Optimization
Iranian Journal of Optimization
Volume 13, Issue 4, 2021, 271-278
Research Paper

Online version is available on: www.ijo.rasht.iau.ir

Islamic Azad University
Rasht Branch
ISSN: 2588-5723
E-ISSN:2008-5427

Technology Decomposition and Energy Intensity in OPEC Countries: DEA-Malmquist Approach

Mehdi Fallah jelodar [1] and somaye sadeghi[2*]

[1] Department of Mathematics, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran,
[*2] Department of Accounting, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran

Revise Date 05 March 2022
Accept Date: 29 April 2022

Abstract

Reduction of energy intensity through gaining energy efficiency is a global agenda for sustainable development goals. The evidence show that the energy intensities of most energy exporting countries (such as OPEC) have historically been very high compared with energy importing and industrialized economies. Hence, the understanding of the main determinants (or drivers) of energy intensity in energy exporting countries is important for economic researchers and policymakers. Therefore, this paper investigates the role of technology and its components on energy intensity changes in OPEC countries using a DEA-Malmquist over the period of 2000-17. The findings show that technological progress has played a significant role in reducing of energy intensity. Moreover, the results after TFP decomposing using DEA method indicates that the negative effect of technical change on energy intensity is much larger than of the efficiency change effect, Although, the estimated values of these components are is relatively weak. Next, we investigate what is main driving of technological progress in the OPEC countries. The findings imply that trade openness is a main factor to causes to improve the productivity.

Keywords:
Energy Intensity
DEA -Malmquist
TFP decomposition
Trade Openness

***Correspondence E-mail**: somysadeghi@yahoo.com

INTRODUCTION

The sustainability of energy and hence economic development, depends crucially on the efficient use of energy (Huang et al, 2018). Therefore, energy intensity of a country is regarded as an important indicator of economic development. Due to the extreme important 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 (Galli, 1998; Taylor et al., 2010; Gillingham et al., 2016; Ward et al., 2017). Many authors have agreed that the technological change has hold a stronger impact on the energy intensity than other factors (Jiang et al, 2014; Huang et al, 2017). Overall, the empirical results are mixed and the literatures have not provided common information. The evidence show that the energy intensities of most energy exporting countries have historically been very high compared with energy importing and industrialized economies. However, the understanding of the determinants (or drivers) of energy intensity in energy exporting countries is important for economic researchers and policymakers, despite in, the studies are scare. Therefore, this paper investigates the main driving factors of energy intensity in OPEC countries, using dynamic panel data during 2000-2017. In order to have a better understanding from technological progress, we employed DEA-Malmquist approach for each country to decompose TFP into the technical change and the efficiency change. It should be noted that we used GAMS optimization software to solve DEA model, although in other studies it is also solved with R software (Hosseinzadeh Lotfi et al, 2020).

In Next step, we would determine the sources of technical efficiency in OPEC countries. The rest of the paper is organized as follows: Next section overview the literature as well as present the research methodology and DEA-Malmquist. In section three, we analyze the empirical results related to DEA-Malmquist and panel GMM regressions for OPEC countries. Last section includes conclusion and recommendations.

LITERATURE REVIEW

Energy intensity is an important index that plays on a significant role in sustainable development. 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 infrastructures factors in any countries. One of main factor is the economic development and technological advancements. The process of economic growth and development is accompanied by widespread structural changes in the economy, technology and lifestyle of society that all influence the consumption behavior and productive structure of the country, resulting in changes in energy intensity (Kaldor, 1978; Lewis, 1980). Some Researchers confirms the relationship between economic growth and energy intensity is inverse U, so that energy consumption would 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 technology progress and its spillovers (Medlace and Soligo, 2001; Szirmai, 2011). Sun (2002) confirms that the main reason of declining energy intensity in OECD countries during 1971-98 was technological advancements. Lin and Du (2015) reveal that technological change has had a stronger impact on the energy intensity than other factors, so that contribute to declining energy intensity in China by 22.4% during 2003- 2010. Huang et al (2017) decomposed technical progress using DEA and found the 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. (2016) 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 the globalization in economic issues, the degree of economic openness (trade and financial) has been another factor affecting energy intensity. Major studies demonstrated that technical spillovers to industrializing countries from advanced economies are given a fillip by trade openness (Elliott et al, 2013; shahbaz et al, 2014; Adom & Amuakwa-Mensah, 2016). Adom (2015 a, b) indicates that energy intensity in Nigeria is significantly reduced by trade openness, and 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 (2012) investigate 22 developing economies' energy intensity, including Angola, Gambia, Namibia, Sudan, and Zambia, demonstrating reduced energy intensity from trade openness. Samarghandi (2019) 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 finding show that trade openness plays a key role in diminishing energy intensity and demonstrates that the innovation is insignificantly associated with energy intensity.

