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Energy Economics

# Do Renewable and Non-Renewable Energy Have Asymmetric Impacts on Total Factor Productivity Growth? Evidence From 17 Asia-Pacific Countries

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This paper examines the asymmetric impacts of renewable energy intensity (REI) and non-renewable energy intensity (NREI) on total factor productivity (TFP) growth in 17 Asia-Pacific countries during 1990–2018. The results reveal that REI positively impacts TFP growth in the long run, while NREI harms TFP growth in the short run. However, the study finds NREI has an asymmetric impact on TFP growth. This study suggests intensifying renewable energy usage in the production process to achieve sustainable growth.

## I. INTRODUCTION

Total factor productivity (TFP) growth has been considered the engine of economic growth (Afridi & Farooq, 2019). It is defined as the growth in output that is not accounted for by input. It can be measured through two approaches: a frontier approach and a non-frontier approach (Mahadevan, 2003). TFP growth is crucial for sustained output growth, since input-induced growth is subject to diminishing returns and is insufficient for producing more output in the long run. Solow's (1956) growth model shows that the probable reason for cross-country differences in per capita income could be the difference in TFP growth.

The Asia-Pacific countries, including South Korea and Singapore (considered advanced countries), have been experiencing low TFP growth over the past decades due to the global financial crisis of 2008 (Felix et al., 2020). The TFP growth of Asia-Pacific countries was -1% in 2016, while it was 0.5% in 2010 (International Monetary Fund, 2017). These countries have growing energy demand, but lack productivity growth (*BP Statistical Review of World Energy*, 2021). Thus, it is essential to examine the dynamics between different types of energy consumption and TFP growth in the Asia-Pacific countries.

After the Kyoto Protocol, many countries concentrated on increasing the share of renewable energy in the energy basket to reduce greenhouse gas emissions. In this context, many studies in energy economics have focused on investigating the linear and nonlinear impacts of renewable energy consumption (REC) and non-renewable energy consumption (NREC) on economic growth across different countries/regions and periods (Apergis & Payne, 2011; Iyke, 2015; Jafri et al., 2021; Shastri et al., 2020; Zafar et al., 2019). However, the number of studies exploring the impact of disaggregated energy consumption on TFP growth is meager. For instance, Tugcu (2013) reported for the Turkish economy that REC positively impacted TFP growth, while nuclear and fossil fuel energy consumption negatively affected TFP growth. For BRICS countries, Tugcu and Tiwari (2016) found bidirectional causality for NREC and TFP growth, but no noticeable causality between REC and TFP growth. In a study of 36 countries, Rath et al. (2019) documented that renewable energy enhanced TFP growth, whereas fossil fuel energy consumption reduced it.

To the best of the authors' knowledge, none of the previous studies on the nexus between disaggregated energy consumption and TFP growth have examined the asymmetric impacts of REC and NREC on TFP growth. Moreover, while previous studies used REC and NREC as key explanatory variables, we instead use renewable energy intensity (REI) and non-renewable energy intensity (NREI). The justification behind this approach is that, as the economy grows, energy usage must increase, but the issues are how intensely the economy uses energy and which sources are used with greater intensity. The objective of this study is to explore both the long- and short-run asymmetric im-

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pacts of REI and NREI on TFP growth in 17 Asia-Pacific countries[1] using a multivariate framework. In this study, we use the nonlinear autoregressive distributed lag (NARDL) model introduced by Shin et al. (2014). We also use foreign direct investment (FDI), trade openness (TO), and carbon emissions ($CO_2$) as control variables (Isaksson, 2007; Kalaitzidakis et al., 2007).

This study finds that REI has a positive impact on TFP growth in the long run, whereas NREI has a negative effect on it in the short run. However, positive and negative shocks of NREI have asymmetric impacts on TFP growth in both the long and short run.

The remainder of the paper is organized as follows. Section II presents the data sources and methodology. The empirical results are discussed in Section III. Section IV draws a conclusion and makes policy implications.

## II. DATA AND METHODOLOGY

### A. Variable Description and Data

The study uses panel data from 1990 to 2018 for 17 Asia-Pacific countries. The dependent variable of our model, TFP growth, is constructed as the logarithmic difference of TFP between two subsequent years. The two key explanatory variables, REI and NREI, are formed as the ratio of energy consumption to the real gross domestic product (GDP). The data for TFP and the real GDP (measured in millions of constant 2011 US dollars) are collected from the Penn World Table (version 10.0). The data for REC and NREC (measured in quadrillions of British thermal units) and $CO_2$ emissions (measured in millions of metric tons) are collected from the U.S. Energy Information Association (EIA). The FDI data (as a percentage of the GDP) are obtained from UNCTAD, and the TO data, measured as the sum of imports and exports (as a percentage of the GDP), are obtained from the World Development Indicators.

