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Driving factors of changes in energy intensity: A comparison between energy exporting and importing countries

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Abstract

This paper compares the driving factors of changes in energy intensity in both net energy exporting and importing countries using a DEA-Malmquist (Data Envelopment Analysis) and panel GMM (Generalized Method of Moments) methods over the period of 2000–2021. The findings show that

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technological progress has played a significant role in reducing of energy intensity in both groups. Moreover, we use the DEA method to decompose the Malmquist total factor productivity (*TFP*) into its components including technical change (*TC*), efficiency change (*EC*), pure efficiency change (*PEC*) and scale efficiency change (*SEC*). The results show that in energy exporting countries, the effects of each of these *TFP* components on energy intensity are negative but relatively weak, while the effects of these components on reducing energy intensity in importing countries is considerable. Specifically, the estimated coefficient of the pure efficiency component in reducing energy intensity in very remarkable, which shows the high importance of the efficiency components of *TFP* in energy management. Next, we investigate what is the main driver of technological progress in both the energy exporting and importing countries. The findings imply that in net energy exporting countries trade openness is a dominant factor to improve productivity, while in net energy importing countries, internal R&D is the dominant factor for improving technological efficiency.

Keywords: energy intensity, DEA-Malmquist, trade liberalization, foreign direct investments, internal R&D, energy dependence countries

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Introduction

The sustainability of energy and hence economic development depends crucially on the efficient use of energy [1]. Therefore, the energy intensity of a country is regarded as an important indicator of economic development. Due to the extreme importance of energy intensity reduction, numerous researchers have focused on identifying the key determinants of energy intensity and providing an improved understanding of this trend. Economic growth, technology, structural effects and international trade are widely accepted as the factors that have contributed most to the decline in energy intensity [2–5]. Many authors have agreed that technological change has a stronger impact on the energy intensity than other factors [6, 7]. Overall, the empirical results are mixed and the literature has not provided any information about whether the energy endowment could influence the driving factors of the energy intensity changes of a country. However, there is a large imbalance between not only regions but also countries with respect to the use of energy resources around the world. The evidence shows that the energy intensities of most energy exporting countries have historically been very high compared with energy importing and industrialized economies. Also, the International Energy Agency (IEA) [8, 9] has emphasized that higher endowment of energy has led to a rapid rise of energy intensity. On the other hand, the scarcity of energy resources around the world begets the emergence of a great competition for increasing energy efficiency among countries, especially energy importing countries. However, understanding the determinants (or drivers) of energy intensity in countries with energy dependence (exporting or importing) is important for economic researchers and policymakers; despite this, the studies are scarce. Therefore, this paper has compared the main driving factors of energy intensity changes between net energy exporting and importing countries using dynamic panel data during 2000–2021. In order to have a better understanding of technological progress, we employed DEA-Malmquist approach for each country to decompose *TFP* into technical change and efficiency change. Next, we would determine the sources of technical efficiency in the selected energy exporting and importing countries; such a comparison enables us to identify the main factors that most effectively influence technical efficiency and result in declining energy intensity.

The rest of the paper is organized as follows. The first section is an overview the literature. Section two presents the research methodology and data description. In section three, we analyze the empirical results related to DEA-Malmquist and GMM regressions for both net energy importing and exporting countries. The last section includes the conclusion and recommendations.

1. Literature review

Energy intensity is an important index that plays a significant role in sustainable development. The experience of economies shows that advanced industrial economies consume less energy per unit of production than traditional economies. This is highly dependent on the economic infrastructure factors in any country. One of the main factors is economic development and technological advancement. The process of economic growth and development is accompanied by widespread structural changes in the economy, technology and lifestyle of society. These all influence the consumption behavior and productive structure of the country, resulting in changes in energy intensity [10, 11]. Some researchers confirm that the relationship between economic growth and energy intensity is an inverse *U*, so that energy consumption will increase at the beginning of the process of economic development and industrialization due to the expansion of the mother industries, infrastructures and other energy-intensive economic activities. Then, in the post-industrial phase, energy intensity decreases due to technological progress and its spillovers [12, 13]. Sun [14] confirms that the main reason of declining energy intensity in OECD countries during 1971–1998 was technological advancements. Lin and Du [15] reveal that technological change has had a stronger impact on the energy intensity than other factors, so that contributes to declining energy intensity in China by 22.4% during 2003–2010. Huang et al [7] decomposed technical progress using DEA and found that technical change and its components (technical efficiency and pure efficiency) have significant influences on the regional energy intensity in China. By contrast, Gillingham et al. [4] claim that the reduced cost of use brought about by technological improvements may increase energy use, which can lead to higher energy intensity.