However, this question that what drive energy intensity decline in OPEC countries is important for economic researchers and policymakers, despite in, the studies are scare.

We use a Cobb-Douglas production function as follows:

$$Q = A\,K^{\propto}\,L^{\beta}\,E^{\gamma} \qquad (1)$$

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:

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

Where P_L, P_K, P_E, and P_M are defined as the prices of labor, capital, energy and raw materials, and also 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:

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

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 equation is extracted as follows:

$$EI = \frac{E}{Q} = \frac{\beta_E A^{-1}P_Q}{P_E} \qquad (4)$$

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

$$\ln(EI)_{it} = \beta_0 + \beta_1 \ln(\frac{\mathrm{P_E}}{\mathrm{P_Q}})_{\mathrm{it}} + \beta_2 \ln(TFP)_{it} + \beta_3 \ln(Induva)_{\mathrm{it}} + \varepsilon_{it} \qquad (5)$$

According to Huang et al (2017) and Lie et al (2013), 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 DEA approach and make the TFP decomposing into the technical progress change (TC) and the comprehensive technical efficiency (EC). Therefore, we get:

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

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

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

DEA-Malmquist

Given, DEA models can be used for estimating efficiency and productivity changes over period using Malmquist productivity index (MPI). Since the presentation of the first DEA models, different modifications from variety of aspects have been provided to strengthen the power of DEA (Wang and Lan, 2011; FarzipoorSaen et al, 2020). As above implied, we employed DEA-Malmquist approach to decomposed TFP (total factor productivity) changes into its components, including TC, PEC and SEC. 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.

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

Where $D(x,y)\leq 1$, if and only if point $(x,y)\epsilon S$; and $D(x,y)=1$, if and only if point (x,y) is in the production frontiers. The Malmquist index is defined as:

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

We have divided it into two functions, D^t and D^{t+1}, in time t and t+1. Thereby, E.q. 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 in time t. Fare and Grosskopf (1992) 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 as “frontier” technological progress and “following” technological progress, respectively (Zhao et al, 2013):

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

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

In above formulas: The Malmquist index 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 indicating 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 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 decline in production technology, and TC=1 means the technological progress remains unchanged.

According to 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 scale distance function. Thereby, the Malmquist index is expressed as E.q. (12):

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

By supposing of 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:

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

RESEARCH FINDING

In this section, we present the results of Panel GMM regression (Eq.7). Table 1 report the results of estimation (Eq.7).

The findings imply that in OPEC countries, technological progress and its components that enhance productivity, thereby they have significant effects to reduce energy intensity. Although, the effects are relatively weak. According the results, a percent increase of total factor productivity (TFP) causes to decrease energy intensity to 0.05 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 to decrease energy intensity to 0.08 and 0.02 percentages, respectively. Interestingly, the coefficient of technical change is much larger than of efficiency change, suggesting that the original technological progress rather than the following technological progress plays a more important role in reducing energy intensity in OPEC countries. 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 significantly negative, although, the estimated coefficients are weak. Some causes such as imperfect infrastructures and relatively lower level of technology and economic development in OPEC countries, induced to positive effects of technology progress on energy intensity is not be maximized.

$$\mathrm{SEC} = \frac{D_c^{t+1}(x^{t+1};y^{t+1})}{D_c^{t}(x^{t};y^{t})} \times \frac{D_v^{t}(x^{t};y^{t})}{D_v^{t+1}(x^{t+1};y^{t+1})} \qquad (14)$$

Table 1: The Results for Energy Intensity Changes in OPEC Countries

Variables	Model 1 (TFP)	Model 2 (TFP=TC*EC)	Model 3 (TFP=TC*PEC*SEC)
$ln(\mathrm{EI})_{-1}$	0.683 (12.40)	0.687 (10.54)	0.630 (8.24)
$ln(\mathrm{TFP})$	-0.053 (-2.41)		
$ln(TC)$		-0.087 (-2.07)	-0.051(-2.33)
$ln(EC)$		-0.026 (-1.95)	
$ln(PEC)$			-0.025 (-1.56)
$ln(SEC)$			-0.062 (-1.87)
$ln(PE/PQ)$	-0.078 (-2.83)	-0.078 (-2.80)	-0.082 (-2.74)
$ln(Induva)$	0.015 (1.80)	0.026 (1.48)	0.020 (2.13)
Sargan – p value	0.313	0.389	0.322

** Figures in parentheses are t- statistics*

Next, we investigate what is main driving of technological progress in OPEC countries. We examine whether innovation activities including internal research and development (R&D) and adoption of foreign technology (FDI) have differential effects on their technological efficiency. Likewise, we examine the role of trade openness on technological efficiency by considering this argument that trade openness enables firms to achieve high levels of efficiency through “learning-by-exporting-effects”.