### B. Methods

Following Rath et al. (2019), we express the relations between *NREI*, *REI*, *FDI*, *TO*, $CO_2$, and TFP growth (*TFPG*) in the following functional form:

$$\begin{aligned}\mathrm{TFPG_{it}} &= \alpha_0 + \alpha_1 \mathrm{lnNREI_{it}} + \alpha_2 \mathrm{lnREI_{it}} \\ &+ \alpha_3 \mathrm{lnFDI_{it}} + \alpha_4 \mathrm{lnTO_{it}} + \alpha_5 \mathrm{lnCO_{2it}} \\ &+ \epsilon_{\mathrm{it}}\end{aligned} \tag{1}$$

where $\epsilon_{\mathrm{it}}$ is the disturbance term.

The NARDL representation of our model is as follows:

$$\begin{aligned}\Delta TFPG_{\mathrm{it}} &= \alpha_0 + \tau \mathrm{TFPG}_{it-1} + \theta_1^{+} \mathrm{lnNREI}_{it-1}^{+} \\ &+ \theta_2^{-} \mathrm{lnNREI}_{it-1}^{+} + \theta_3^{+} \mathrm{lnREI}_{it-1}^{+} + \theta_4^{-} \mathrm{lnREI}_{it-1}^{-} \\ &+ \theta_5 \mathrm{lnFDI}_{it-1} + \theta_6 \mathrm{lnTO}_{it-1} \\ &+ \theta_7 lnCO_{2it-1} + \sum_{j=1}^{p-1} \pi_j \Delta TFPG_{it-j} \\ &+ \sum_{j=0}^{q-1} ({\varphi_1}^{+} \Delta lnNREI_{it-j}{}^{+} + {\varphi_2}^{-} \Delta lnNREI_{it-j}{}^{-}) \\ &+ \sum_{j=0}^{q-1} ({\varphi_3}^{+} \Delta lnREI_{it-j}{}^{+} + {\varphi_4}^{-} \Delta lnREI_{it-j}{}^{-}) \\ &+ \sum_{j=0}^{q-1} \varphi_5 \Delta lnFDI_{it-j} + \sum_{j=0}^{q-1} \varphi_6 \Delta lnTO_{it-j} \\ &+ \sum_{j=0}^{q-1} \varphi_7 \Delta lnCO_{2it-j} + \mu_{\mathrm{it}}\end{aligned} \tag{2}$$

where $\mathrm{lnNREI}_{\mathrm{it}}^{+}$ and $\mathrm{lnNREI}_{\mathrm{it}}^{-}$ represents the partial sum decomposition of positive and negative changes in $\mathrm{lnNREI}_{\mathrm{it}}$, while $\mathrm{lnREI}_{\mathrm{it}}^{+}$ and $\mathrm{lnREI}_{\mathrm{it}}^{-}$ are the same for $\mathrm{lnREI}_{\mathrm{it}}$. Moreover, the φ terms are the short-run coefficients, and the long-run coefficients can be calculated as $\lambda' = \frac{\theta'}{\tau}$. To test the asymmetric impacts of *REI* and *NREI* on *TFPG*, the Wald test is employed.

## III. RESULTS AND DISCUSSION

This study finds the presence of slope heterogeneity and cross-sectional dependence in the variables studied.[2] First-generation unit root tests (Breitung, 2001; Im et al., 2003; Levin et al., 2002; Maddala & Wu, 1999) and second-generation unit root tests (Pesaran, 2007) are employed to check the order of integration of the variables. Table 1 shows the results of the unit root tests (both first and second generation).

Table 1 shows that the variables are integrated in mixed order, that is, I(0) or I(1). This is why the panel NARDL model is used in this study, since it allows one to estimate whether the variables are I(0) or I(1) (but not I(2)) and to test for asymmetry in both the short and long run.

Table 2 reports the results of the NARDL estimation and shows that, in the long run, a positive shock in REI increases TFP growth, whereas a negative shock in REI decreases TFP growth. On the other hand, a positive shock in NREI raises TFP growth in the short run, while a negative shock reduces it. So, the empirical results reveal that renewable energy positively impacts TFP growth (in the long run) and non-renewable energy negatively affects TFP growth (in the short run), which is along the same lines as the findings of Tugcu (2013) and Rath et al. (2019). In addition, FDI hampers TFP growth in the long run. This finding contradicts the finding of Rath et al. (2019), but is supported by Binh et al. (2014), who stated that, if FDI con-

1 Australia, China, Fiji, Hong Kong, India, Indonesia, Japan, Macao, Malaysia, Mongolia, New Zealand, Philippines, Russia, Singapore, South Korea, Sri Lanka, and Thailand. The countries are selected on the basis of availability of data.

