment shares, successfully reproducing the decline in agriculture and the continued expansion of the service sector. Specifically, the model implies a decline in the agricultural employment share from 49.28% in 1978 to 19.45% in 2019, closely aligning with the observed data which displays a decline from 49.26% to 18.14% for the same period. Similarly, the model accurately captures the dynamics in the service sector, where the employment share increased from 27.06% to 57.68% over the studied period, which is consistent with the increase in observed data, which was from 27.75% to 56.52%. While the model predicts a slight decline in the manufacturing employment share from 23.65% to 22.86%, the data show a modest increase from 22.98% to 25.32% over the period.

This discrepancy may be attributed to model's assumption of a closed economy. As noted by Rodrik (2016), in a small open economy that takes world prices as given, faster productivity growth in manufacturing can lead to industrialization, a dynamic not captured in our closed-economy framework. However, the model successfully captures the relatively stable overall trend in this sector, as well as the dominant trends in agricultural and services employment.

Figure 6b assesses the model's performance in replicating the trends in energy consumption shares across sectors. The model successfully reproduces the general trends, despite some limitations in precisely matching short-run fluctuations. Specifically, the model captures the stable and low energy

Figure 6: Model versus data: Sectoral employment and energy shares. (a) Employment shares, (b) Energy shares

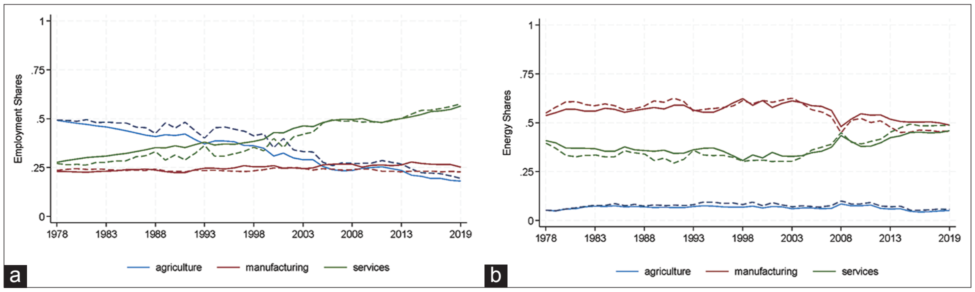


Figure 7: Model versus data: Normalized aggregate energy productivity

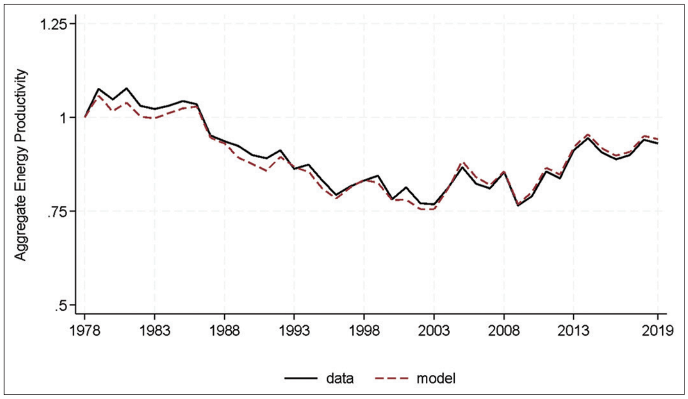


Table 2: Model performance statistics

Statistical Criteria	Türkiye		USA	
	Employment	Energy	Employment	Energy
MAE				
Agriculture	0.0369	0.0106	0.0068	0.0039
Manufacturing	0.0168	0.0252	0.0122	0.0173
Services	0.0289	0.0266	0.0082	0.0142
Total	0.0826	0.0624	0.0271	0.0354
mSNE				
Agriculture	0.9811	0.9820	0.9924	0.9913
Manufacturing	0.9663	0.9720	0.9943	0.9861
Services	0.9844	0.9735	0.9972	0.9893
CORR				
Agriculture	0.9821	0.9186	0.9801	0.9395
Manufacturing	-0.1744	0.9148	0.9787	0.9239
Services	0.9819	0.9427	0.9866	0.9225
MD				
Agriculture	0.9585	0.7727	0.7554	0.5598
Manufacturing	0.4057	0.9032	0.9686	0.8919
Services	0.9657	0.9166	0.9855	0.9112