Table 2 report the results of panel GMM estimations for TFP in OPEC countries. The findings imply that FDI inflows and trade openness causes to improve the productivity. Although, the estimated coefficient for trade openness is larger than FDI inflows, so that a percent of increases in FDI inflows and trade openness causes to enhance TFP to 0.032 and 0.143 percentages, respectively. Also, the effect of internal R&D is not significant. This result is reasonable because of the internal R&D is a risky and costly path-dependent process in comparison to 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.

Table 2: The Results for TFP Change in OPEC Countries

Variables	Coefficient	t-statistics
$ln(\text{TFP})_{-1}$	0.416	11.21
$\ln(TRADE)$	0.143	6.74
$ln(FDI)$	0.032	1.63
$ln(internal\ R\&D)$	0.0005	1.02
Sargan – p value	0.326	

CONCLUSION

The energy intensities of most energy exporting countries have historically been very high compared with energy importing and industrialized economies. Therefore, this question is still as an important argue that the factors that are driving the decline in energy intensity in exporting countries. Hence, this paper investigates the role of technology on driving factors of energy intensity changes in OPEC countries, using DEA-Malmquist during 2000-2017. In order to have a better understanding from technological progress, we employed DEA-Malmquist approach for each country to decompose TFP into the technical change (TC) and the efficiency change (EC). The result indicates that both technical and efficiency changes led to decrease the energy intensity. Interestingly, the negative effect of technical change on energy intensity is much larger than of the efficiency change effect, suggesting that the original technological progress rather than the following technological progress plays a more important role in reducing energy intensity in OPEC countries.

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 significantly negative, although, the estimated coefficients are relatively weak. Some causes such as imperfect infrastructures and relatively lower level of technology and economic development in most energy exporting countries, induced to positive effects of technology progress on energy intensity is not be maximized.

Next, we investigate what is main driving of technological progress in the OPEC countries. We examine whether innovation activities including internal research and development (R&D) and adoption of foreign technology (FDI) have differential effects on their technological efficiency. Likewise, we examine the role of trade openness on technological efficiency by considering this argument that trade openness enables firms to achieve high levels of efficiency through “learning-by-exporting-effects”. The findings imply that the FDI inflows and trade openness causes to improve the productivity, although, the estimated coefficient for trade openness is larger than FDI inflows. Also, the effect of internal R&D is not significant. This result is reasonable because of the internal R&D is a risky and costly path-dependent process in comparison to 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.

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, the estimated coefficients are relatively weak. In other words, domestic technological innovation plays a relatively weak role minimizing energy intensity, indicating that technological innovation remains underdeveloped in OPEC. However, the policy makers in energy exporting countries need to be aware of the fact that the technological progress and innovation is as powerful implements in reducing energy intensity. Hence, this study suggests that the governments should encourage the advanced technologies and management experiences. Moreover, it is important that policy makers focus on trade openness, because the trade openness facilitates competitiveness in domestic economies and local-economy access to developed-country technology, leading to a gain in energy efficiency.

Further studies based on larger sample of energy exporting countries with more comprehensive data may prove useful in substantiating our findings. Likewise, comparing of these finding (technology effect by considering its components) with a sample of energy importing countries, will make a valuable contribution of future studies, allowing more conclusive interpretation of findings.

REFERENCES

Adom, P. K. (2015a). "Asymmetric Impacts of the Determinants of Energy Intensity in Nigeria". *Energy Economics*, 49(C), 570-80.

Adom, P. K., and Amuakwa-Mensah, F. (2016). "What Drives the Energy Saving Role of FDI and Industrialization in East Africa?" *Renewable and Sustainable Energy Review*, 65(C), 925-42.

Arellano, M. and Bond, S. (1991), "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations", *Review of Economic Studies*, 58, 277-297.

Arellano, M., and Bover, O. (1995), "Another Look at the Instrumental Variable Estimation of Error-Components Models". *Journal of Econometrics*, 68 (1), 29–51.

Baltagi, B. H. (2005), *Econometric Analysis of Panel Data*, third ed, John Wiley and Sons Press.

Barasa, L., Vermeulen, P., Knoben, J., Kinyanjui, B. and Kimuyu, P. (2019), "Innovation Inputs and Efficiency: Manufacturing Firms in Sub-Saharan Africa", *European Journal of Innovation Management*, 22, 59-83.