2 The results are not provided in this paper to conserve of space, but they are available from the authors upon request.

**Table 1. Panel unit root tests results**

| Variables | Levin, Lin & Chin t* (LLC) (Constant& Trend) | | Breitung (Constant& Trend) | | Im-Pesaran-Shin (IPS) (Constant& Trend) | | Fisher ADF Chi-Squared (Constant& Trend) | | CIPS (Constant& Trend) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | I(0) | I(1) | I(0) | I(1) | I(0) | I(1) | I(0) | I(1) | I(0) | I(1) |
| *TFPG* | -7.119*** | | -8.994*** | | -10.9328*** | | 320.940*** | | -4.552*** | |
| *lnNREI* | -0.587 | -5.761*** | 1.406 | -7.6369*** | -2.1298 | -10.9934*** | 34.317 | 98.620*** | -2.212 | -4.808*** |
| *lnREI* | -1.595* | | -0.290 | -10.391*** | -4.0483*** | | 21.804 | 126.335*** | -3.091** | |
| *lnFDI* | -5.683*** | | -5.139*** | | -7.9774*** | | 99.370*** | | -3.696** | |
| *lnTO* | -2.135** | | 0.279 | -11.542*** | -3.3532*** | | 29.305 | 81.869*** | -2.871** | |
| $lnCO_2$ | -2.986*** | | 2.965 | -8.704*** | -1.4962 | -11.4108*** | 35.979 | 59.767*** | -2.416 | -4.688*** |

This table reports the results of panel unit root tests. *, **, and *** represent the significance level at 10%, 5%, and 1% respectively. The values in the parentheses represent standard errors. ADF denotes Augmented Dickey-Fuller, while CIPS denotes Cross-sectional Augmented IPS.

**Table 2. Results of NARDL model**

| Variables | Coefficients | | | |
|---|---|---|---|---|
| Long run | | | | |
| *poslnNREI* | 0.733 (0.499) | | | |
| *neglnNREI* | 0.777 (0.501) | | | |
| *poslnREI* | 1.147*** (0.301) | | | |
| *neglnREI* | 1.185*** (0.310) | | | |
| *lnFDI* | -2.421** (1.031) | | | |
| *lnTO* | 0.401 (0.275) | | | |
| *lnCO$_2$* | 0.801*** (0.307) | | | |
| Short-run | | | | |
| *ECT* | -0.942*** (0.078) | | | |
| *D.poslnNREI* | -39.18*** (5.836) | | | |
| *D.neglnNREI* | -39.20*** (5.844) | | | |
| *D.poslnREI* | 0.422 (1.483) | | | |
| *D.neglnREI* | 0.507 (1.493) | | | |
| *D.lnFDI* | 7.164 (6.363) | | | |
| *D.lnTO* | 1.632 (1.556) | | | |
| *D.lnCO$_2$* | 32.35*** (5.208) | | | |
| *Constant* | -9.090*** (0.822) | | | |
| Diagnostics test | Log Likelihood = -845.1183 | | | |
| Long-run and short-run asymmetric test (Wald test) | | | | |
| Variables | Long run | | Short run | |
| | $\chi^2$ | Prob. | $\chi^2$ | Prob. |
| *NREI* | 9.54 | 0.002 | 8.19 | 0.004 |
| *REI* | 0.09 | 0.765 | 0.000 | 0.948 |

This table shows the results of the NARDL model. *, **, and *** represent the significance level at 10%, 5%, and 1% respectively. The values in the parentheses represent standard errors.

centrates more on natural resource extraction than manufacturing, it will tend to reduce TFP growth. On the other hand, $CO_2$ emissions positively affect TFP growth in both the long and short run, which is consistent with the finding of Kalaitzidakis et al. (2007). Due to concerns about growing emissions and their negative impact on the environment, countries are introducing new cleaner technology, which in turn is boosting TFP growth.

Lastly, the statistical significance of the error correction term (ECT) confirms the asymmetric long-run relation between the concerned variables. However, Wald test results reveal that NREI asymmetrically impacts TFP growth, while REI symmetrically impacts TFP growth in both the long and short run.

## IV. CONCLUSION AND POLICY SUGGESTIONS

This study aims to investigate the asymmetric impact of renewable and non-renewable energy on TFP growth throughout 1990–2018 for 17 Asia-Pacific countries. It concludes that. in the long run, an increase (decrease) in REI leads to a rise (fall) in TFP growth, whereas an increase (decrease) in NREI depresses (expands) TFP growth in the short run. Moreover, FDI negatively affects TFP growth in the long run, while $CO_2$ emissions positively impact TFP growth in both the long and short run. The result of the Wald test confirms the asymmetric linkage between only NREI and TFP growth.

In view of these findings, this study's policy implication is that, to achieve sustained TFP growth as well as economic growth, the Asia-Pacific countries need to focus on using renewable energy sources more intensely, which, in turn, will help to reach the goal of reducing carbon emissions and achieving sustainable development.