MAE: Mean Absolute Error. MSNE: Modified Nash-Sutcliffe Efficiency. CORR: Correlation statistic. MD: Modified index of agreement

consumption share in agriculture, the initially large and later decreasing energy consumption share in manufacturing, and the upward trend of energy use in services. The deviations observed in energy shares are attributable to the Leontief production technology, which creates a direct link between labor and energy inputs. Consequently, discrepancies in predicted employment shares translate into corresponding deviations in energy shares. Overall, Figure 6 confirms that the model provides a reasonably good approximation of the structural trends in labor and energy allocation for the Turkish economy.

Figure 7 shows the model-generated paths of normalized aggregate energy productivity, respectively, with the corresponding data from 1978 to 2019. Figure 7 demonstrates the model's success in replicating the overall trend in aggregate energy productivity, despite a slight overestimation, especially in the later years (a 7% decline predicted by the model vs. a 6% decline in the data). Despite these minor deviations, the model's ability to capture the overarching trends in aggregate energy productivity further validates its capacity to represent the core dynamics of structural change in the Turkish economy. These figures, together with the sectoral analysis in Figure 6, suggest that the model provides a reasonably accurate representation of the key trends in energy allocation and productivity in Türkiye.

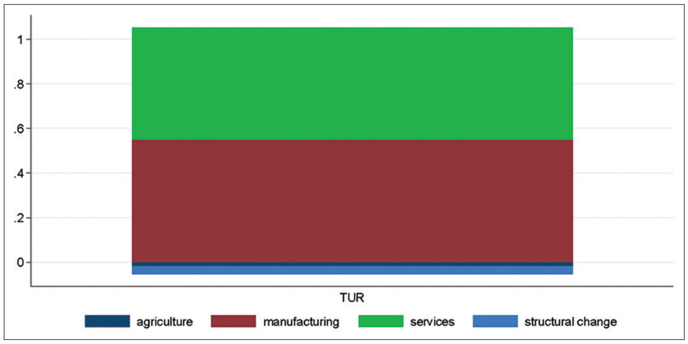
3.3.2. Model performance

To provide a more rigorous evaluation of the model's fit, we employ several statistical measures, as reported in Table 2. These metrics quantify the discrepancies between the model's predictions and the observed data for sectoral employment and energy shares in both Türkiye and the U.S. We use the Mean Absolute Error (MAE), the modified Nash-Sutcliffe efficiency (mNSE), the correlation statistic (CORR), and the modified index of agreement (md). Lower MAE values signify a better fit, with zero representing a perfect match. For mNSE and md, values closer to one indicate a better fit, ranging from zero to one. The CORR measures the linear association between the model and the data, with values closer to one indicating a stronger positive relationship.

For Türkiye, the total MAE across all sectors is 0.0826 for employment and 0.0624 for energy. This suggests that the model performs slightly better in replicating energy shares compared to employment shares. However, it is important to note that the MAE for manufacturing employment in Türkiye (0.0168) is the lowest among the three sectors, despite the visual discrepancies observed in Figure 8. This apparent contradiction is due to the smaller magnitude of change in the manufacturing labor share over time, even though the model does not perfectly capture the trend. As such, while MAE provides a useful measure of average absolute deviations, it should be interpreted in conjunction with other metrics and the visual assessment.

The model exhibits a particularly good fit for the agricultural sector in Türkiye, with an mNSE of 0.9811 for employment and 0.9820 for energy, and high correlations (0.9821 for labor and 0.9186 for energy). The manufacturing sector presents a mixed picture, with a high mNSE for employment (0.9663) but a negative correlation

Figure 8: Decomposition of aggregate energy productivity gap, Türkiye versus U.S. in 2019



(−0.1744), highlighting the limitations of the closed-economy assumption in capturing this sector's dynamics. In contrast, manufacturing energy predictions fare better, with an mNSE of 0.9720 and a positive correlation of 0.9148. The services sector shows a good fit for both employment and energy, with high mNSE and CORR values. The md values for Türkiye offer further insights, indicating some deviations from the data.