At the same time as globalization in economic issues, the degree of economic openness (trade and financial) has been another factor affecting energy intensity. Major studies have demonstrated that technical spillovers to industrializing countries from advanced economies are given a fillip by trade openness [16–19]. According to the literature, the impact of economic openness on energy intensity varies, and the final effect depends on the resultant force of scale, composition and technical effects. The scale effect suggests that along with economic opening and expanding trade, economic activities increase and thus lead to changes in energy consumption. The composition effect shows up in a change in the composition of the manufactured goods. Thus, how energy intensity is affected depends on the pattern of specialization of the economies and in other words on the type of comparative advantage. According to the composition effect, energy consumption is reduced when the economy is specialized in less energy-intensive sectors. The technique effect refers to utilizing energy-saving technologies and their spillover effects in the domestic economy [6]. The technique effect indicates that economic opening and foreign direct investment enhance the chances of imitating and learning from foreign firms and hence would encourage domestic firms to adopt technologies with higher energy efficiency. Ultimately, the competition created by economic opening reduces energy intensity in the host country [20, 21]. Adom [18, 22] indicates that energy intensity in Nigeria is significantly reduced by trade openness, and the author reports similar results for South Africa. He argues that shifts in trade patterns in favor of imports tend to decrease energy intensity, implying that the reduction in energy intensity in South Africa is the result of an increase in imports relative to exports. Rafiq, Salim, and Nielsen [23] investigate 22 developing economies' energy intensity, including Angola, Gambia, Namibia, Sudan, and Zambia, demonstrating reduced energy intensity from trade openness. Cole [24] found that trade openness and energy use can have either a positive or a negative relationship, depending on the structure of trade; in particular, this is affected by countries being net exporters or importers of energy-intensive products. This intersection leads each country to shift resources into sectors that make the most efficient use of lucrative resources in order to decrease energy intensity.

Resource endowment is associated with the reserves of coal, oil and natural gas, exerting great influence on the selection and development of industry (or technology) and indirectly determining energy consumption. IEA [8, 9] has reported that higher endowment of energy has led to a rapid rise of energy intensity. Jiang et al [25] analyzed the China provinces' energy consumption taking into account energy-resource endowment. They indicate that provinces endowed with rich energy reserves were inclined to consume much more energy than those otherwise. Evidence also shows that in countries with greater domestic resource availability, their energy intensity is relatively high because of lower prices, fewer incentives to maximize energy efficiency and less fear of import dependency [26, 27]. Likewise, government subsidies and naturally low energy prices (due to proximity to source) in these countries impede factor productivity and reduce the incentive for investment in energy efficiency. Wing [28] indicates that eliminating energy subsidies can optimize energy consumption and thereby reduce energy intensity, especially if it follows investments in the appropriate infrastructures that increase productivity and modernize technology and equipment. Also, Samarghandi [29] explains that all OPEC countries have begun to tentatively eliminate or reduce their subsidized energy sectors, though much more must be done as these countries have to adopt energy efficient production technologies.