## References


Afridi, M. A., & Farooq, S. (2019). Determinant of productivity growth: Evidence from emerging Asian countries. *Central Asia*, *85*(Winter), 119–131. https://doi.org/10.54418/ca-85.14

Apergis, N., & Payne, J. E. (2011). Renewable and non-renewable electricity consumption–growth nexus: Evidence from emerging market economies. *Applied Energy*, *88*(12), 5226–5230. https://doi.org/10.1016/j.apenergy.2011.06.041

Binh, Q. M. Q., Hoai, N. T., & Van, P. H. (2014). Bad FDI? Resource extraction and technology transfer.

*BP Statistical Review of World Energy*. (2021). https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf

Breitung, J. (2001). The local power of some unit root tests for panel data. In B. H. Baltagi, T. B. Fomby, & R. Carter Hill (Eds.), *Nonstationary Panels, Panel Cointegration, and Dynamic Panels (Advances in Econometrics, Vol. 15)* (pp. 161–177). Emerald Group Publishing Limited. https://doi.org/10.1016/s0731-9053(00)15006-6

Felix, N. S. M. S., Abdullah, M. A., & Hui, J. K. S. (2020). Assessing the productivity of countries in the Asia Pacific. *International Journal of Academic Research in Business and Social Sciences*, *10*(7), 245–264. https://doi.org/10.6007/ijarbss/v10-i7/7413

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74. https://doi.org/10.1016/s0304-4076(03)00092-7

International Monetary Fund. (2017). https://blogs.imf.org/2017/04/03/chart-of-the-week-slowing-productivity-why-it-matters-and-what-to-do/

Isaksson, A. (2007). *Determinants of total factor productivity: A literature review*. Research and Statistics Branch, UNIDO.

Iyke, B. N. (2015). Electricity consumption and economic growth in Nigeria: A revisit of the energy-growth debate. *Energy Economics*, *51*, 166–176. https://doi.org/10.1016/j.eneco.2015.05.024

Jafri, M. A. H., Liu, H., Usman, A., & Khan, Q. R. (2021). Re-evaluating the asymmetric conventional energy and renewable energy consumption-economic growth nexus for Pakistan. *Environmental Science and Pollution Research*, *28*(28), 37435–37447. https://doi.org/10.1007/s11356-021-13131-1

Kalaitzidakis, P., Mamuneas, T. P., & Stengos, T. (2007). *The contribution of greenhouse pollution to productivity growth*. University of Guelph, Department of Economics.

Levin, A., Lin, C.-F., & James Chu, C.-S. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, *108*(1), 1–24. https://doi.org/10.1016/s0304-4076(01)00098-7

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 631–652. https://doi.org/10.1111/1468-0084.0610s1631

Mahadevan, R. (2003). To measure or not to measure total factor productivity growth? *Oxford Development Studies*, *31*(3), 365–378. https://doi.org/10.1080/1360081032000111742

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*, 265–312. https://doi.org/10.1002/jae

Rath, B. N., Akram, V., Bal, D. P., & Mahalik, M. K. (2019). Do fossil fuel and renewable energy consumption affect total factor productivity growth? Evidence from cross-country data with policy insights. *Energy Policy*, *127*, 186–199. https://doi.org/10.1016/j.enpol.2018.12.014

Shastri, S., Mohapatra, G., & Giri, A. K. (2020). Economic growth, renewable and nonrenewable energy consumption nexus in India: Evidences from nonlinear ARDL approach and asymmetric causality analysis. *International Journal of Energy Sector Management*, *14*(4), 777–792. https://doi.org/10.1108/ijesm-06-2019-0016

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in Honor of Peter Schmidt* (pp. 281–314). Springer. https://doi.org/10.1007/978-1-4899-8008-3_9

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, *70*(1), 65. https://doi.org/10.2307/1884513

Tugcu, C. T. (2013). Disaggregate energy consumption and total factor productivity: A cointegration and causality analysis for the Turkish economy. *International Journal of Energy Economics and Policy*, *3*(3), 307–314.

Tugcu, C. T., & Tiwari, A. K. (2016). Does renewable and/or non-renewable energy consumption matter for total factor productivity (TFP) growth? Evidence from the BRICS. *Renewable and Sustainable Energy Reviews*, *65*, 610–616. https://doi.org/10.1016/j.rser.2016.07.016

Zafar, M. W., Shahbaz, M., Hou, F., & Sinha, A. (2019). From nonrenewable to renewable energy and its impact on economic growth: The role of research & development expenditures in Asia-Pacific Economic Cooperation countries. *Journal of Cleaner Production*, *212*, 1166–1178. https://doi.org/10.1016/j.jclepro.2018.12.081