For the U.S., the model exhibits very low MAE values across all sectors and for both employment and energy, with the highest MAE being 0.0173 for manufacturing energy. The mNSE values consistently exceed 0.98, and the correlation statistics are close to unity, confirming the model's strong performance for the benchmark economy. This is expected, given that the model's preference parameters were calibrated to the U.S. data. Overall, the statistical evaluation in Table 2, combined with the visual assessment in Figures 6 and 7, suggests that the model provides a reasonably accurate representation of the structural change process in Türkiye, while performing exceptionally well for the U.S. benchmark.

3.3.3. Relative energy productivity levels in Türkiye

This section examines the relative energy productivity levels in Türkiye compared to the U.S. in both 1978 and 2019. These relative productivities, derived using the calibrated model and presented in Table 3, offer insights into the initial conditions and the evolution of sectoral energy productivity over time. We focus specifically on energy productivity, as it is central to our analysis of Türkiye's energy performance and its structural change.

In 1978, Türkiye exhibited higher energy productivity than the U.S. across all sectors. This advantage was particularly pronounced in manufacturing (4.15 times the U.S. level) and services (4.79 times). Even in agriculture, Türkiye's energy productivity was 20% higher. It's important to reiterate that these figures reflect higher PPP-adjuested value-added generated per unit of energy consumed, not necessarily superior energy technologies in Türkiye. However, by 2019, this picture had changed significantly. Türkiye's relative energy productivity declined in all sectors. The most dramatic drop occurred in agriculture, falling from 1.20 to 0.21, indicating a substantial deterioration in relative energy productivity. Services also experienced a considerable decline, from 4.79 to 1.57. While manufacturing maintained higher energy productivity than the U.S. (2.88 times), its relative advantage decreased compared to 1978.

Table 3: Calibrated relative energy productivity levels

Sector	$\theta^{e}_{i,1978}$	$\theta^{e}_{i,2019}$
Agriculture	1.20	0.21
Manufacturing	4.15	2.88
Services	4.79	1.57
USA	1.00	1.00

Values are expressed relative to the U.S. For example, a value of 1.20 for agriculture in 1978 indicates that energy productivity in Türkiye's agricultural sector was 20% higher than the U.S. level in that year

These findings reveal a clear trend of declining relative energy productivity in Türkiye across all sectors between 1978 and 2019. This erosion of Türkiye's initial energy productivity advantage has important implications for the country's overall energy performance and motivates a deeper investigation into the underlying drivers. The following sections analyze the factors contributing to these changes, including sectoral growth rates, structural shifts, and technological progress, using decomposition and counterfactual analyses.

4. DETERMINANTS OF AGGREGATE ENERGY PRODUCTIVITY

This section investigates the factors driving changes in aggregate energy productivity in Türkiye, comparing its performance to the U.S. and exploring the role of sectoral dynamics. We employ a shift-share analysis to decompose aggregate energy productivity growth, followed by an analysis of the sources of the energy productivity gap between the two countries. Finally, we conduct counterfactual experiments to isolate the effects of sectoral energy productivity growth on the aggregate level.