However, this question of what drives a decline in energy intensity in countries with energy dependence (exporting or importing) is important for economic researchers and policymakers; despite that, the studies are scarce. Samarghandi [29] investigates the roles of trade openness, technological innovation, and energy price in energy intensity in OPEC countries using panel ARDL approaches during the period 1990–2016. The findings show that trade openness plays a key role in diminishing energy intensity and demonstrates that innovation is insignificantly associated with energy intensity. Huang et al [7] investigate the driving forces of China's provincial energy intensity by using DEA-Malmquist approaches during 2000–2014. The results indicate that technological progress plays a dominant role in decreasing China's overall energy intensity. Moreover, rapid industrialization should be responsible for China's currently high energy intensity, while energy price hikes are conducive to reducing energy intensity. Atalla and Bean [30] investigated the drivers of energy productivity changes occurring in 39 countries during 1995–2009. They found that higher levels of income per capita and higher energy prices are associated with greater energy productivity, while a greater share of output from industry is associated with lower energy productivity levels. In particular, higher energy prices and income levels are associated with improvements in sectoral energy productivity. Rühl et al. [31] draw on evidence from the last two centuries of industrialization and analyze energy intensity over the long- and short-run. They argue that the increased specialization of the fuel mix, coupled with accelerating convergence of both the sectoral and technological composition of economies, has improved energy intensity of economic output. Fankhauser and Cornillie [32] investigate energy intensity in transition countries. Their findings show that energy prices and progress in enterprise restructuring are the two most important drivers for more efficient energy use.

2. Methodology and data description
2.1. Model specification

We use a Cobb–Douglas production function as follows:

$$Q = A\,K^{\alpha}\,L^{\beta}\,E^{\gamma}, \tag{1}$$

where Q is the output;

A is the total factor productivity (TFP);

K is the capital stock;

L is the employment;

E is the energy consumption.

Assuming constant returns to scale, production cost can be expressed as follows:

$$C(P_K;P_L;P_E;P_M;A) = A^{-1} P_K^{\beta_K} P_L^{\beta_L} P_E^{\beta_E} P_M^{\beta_M} Q, \tag{2}$$

where P_L, P_K, P_E and P_M are defined as the prices of labor, capital, energy and raw materials;

β_L, β_K, β_E and β_M represent the related price elasticity, respectively.

According to Shepard's lemma, after making P_E-derivation, *Eq. 2* can be changed to the following as:

$$E = \frac{\beta_E A^{-1} P_K^{\beta_K} P_L^{\beta_L} P_E^{\beta_E} P_M^{\beta_M} Q}{P_E}. \tag{3}$$

By setting $P_Q = P_K^{\beta_K} P_L^{\beta_L} P_E^{\beta_E} P_M^{\beta_M}$ and dividing both sides on Q, the energy intensity (*EI*) equation is extracted as follows:

$$EI = \frac{E}{Q} = \frac{\beta_E A^{-1} P_Q}{P_E}. \tag{4}$$

Now, by taking a logarithm on both sides, we get the energy intensity equation for country i as follows:

$$\ln(EI)_{it} = \beta_0 + \beta_1 \ln\left(\frac{P_E}{P_Q}\right)_{it} + \beta_2 \ln(TFP)_{it} + \beta_3 \ln(Induva)_{it} + \varepsilon_{it}. \tag{5}$$

According to Huang et al. [7], the Malmquist total factor productivity (*TFP*), which is expressed as a Data Envelopment Analysis (DEA), measures the *TFP* change over time and has been proven well-suited for measuring technological progress. Hence, to capture the influence of technological progress on energy intensity exactly, we use the DEA approach and make the *TFP* decompose into technical progress change (*TC*) and comprehensive technical efficiency (*EC*). Therefore, we get:

$$\ln(EI)_{it} = \beta_0 + \beta_1 \ln\left(\frac{P_E}{P_Q}\right)_{it} + \beta_2 \ln(TC)_{it} + \beta_3 \ln(EC)_{it} + \beta_4 \ln(Induva)_{it} + \varepsilon_{it}. \tag{6}$$

Moreover, the comprehensive technical efficiency change (*EC*) can be further decomposed into pure technical efficiency change (*PEC*) and scale efficiency change (*SEC*) by introducing variable returns to scale distance functions. The model reads as follows:

$$\ln(EI)_{it} = \beta_0 + \beta_1 \ln\left(\frac{P_E}{P_Q}\right)_{it} + \beta_2 \ln(TC)_{it} + \beta_3 \ln(PEC)_{it} + \beta_4 \ln(SEC)_{it} + \beta_5 \ln(Induva)_{it} + \varepsilon_{it}. \tag{7}$$

According to the production process, accessing energy resources, technical standards and the extent of opening up are different in countries, hence the energy intensity of each country is quite different. Thus, such an analysis is likely most useful at the comparison level between energy exporting and importing countries. Therefore, we classify the countries into two groups including net energy exporting and importing countries. Then, we estimate *Eq. 7* for each group. In addition, following previous studies, the countries may seek to increase efficiency, encourage the firms to conduct internal R&D [33] or adopt foreign technology [34, 35] or trade openness [36]. Hence, for determining the sources of technical efficiency in energy exporting and importing countries, such a comparison enables us to identify the main factors that most effectively influence technical efficiency and result in declining energy intensity.