Blundell, R., and Bond, S. (1998), "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models". *Journal of Econometrics*, 87(1), 115–143.

Blundell, R., and Bond, S. (2000),"GMM Estimation with Persistent Panel Data: Application to Production Functions, Econometric Reviews," *Taylor and Francis Journals*, 19(3), 321-340.

Elliott, R. J. R. Sun, P. Y., and Chen, S. Y. (2013). "Energy Intensity and Foreign Direct Investment: A Chinese City-Level Study". *Energy Economics*, 40(C), 484-94.

Farzipoor Saen, R., Moghaddas, Z., Vaez-Ghesemi, M., and Hosseinzadeh Lotfi, F., (2020), "Stepwise Pricing in Evaluating Revenue Efficiency in Data Envelopment Analysis: Case Study in Power Plants". *Scientia Iranica, doi /10.24200/sci.2020.55350.4184*

Fisher-Vanden, K., Jefferson, G. H., Liu, H. and Tao, Q., (2004), "What is Driving China's Decline in Energy Intensity?" *Resource and Energy Economics*, 26(1), 77-97

Fu, X., and Gong, Y. (2011), "Indigenous and Foreign Innovation Efforts and Drivers of Technological Upgrading: Evidence from China". *World Development*, 39 ,1213-1225

Fu, X., Pietrobelli, C., and Soete, L. (2011), "The Role of Foreign Technology and Indigenous Innovation in the Emerging Economies: Technological Change and Catching-up". *World Development*, 39, 1204-1212

Galli, R. (1998). "The Relationship between Energy Intensity and Income Levels: Forecasting Long Term Energy Demand in Asian Emerging Countries", *The Energy Journal, 19 (4), 85-105.*

Gillingham, K. , Rapson, D., and Wagner, G. (2016), "The rebound effect and energy efficiency policy" *Review of Environmental Economics and Policy* ,10 (1), 68-88

Hosseinzadeh Lotfi, F., Ebrahimnejad, A., Vaez-Ghasemi, M., and Moghaddas, Z. (2020), "*Data Envelopment Analysis with R*" Springer International Publishing.

Huang, J., Du, D. and Hao, Y., (2017). "The Driving Forces of the Change in China Energy Intensity: Empirical Research Using DEA-Malmquist and Spatial Panel Estimations", *Economic Modelling*, 65(C),41-50.

Huang, J., Hao, Y., and Lei, H. (2018). "Indigenous Versus Foreign Innovation and Energy Intensity in China". *Renewable and Sustainable Energy Reviews*, 81(P2), 1721-1729.

Im, K. S., Pesaran, M. H. and Shin, Y. (2003). "Testing for Unit Roots in Heterogeneous Panels". *Journal of Econometrics*, 115(1), 53-74.

Kaldor, N. (1978), *Further Essays on Economic Theory*, London, Duckworth.

Kishi, K. and Okada, K. (2021), "The impact of trade liberalization on productivity distribution under the presence of technology diffusion and innovation", *Journal of International Economics*, 128(C).

Lewis, W. A. (1980), "the Slowing Down of the Engine of Growth". *American Economic Review*, 70(4), 64-555.

Medlock, K. and Soligo, R. (2001), "Economic Development and End-Use Energy Demand", *The Energy Journal*, 22(2), 77–105. 7

Roodmn, D. (2009), "How to do xtabond2: An introduction to difference and system GMM in Stata", *The Stata Journal, 9(1),86-136*

Samargandi, N. (2019). "Energy Intensity and its Determinants in OPEC Countries", *Energy*, 186, Article 115803

Shahbaz, M., Nasreen, S., Ling, C. H. and Sbia, R. (2014), "Causality between Trade Openness and Energy Consumption: What Causes what in High, Middle and Low Income Countries". *Energy Policy*, 70, 126-143

Sun, J.W., and Ang, B.W., (2000). "Some Properties of an Exact Energy Decomposition Model". *Energy*, 25 (12), 1177–1188.

Tarek Atalla, T. and Bean, P. (2017). "Determinants of Energy Productivity in 39 Countries: An Empirical Investigation", *Energy Economics*, 62, 217–229

Wooldridge, J. M. (2002), *Econometric Analysis of Cross-Section and Panel Data*, MIT Press, Cambridge Massachusetts

Wang, Y. M., and Lan, Y. X., (2011). "Measuring Malmquist Productivity Index: a New Approach Based on Double Frontiers Data Envelopment Analysis", *Mathematical and Computer Modelling*, 54, 2760–2771