4.1. Shift-share Analysis

We decompose the growth rate of aggregate energy productivity into within-sector and between-sector effects using a shift-share analysis. This allows us to distinguish the contributions of changes in sectoral energy productivity from shifts in the allocation of energy across sectors. The decomposition is based on the following equation:

$$\frac{\theta_t^{e,j}-\theta_{t-1}^{e,j}}{\theta_{t-1}^{e,j}} = \sum_{i\in\{a,m,s\}} \frac{\left(\theta_{i,t}^{e,j}-\theta_{i,t-1}^{e,j}\right)\bar{s}_{i,t}^{j}}{\theta_{i,t-1}^{e,j}} + \sum_{i\in\{a,m,s\}} \frac{\left(s_{i,t}^{j}-s_{i,t-1}^{j}\right)\bar{\theta}_{i,t}^{e,j}}{\theta_{t-1}^{e,j}} \tag{13}$$

Where $\theta_t^{e,j}$ represents aggregate energy productivity for country *j* in period *t*, $\theta_{i,t}^{e,j}$ is the energy productivity of sector *i*, $s_{i,t}^{j}$ is the energy share of sector *i*, and $\bar{s}_{i,t}^{j}$ and $\bar{\theta}_{i,t}^{e,j}$ are the average energy share and average energy productivity between periods *t* and *t-1* for sector *i* in country *j*. The first term captures the within-sector effect, reflecting changes in sectoral energy productivity, while the second term represents the between-sector or structural change effect.

Figure 9 presents a decomposition of aggregate energy productivity growth in Türkiye and the U.S., averaged over the 1978-2019 period. Because Türkiye experienced a decline in aggregate energy productivity over this period, the overall growth is negative. To facilitate interpretation, we normalize this negative growth to −1, representing a 100% decline in aggregate energy productivity from the hypothetical starting point of zero growth. The decomposition then shows the contributions of each sector to this normalized negative growth.

For Türkiye, the decomposition reveals that the decline in aggregate energy productivity is primarily attributable to the services sector. The services sector accounts for 99.8% of the normalized negative growth, indicating that its declining energy productivity is the dominant driver of the overall decrease. Manufacturing, while exhibiting positive energy productivity growth, only offsets a small portion of this decline (33.8%). Similarly, agriculture offsets 48% of the decline, which also indicates the presence of positive energy productivity growth in this sector. The relatively small positive contribution of structural change (14%) indicates that shifts in energy allocation across sectors had a limited positive impact on aggregate energy productivity, but not enough to counteract the negative influence of declining sectoral energy productivities, especially in services.

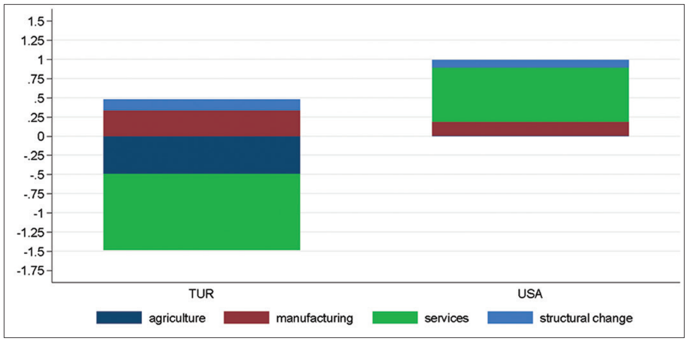
In contrast, the U.S. experienced positive aggregate energy productivity growth. Therefore, the decomposition for the U.S. shows the positive contributions of each sector to this growth. Services accounts for the largest share (approximately 70%), followed by manufacturing (18%), with a negligible contribution from agriculture (<1%). The structural change effect is positive and modest (10.6%), indicating a small positive impact from shifts in energy allocation.

This corrected analysis accurately reflects the dynamics of aggregate energy productivity growth in Türkiye, emphasizing the substantial negative contribution of the services sector and the relatively minor positive influence of structural change. The contrast with the U.S., where all sectors contributed positively, further highlights the importance of sector-specific policies in addressing Türkiye's energy productivity challenges.