2.2. Data description

As implied before, we attempt to evaluate the driving factors of energy intensity changes by comparing between energy exporting[1] and importing[2] countries. The final regression model for each group follows from *Eq. 7.* Data are annual and per constant price GDP 2015 year and extracted from the World Bank and IEA. The studied period is selected during 2000–2021, considering availability of data.

The data description is as follows: EI_{it} denotes energy intensity of country i at time t. Energy intensity is calculated as the ratio of energy consumption (barrels of oil) to GDP at constant purchasing power parities of the year 2015; α_i are country-fixed effects; P_E/P_Q is the energy relative price that is calculated as the ratio of the fuel and power price index to producer price index. *Induva* is the share of the industrial sector in economic, and ε_{it} is disturbance terms assumed to be white-noise and uncorrelated.

TC, *PEC*, *SEC* are the technological progress and its components. In order to measure these dynamic efficiencies, we employed the DEA-Malmquist approach to gain *TFP* changes for all countries. We use the productivity with distance function. There is a production possibility set *S*. *S* represents the ability to achieve the transformation of x to y, and the point (x, y) in the S at which it can achieve the largest output y in every given input x is in the production frontier. With production possibility set S, the distance function in time t (1, 2, ..., T) is shown in *Eq. 8.*

$$D(x;y)=\inf\left\{\theta:\left(x;y\middle|\theta\right)\in S\right\}=\left(\theta:(x;\theta y)\in S\right)^{-1}, \quad (8)$$

where $D(x, y) \leqslant 1$, if and only if point $(x, y) \in S$; and $D(x, y) = 1$, if and only if point (x, y) is in the production frontiers.

The Malmquist index is defined as:

$$M(x^{(t+1)};y^{(t+1)};x^t;y^t)=\left[\left(\frac{D^t(x^{t+1};y^{t+1}}{D^t(x^t;y^t)}\right)\cdot\left(\frac{D^{t+1}(x^{t+1};y^{t+1}}{D^{t+1}(x^t;y^t)}\right)\right]^{1/2}. \quad (9)$$

We have divided it into two functions, D^t and D^{t+1}, in time t and $t+1$. Thereby, *Eq. 9* has two parts: the first one is the percentage in the distance function D^t, between the possible output in time $t+1$ and its real time t. The second part is the distance function D^{t+1}, between the real output in $t+1$ and the possible output in time t. Fare and Grosskopf [37] constructs the technical Malmquist index from t to $t+1$ and decompose it into two parts: comprehensive technical efficiency (*EC*) and technical progress change (*TC*) that are called "frontier" technological progress and "following" technological progress, respectively:

$$EC=\frac{D^{t+1}(x^{t+1};y^{t+1})}{D^t(x^t;y^t)}. \quad (10)$$

$$TC=\left(\frac{D^t(x^{t+1};y^{t+1})}{D^{t+1}(x^{t+1};y^{t+1})}\cdot\frac{D^t(x^t;y^t)}{D^{t+1}(x^t;y^t)}\right)^{1/2}. \quad (11)$$

In the formulas above: the Malmquist index M is defined as productivity changes, $M > 1$ means productivity level increase, $M < 1$ indicates productivity level decrease and $M = 1$ means productivity level remains unchanged. Also, *EC* is defined as the comprehensive technical efficiency and indicates the advantages and disadvantages of management decisions and resource allocation, $EC > 1$ means improvement in *EC* , management methods and resource allocation. $EC < 1$ indicates decline of technical efficiency, inappropriate management decisions and insufficient

[1] Net energy exporting countries include Norway, Kazakhstan, Russia, Uzbekistan, Canada, Colombia, Mexico, Venezuela, Indonesia, Malaysia, Australia, Algeria, Egypt, Nigeria, South Africa, Iran, Kuwait, Saudi Arabia and United Arab Emirates.