4.2. Sources of Aggregate Energy Productivity Differences

We decompose the aggregate energy productivity gap between Türkiye and the U.S. in 2019 using the following equation adapted from Święcki (2017):

Figure 9: Decomposition of average aggregate energy productivity growth



$$\frac{\theta^e_{TUR}-\theta^e_{US}}{\theta^e_{US}} = \sum_{i\in\{a,m,s\}} \frac{\left(\theta_i^{e,TUR}-\theta_i^{e,US}\right)\overline{s}_i}{\theta^e_{US}} + \sum_{i\in\{a,m,s\}} \frac{\left(s_{i,TUR}-s_{i,US}\right)\overline{\theta}_i^{e}}{\theta^e_{US}} \qquad (14)$$

This equation separates the within-sector effects (differences in sectoral energy productivity levels) from the structural change effects (differences in energy shares). Figure 8 illustrates this decomposition. The positive gap (61%) is primarily driven by higher energy productivity in Türkiye's manufacturing (54.9%) and services (50.6%) sectors. Agriculture (−1.6%) and structural change (−3.9%) have small negative contributions.

4.3. Exploring the Role of Sectoral Energy Productivity

The counterfactual experiments, summarized in Table 4, isolate the impact of each sector's energy productivity growth on the aggregate gap between Türkiye and the U.S. By comparing the counterfactual outcomes to the baseline (observed data), we quantify each sector's contribution and identify potential areas for policy intervention. Specifically, we examine how Türkiye's relative aggregate energy productivity in 2019 (1.61 in the observed data) would change if the U.S. had experienced the same sectoral energy productivity growth rates as Türkiye. Simultaneously, we assess how the observed U.S. aggregate energy productivity (1 in the baseline) compares to the counterfactual U.S. values.

In the first counterfactual (CF1), aligning U.S. agricultural energy productivity growth with Türkiye's rate (−2.31%) results in a small increase in Türkiye's relative energy productivity to 1.78. In CF2, adjusting U.S. manufacturing energy productivity growth to Türkiye's rate (0.82%) has a larger impact, raising Türkiye's relative productivity to 2.02. CF3, aligning U.S. services sector growth with Türkiye's (−0.89%), shows the most dramatic effect, increasing Türkiye's relative energy productivity to 3.67. These results highlight the substantial role of the services sector in driving the aggregate energy productivity gap between the two countries.

In the first counterfactual (CF1), aligning U.S. agricultural energy productivity growth with Türkiye's (−2.31%) raises Türkiye's relative aggregate energy productivity to 1.78, while the U.S. value reaches 1.09. This modest change indicates that differences in agricultural energy productivity growth have a limited impact on the overall gap. CF2 adjusts U.S. manufacturing energy productivity growth to Türkiye's rate (0.82%). This leads to a more substantial increase in Türkiye's relative productivity (2.02), and the U.S. value rises to 1.24. This suggests that the manufacturing sector plays a larger, albeit still moderate, role in the productivity

Table 4: Counterfactual analysis of relative aggregate energy productivity

Country	$\theta^{e,data}_{1978}$	$\theta^{e,data}_{2019}$	$\theta^{e,cf1}_{2019}$	$\theta^{e,cf2}_{2019}$	$\theta^{e,cf3}_{2019}$
TUR	4.15	1.61	1.78	2.02	3.67
USA	1	1	1.09	1.24	2.26

gap. CF3, aligning U.S. services sector growth with Türkiye's (−0.89%), reveals the most dramatic effect. Türkiye's relative energy productivity jumps to 3.67, while the U.S. value reaches 2.26. This substantial shift underscores the dominant role of the services sector in driving the aggregate energy productivity gap. These findings have significant policy implications, suggesting that targeting energy productivity improvements within the services sector offers the greatest potential for closing the productivity gap between Türkiye and the U.S.

5. CONCLUSION

This paper investigates the relationship between structural change and sectoral energy productivity in Türkiye from 1978 to 2019. Motivated by Türkiye's slow growth in aggregate energy productivity, and its persistently high energy intensity despite low per capita energy consumption, we sought to understand the role of sectoral dynamics and technological progress in shaping these trends. Using a calibrated three-sector general equilibrium model, adapted from Duarte and Restuccia (2010) and extended by Marcolino (2021), we quantify sectoral energy productivities relative to the United States, serving as a benchmark economy. A key contribution of our analysis is the first-time calculation of relative sectoral energy productivities for Türkiye, providing novel insights into the country's energy productivity performance.