[2] Net energy importing countries include Ukraine, South Korea, China, Thailand, United States, The Czech Republic, New Zealand, Belgium, Sweden, Argentina, Poland, India, Brazil, Chile, France, The Netherlands, Japan, Germany, Spain, Portugal, Romania, Italy, Turkey and the United Kingdom.

utilization of resource, and $EC = 1$ means the EC remains unchanged. Moreover, TC indicates changes in technological progress, that is, changes in technological innovation and industrial production technology. $TC > 1$ indicates progress in production technology. $TC < 1$ indicates a decline in production technology, and $TC = 1$ means the technological progress remains unchanged.

According to the DEA model, the technical efficiency change (EC) can be further decomposed into pure technical efficiency change (PEC) and scale efficiency change (SEC), by introducing variable returns to the scale distance function. Thereby, the Malmquist index is expressed as *Eq. 12*:

$$M(x^{t+1}; y^{t+1}; x^t; y^t) = EC \cdot TC = (PEC \cdot SEC) \cdot TC. \quad (12)$$

By supposing the subscripts v and c refer to variable returns to scale technology and constant return to scale technology, respectively, thereby, the PEC and SEC can be expressed as:

$$PEC = \frac{D_v^{t+1}(x^{t+1}; y^{t+1})}{D_v^t(x^t; y^t)}. \quad (13)$$

$$SEC = \frac{D_c^{t+1}(x^{t+1}; y^{t+1})}{D_c^t(x^t; y^t)} \cdot \frac{D_v^t(x^t; y^t)}{D_v^{t+1}(x^{t+1}; y^{t+1})}. \quad (14)$$

Finally, we employ the dynamic panel data method to run the regression model. A reliable solution for the efficient estimation of dynamic panels was set by Arellano and Bond [38] by using the Generalized Method of Moments (GMM). This estimator has become extremely popular, especially in the context of empirical dynamic research, because it allows one to relax some of the OLS assumptions. The Arellano and Bond estimator corrects for the endogeneity in the lagged dependent variable and provides consistent parameter estimates even in the presence of endogenous right-hand-side variable. It also allows for individual fixed effects, heteroscedasticity and autocorrelation within individuals [39]. Consistency of the GMM estimator depends on the validity of the instruments. As suggested by Arellano and Bond [38], Arellano and Bover [40], and Blundell and Bond [41], two specification tests are used. Firstly, the Sargan/Hansen test of over-identifying restrictions which tests for overall validity of the instruments and the null hypothesis is that all instruments as a group are exogenous. The second test examines the null hypothesis that error term ε_{it} of the differenced equation is not serially correlated particularly at the second order (AR(2)), and one should not reject the null hypothesis of both tests.

Table 1.

IPS unit root test at level

Variables	Energy exporting countries	Energy importing countries
ln(*EI*)	–7.44 (0.000) *	–3.14 (0.0008)
ln(*TFP*)	–6.88 (0.000)	–3.67 (0.0001)
ln(*TC*)	–8.64 (0.000)	–3.180 (0.0007)
ln(*EC*)	–11.96 (0.000)	–14.08 (0.000)
ln(*PEC*)	–8.41 (0.000)	–10.26 (0.000)
ln(*SEC*)	–12.47 (0.000)	–12.61 (0.000)
ln(*PE/PQ*)	–4.56 (0.000)	–2.93 (0.0017)
ln(*Induva*)	–5.09 (0.000)	–7.01 (0.000)
ln(*trade*)	–2.05 (0.020)	–2.32 (0.010)
ln(*FDI*)	–2.85 (0.002)	–3.46 (0.0003)
ln(*internal RD*)	–5.78 (0.000)	–2.79 (0.0026)

* Figures in parentheses are significant prob. value

3. Results

Before estimating the regression models for each group of countries, an important step was to test for unit roots with stationary covariates. Hence, we used the Im, Pesaran, and Shin [42] unit root test assuming that the series are non-stationary. *Table 1* presents the results of the IPS unit root test. The findings demonstrate that all variables in both groups are stationary at the level. In other words, all variables are integrated with order (0).