Our findings reveal a complex and evolving relationship between structural change and energy productivity in Türkiye. While Türkiye initially exhibited higher energy productivity than the U.S. across all sectors in 1978, this advantage eroded considerably over the subsequent four decades. Manufacturing was the only sector to experience positive energy productivity growth in Türkiye. However, due to even faster growth in the U.S., Türkiye's relative energy productivity in manufacturing declined. The most substantial declines occurred in agriculture and, critically, in services. This divergence in energy productivity, especially within the services sector, emerged as a key driver of the widening gap in aggregate energy productivity between Türkiye and the U.S.

A decomposition analysis of aggregate energy productivity growth revealed the dominant role of within-sector changes, highlighting the large negative contribution of the services sector in Türkiye. Conversely, in the U.S., all sectors contributed positively to aggregate energy productivity growth, with services playing the most significant role. A further decomposition of the aggregate energy productivity gap in 2019 confirmed the substantial influence of sectoral energy productivities, with manufacturing and services being the primary drivers of the observed difference between Türkiye and the U.S.

Counterfactual experiments provided further insights into the relative importance of each sector. Aligning U.S. sectoral energy productivity growth rates with those of Türkiye demonstrated that changes in services sector productivity had the most pronounced impact on the aggregate gap. This finding underscores the crucial role of the services sector in shaping energy productivity dynamics and has important implications for policy. Specifically, our results suggest that policies aimed at improving energy productivity within sectors, particularly services, are likely to be more effective than those focused solely on shifting the composition of economic activity. Given the services sector's growing dominance in the Turkish economy, promoting energy-efficient technologies and practices within this sector should be a priority for policymakers. Investigating the role of international trade and relaxing the closed-economy assumption of the model are promising avenues for future research. By addressing these critical areas, Türkiye can enhance its energy productivity, promote sustainable economic growth, and contribute to global efforts in mitigating climate change.

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APPENDIX

Appendix A: Data Sources

1. Value Added: Sectoral value-added data for Türkiye, both in constant 2015 prices and current prices, are sourced from the United Nations National Accounts Main Aggregates Database. The data, classified according to the International Standard Industrial Classification (ISIC Rev. 3.1), cover the period from 1978 to 2019. The three sectors considered in this study are defined as follows:
    - Agriculture: Agriculture, Hunting, Forestry, and Fishing.
    - Manufacturing: Mining, Manufacturing, Utilities, and Construction.
    - Services: Wholesale and retail trade, Transportation storage and communication, Financial and insurance activities, other service activities.
2. Employment: Sectoral employment data for Türkiye, corresponding to the same sectors and time period as the value-added data, are obtained from TurkStat.
3. Energy Consumption: Sectoral energy consumption data (measured in ktoe) are taken from the IEA World Energy Balances database. The "final consumption" series is combined with the "energy industry own use and losses" to obtain a comprehensive measure of energy use. The following sector classifications are used:
    - Agriculture: Agriculture/Forestry (AGRICULT) and Fishing (FISHING).
    - Manufacturing: Industry (TOTIND), Non-energy use industry (NEINTREN), Non-energy use chemical/petrochemical (NECHEM), and Energy Industry Own Use and Losses (TOTENGY).
    - Services: Transport (TOTTRANS), Commercial and Public Services (COMMPUB), Non-specified (ONONSPEC), Non-energy use in transport (NETRANS), and Non-energy use in other (NEOTHER). Residential (RESIDENT) energy consumption is excluded, as this study focuses on energy productivity in production activities, not final consumption.
4. Relative Prices: The relative price of manufacturing to energy is calculated using the manufacturing price index and the energy price index. The energy price data used to calculate ψ comes from the IEA's "End-use prices: Indices of energy prices by sector" database, specifically the "Nominal index for industry and households."

Appendix B: The U.S. Results. (a) Employment shares, (b) Energy shares, (c) Aggregate energy productivity