Tables 2, *3* report the results of dynamic panel estimations in net energy exporting and importing countries. The findings imply that in net energy exporting countries, technological progress and its components enhance productivity; thereby they have significant effects to reduce energy intensity. However, the effects are relatively weak. According to the results, a percent increase of total factor productivity (*TFP*) in the energy exporting countries causes a decrease in energy intensity of 0.047 percent. Also, after *TFP* decomposing into the technical change (*TC*) and the efficiency change (*EC*), in energy exporting countries *TC* has a negative and significant effect on energy intensity, interestingly, so that a percent increase in *TC* causes a decrease in energy intensity by 0.051 percentage. The effect of *EC* on declining energy intensity is not significant, as expected. When *TFP* is further decomposed into the technical change (*TC*), the pure efficiency (*PEC*) and the scale efficiency change (*SEC*), the results show that the coefficients of the components related to *TC* and *SEC* are significantly negative in energy exporting countries, although, the estimated coefficients are weak. Some causes are the imperfect infrastructures and relatively lower level of technology and economic development in most energy exporting countries, so the positive effects of technology progress on energy intensity are not be maximized. Another main note is that the negative effect of *PEC* on energy intensity is not significant in these countries. In other words, due to the cheapness of energy resources in exporting countries, the role of net efficiency in reducing energy intensity has not been paid enough attention.

The findings in net energy importing countries indicate that technological progress and its components have significant and negative effects on energy intensity, so that these effects are at least very much greater than those in energy exporting countries. The results show that a percent increase of total factor productivity (*TFP*) in the importing countries causes a decrease in energy intensity of 0.120 percent. Also, after *TFP* decomposing into the technical change (*TC*) and the efficiency change (*EC*), both coefficients are significant and negative, so that a percent of increases in *TC* and *EC* causes a decrease in energy intensity by 0.078 and 0.245 percentages, respectively. This means that in energy importing countries, the coefficient of efficiency change is very much larger than that of technical change. It implies that the effects of technical progress on energy intensity can occur through both technical and efficiency changes. When *TFP* is further decomposed into the technical change (*TC*), the pure efficiency (*PEC*) and the scale efficiency change (*SEC*), the coefficients of these components are negative and highly significant in energy importing countries. Specifically, the estimated coefficient of the pure efficiency component in reducing energy intensity in very remarkable and shows the high importance of the efficiency components of *TFP* in energy management.

Overall, we can say that technological progress and its components are a main driver of energy intensity changes in both energy exporting and importing countries. However, the elasticity in energy importing countries is much greater than in energy exporting countries. A large portion of the stronger effects of *TFP* on the energy intensity in energy importing countries is through the pure efficiency change and its spillovers.

Next, we investigated what is the main driver of technological progress in the energy exporting and importing countries. However, there are differences in the development level, R&D inputs, energy resources and education between energy exporting and importing countries. We examine whether innovation activities

Table 2.

The GMM results for energy intensity changes in energy exporting countries

Variables	Model 1 (TFP)	Model 2 $(TFP = TC \cdot EC)$	Model 3 $(TFP = TC \cdot PEC \cdot SEC)$
$\ln(EI)$	0.9011 (0.0000) *	0.9127 (0.0000)	0.8973 (0.0000)
$\ln(TFP)$	–0.0475 (0.0003)		
$\ln(TC)$		–0.0513 (0.0024)	–0.0392 (0.0064)
$\ln(EC)$		–0.0428 (0.136)	
$\ln(PEC)$			–0.0189 (0.1144)
$\ln(SEC)$			–0.0300 (0.0020)
$\ln(PE/PQ)$	–0.0178 (0.337)	–0.0167 (0.486)	–0.0379 (0.6062)
$\ln(Induva)$	0.1215 (0.0000)	0.1198 (0.0000)	0.0502 (0.0058)
Sargan – p-value	0.358	0.325	0.337

* Figures in parentheses are significant prob. values

Table 3.

The GMM results for energy intensity changes in energy importing countries

Variables	Model 1 (TFP)	Model 2 $(TFP = TC \cdot EC)$	Model 3 $(TFP = TC \cdot PEC \cdot SEC)$
$\ln(EI)$	0.9760 (0.0000) *	0.9643 (0.0000)	0.9662 (0.0000)
$\ln(TFP)$	–0.1202 (0.0000)		
$\ln(TC)$		–0.0782 (0.0000)	–0.0590 (0.0000)
$\ln(EC)$		–0.2454 (0.0000)	
$\ln(PEC)$			–0.2584 (0.0000)
$\ln(SEC)$			–0.1613 (0.0000)
$\ln(PE/PQ)$	–0.1035 (0.0000)	–0.0998 (0.0000)	–0.1016 (0.0007)
$\ln(Induva)$	0.12173 (0.0000)	0.1262 (0.0000)	0.1526 (0.0003)
Sargan – p-value	0.397	0.364	0.327

* Figures in parentheses are significant prob. values

including internal R&D and adoption of foreign technology (*FDI*) have differential effects on their technological efficiency. Likewise, we examined the role of trade liberalization on technological efficiency by considering the argument that trade liberalization enables firms to achieve high levels of efficiency through "learning-by-exporting-effects". *Table 4* reports the results of GMM estimations for *TFP* in both groups of selected energy exporting and importing countries. The findings imply that in net energy exporting countries, *FDI* inflows and trade openness causes improved productivity. The estimated coefficient for trade openness is larger than *FDI* inflows, so that a percent of increase in *FDI* inflows and trade openness causes enhancement of *TFP* by 0.014 and 0.058 percentages, respectively. Also, the effect of internal R&D is not significant. This result is reasonable because internal R&D is a risky and costly path-dependent process in comparison with the adoption of foreign technology by *FDI* inflows and trade openness, especially for firms in energy exporting countries. Hence the firms in these countries spend low levels of investment in internal R&D and thereby, there is a lack of organized R&D activity in most energy exporting countries.

As expected, the findings in net energy importing countries indicate that the internal R&D, trade openness and *FDI* inflows have positive and significant effects on technological efficiency. The role of internal R&D is dominant, so that a percent of increase in the internal R&D, trade openness and *FDI* inflows causes enhancement of *TFP* by 0.0269, 0.0045 and 0.0007 percentages, respectively.

However, it is important to note that the result confirms that in energy exporting countries trade openness is a dominant factor for improving technological efficiency. This result is reasonable, because trade liberalization policies can increase competition between domestic and foreign firms that may allow domestic firms access to cheaper and better technology and better quality inputs and managerial skills from abroad, thereby increasing productivity. Additionally, we found that in energy importing countries, R&D activities were important contributors to the decline in energy intensity. This finding can be attributed to the greater share of foreign R&D expenditures in this group. Put differently, energy exporting countries lack incentives to incur domestic expenditures on technology development and technological innovation because, presumably, this costs a lot and is time-consuming. Thus, exporting countries opt to purchase international technology that is from R&D activities in importing countries.

Table 4.

The GMM results for TFP change model

Variables	Energy exporting countries	Energy importing countries
ln(*TFP*)	0.1593 (0.0006) *	0.1405 (0.0000)
ln(*TRADE*)	0.0584 (0.0256)	0.0045 (0.0134)
ln(*FDI*)	0.0149 (0.0253)	0.0007 (0.0090)
ln(internal R&D)	0.0387 (0.2965)	0.0269 (0.0000)
Sargan – *p*-value	0.330	0.559

* Figures in parentheses are significant prob. values.

Finally, we performed the Sargan test for over-identification, and tests for serial correlation of the differenced error term. As can be seen from the corresponding *p*-values of these tests, reported at the bottom of all *Tables 2–4*, the null hypothesis of the validity of instruments cannot be rejected. Also, the first- and second-order serial correlation tests show that there exist negative first-order serial correlations and there is no evidence of second-order serial correlation in the differenced error terms.

Conclusion

The energy intensities of most energy exporting countries have historically been very high compared with energy importing and industrialized economies. Although energy efficiency improved over the period 2000–2021, the production process, access to energy resources, technical standards and the extent of opening up are different in energy exporting and importing countries, and hence their energy intensity changes are quite different. Therefore, this question is still an important argument for the factors that are driving the decline in energy intensity in each group of countries. Hence, this paper has compared the main driving factors of energy intensity changes in net energy exporting and importing countries using dynamic panel data during 2000–2021. The findings show that technological progress has played a negative role in energy intensity in both groups; of course, this effect is greater in importing countries, as expected. Furthermore, in order to have a better understanding of technological progress, we employed the DEA-Malmquist approach for each country to decompose *TFP* into the technical change (*TC*) and the efficiency change (*EC*), the pure efficiency (*PEC*) and the scale efficiency change (*SEC*).

The findings for energy exporting countries indicate that *TC* has a negative and significant effect on energy intensity, although, the estimated coefficient is relatively weak. Meanwhile, the effect of *EC* on declining energy intensity is not significant, as expected. Also, the coefficient of the component related to *SEC* is significantly negative in energy exporting countries. Because of imperfect infrastructures and relatively lower level of technology and economic development in most energy exporting countries, this finding is reasonable. Finally, the negative effect of the *PEC* on energy intensity is not significant in exporting countries. Hence, these findings confirm that due to the cheapness of energy resources in exporting countries, they have not paid enough attention to the role of net efficiency in reducing energy intensity.

The results for net energy importing countries indicate that the negative effects of efficiency change (*PE*) on energy intensity are slightly larger than that of *TC*, implying that the effects of technical progress on the energy intensity can occur through both technical and efficiency changes. Also, the coefficient of the component related to *SEC* is significantly negative in energy importing countries, as expected. Finally, the estimated coefficient of *PEC* in reducing energy intensity is very remarkable, which shows the high importance of the efficiency components of *TFP* in energy management. However, the results confirm that a large portion of the stronger effects of *TFP* on declining energy intensity in energy importing countries has occurred through the pure efficiency change and its spillovers.

Next, we investigated what is the main driver of technological progress in the energy exporting and importing countries. However, there is a difference in the development level, research and development (R&D) inputs, energy resources and education between energy exporting and importing countries. We examined whether innovation activities including internal R&D and adoption of foreign technology (*FDI*) have differential effects on their technological efficiency. Likewise, we examined the role of trade liberalization on technological efficiency by considering the argument that trade liberalization enables firms to achieve high levels of efficiency through "learning-by-exporting-effects." The findings imply that in net energy exporting countries, trade openness is a dominant factor for improving technological efficiency. Because trade liberalization policies can increase competition between domestic and foreign firms they may allow domestic firms access to cheaper and better technology and better quality inputs and managerial skills from abroad and finally increase the productivity. Also, the effect of internal R&D is not significant. This result is reasonable because internal R&D is a risky and costly path-dependent process in comparison with the adoption of foreign technology by trade openness, especially for firms in energy exporting countries. Hence the firms in these countries spend low levels of investment in internal R&D and exporting countries opt to purchase international technology that is from R&D activities in importing countries. Meanwhile, the findings in net energy importing countries indicate that R&D activities were important contributors to the decline in energy intensity. This finding can be attributed to the greater share of internal R&D expenditures in this group.

Overall, the results of this study might have important policy implications. Most significantly, it shows that the energy intensity fluctuation is simultaneously forced by both technical change and efficiency change, although these effects are stronger in net energy importing countries compared with net energy exporting countries, as expected. Specifically, the role of pure efficiency change in reducing energy intensity is very considerable. However, policy makers in both energy exporting and importing countries need to be aware of the fact that technological progress and innovation are powerful tools in reducing energy intensity. Hence, this study suggests that the governments should encourage use of advanced technologies and management experience, especially in energy exporting countries. Also, policy makers in exporting countries should focus on trade liberalization, especially on information exchange via learning-by-exporting effects. As well, we found that innovation investments (internal R&D) play a substantial role to improve energy efficiency in importing countries. Therefore, this study suggests that governmental intervention especially in exporting countries should strengthen innovation capacity and also promote energy saving technology. ■

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