



Research article

Income and energy consumption in Asia-Pacific countries – A panel cointegration analysis enhanced with common factors

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ABSTRACT

The research presented in this paper re-examines the relationship between energy consumption and income for a panel of Asian economies for the period 1971–2018. The Asian economies represent a dynamic, diverse, and interesting set of countries on which to base an examination of these relationships and the tendencies for these economies to be on a path of convergence and integration in their energy consumption and use characteristics. Our convergence analysis provides evidence of convergence in energy intensity among the countries. Panel data methodologies are employed to gain the advantage of increased explanatory power of the econometric analysis. Importantly, we incorporate common factors as a means of accounting for variables beyond the bivariate relationship. The results find support for the flow of causality running from income to energy consumption, albeit with short-run feedback. As a result, current policies aimed at reducing energy intensity and CO₂ emissions are not expected to significantly inhibit economic growth. The results are consistent with the seminal paper by Kraft and Kraft (1978). Additionally, we find the long-run income elasticity estimates for the panel double in size when unobserved common factors are excluded.

1. Introduction

This paper investigates the relationship between energy consumption and GDP with a focus on Asia-Pacific economies over the last four decades. We study twenty Asia-Pacific countries including Australia, Bangladesh, People's Republic of China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Nepal, New Zealand, Pakistan, Singapore, Chinese Taipei, Thailand, Vietnam, Philippines, Myanmar, Democratic People's Republic of Korea, Brunei Darussalam. We believe these economies represent a dynamic, diverse, and interesting set of countries on which to base an examination of the evolution of these relationships. They exhibit a wide range of growth patterns in both energy consumption and gross domestic products (GDP), and due to this variety, they may provide useful insights for policy makers well beyond the region.

There is a long thread of research reaching back to the seminal paper by Kraft and Kraft (1978) that addresses various aspects of the questions around the relationship between economic activity and energy consumption (EY nexus thereafter), as our literature review in section 2 sets out. What our paper aims to do, however, is to reduce the gaps in this research by employing state-of-the-art panel cointegration

methodologies that account for unobserved common factors. The results provide useful insights into the relationships and provide further support for the original Kraft and Kraft findings of causality running primarily from income to energy consumption. Our results also highlight the potential importance of specifically modeling common factors in the analysis of the EY nexus. To support our inclusion of unobserved common factors in the modeling of the panel of Asian countries, we perform convergence tests to the energy intensity and share of electricity consumption in total final energy consumption across the countries as a precursor.

The policy relevance of these myriad empirical studies of the relationship between energy consumption (in its various forms) and income (also measured over a range of variable and data specifications) has evolved to some extent since the work of Kraft and Kraft (1978). The original Kraft and Kraft (1978) motivation was to evaluate and assess the potential for negative impacts on economic growth from the then relatively new focus in the US on energy conservation. The conservation drive in the US was the result of concerns over crude oil supply disruptions that followed the OPEC oil embargo in 1973–1974. The many studies that have followed were motivated by both efforts to correct

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perceived and real methodological errors and to address the ongoing evolution of the crude oil market that saw prices pushed higher in relation to the OPEC oil embargo and the Iran-Iraq war from the mid-1970s to the early 1980s and the rapid growth of several Asian economies in the 2000s; the first being a supply disruption and the second a demand disruption, but both were primarily concerned with oil supply sufficiency.

The fundamental concern was whether or not an attempt to systematically reduce energy consumption through conservation measures would have a negative effect on economic growth (Kraft and Kraft, 1978). Thus, the approaches were focused on estimating the direction of causality between two basic, but key, variables: energy consumption and income. The policy concern was if energy consumption “caused” income then policies emphasizing conservation would be expected to hinder economic growth. And if this were the case, policy development and implementation would be much trickier. Toward the end of the 20th Century and early 21st Century, the focus of concern evolved to be on what impact there may be on economic growth from policies aimed at reducing CO₂ emissions linked to concerns related to global climate change. There was much less concern over supply during this period. However, from around 2005, the concern once again refocused on the role of supplies. This time it was due not to embargoes from, or wars within, the primary OPEC producing countries and regions, but rather from significant, un-forecasted demand for crude oil and all forms of primary energy from China and India and other rapidly growing developing economies; a good many of them being in Asia (Li and Lin, 2011).

The effect of such demand on energy prices across the world re-sparked discussions around peak oil concerns, and once again drove interest in a drive for conservation through advances in energy efficiency and behavioral adjustments. So, from roughly 2005 to present, there was once again concern that policies aimed at conservation and at CO₂ emissions reduction, primarily through reductions in fossil fuel use, could have the unintended consequence of stunting economic growth in both the developed and developing economies. Indeed, rightly or wrongly, the US Trump Administration supported its announced withdrawal from the Paris agreement on the grounds that the required emissions reductions were too restrictive, would put the US at competitive disadvantage, and stunt US domestic economic growth.

Peak oil concerns have abated due to the technological advances being employed in the US with the combination of two old technologies (horizontal drilling and hydraulic fracturing), but there are still concerns regarding climate change and the linked desire to reduce the consumption of primary fossil fuels (Abrahamse and Shwom, 2018). The aim to abate climate change through reduced energy consumption, or to at least slow the process through reduced energy intensity, means that the earlier concerns that set this thread of research in motion over 40 years ago still exist. The analyses that follow in this paper aim to improve upon the methodologies applied to this policy issue while focusing on the fastest growing energy consumption region in the world and over a longer time horizon.

In a first step, we evaluate the evolution of energy intensity and the share of electricity in the total final consumption using convergence tests developed by Phillips and Sul (2007). Their test is based on a simple regression-based convergence test and a new method of clustering panels into club convergence groups. We find that the countries included in our panel do show convergence over the period under study for key energy sector variables.

In a second step, we employ panel data methodologies to test for causality between income and energy consumption. We distinguish between long-run and short-run causality. We are mindful that long-run relationships such as cointegration might only be present for some of the countries and use panel unit root tests and panel cointegration tests which reveal the countries for which unit roots and cointegration are detected (Westerlund et al., 2014; Smeekes, 2015). Importantly, we incorporate common factors as a means of accounting for variables beyond the bivariate relationship. The results find support for the flow of

causality running from income to energy consumption, albeit with short-run feedback. Additionally, we find the long-run income elasticity estimates for the panel double in size when unobserved common factors are excluded.

Section 2 presents a brief literature review on the relationship between energy consumption and income. Methods used in this paper are described in section 3 and the results are reported in section 4. Section 5 provides a discussion and conclusion for the paper.

2. Literature review

2.1. The EY nexus

Studies in the EY nexus area can roughly be differentiated by (i) the choice of geographic coverage, (ii) the choice of variables, and (iii) the choice of econometric techniques. Payne (2010) and Ozturk (2010) provide extensive surveys of the literature up to the year 2009, followed by more up-to-date surveys by Omri (2014), Isa et al. (2015) and Waheed et al. (2019). Waheed et al. (2019) note that for countries having strong economic growth (e.g., China, Malaysia, etc.), there tends to be a uni-directional relationship from economic growth to energy consumption. However, the causal directions are generally mixed for developed countries. As this paper uses panel data econometric techniques, this literature review will place a stronger emphasis on panel data studies.

As noted by Payne (2010), partly because of the availability of reliable data, the majority of the studies in the literature have focused on industrialized and developed countries. However, the empirical literature has expanded beyond the industrialized economies in terms of country/regional coverage since then, possibly because of the importance and policy relevance of the energy-economy relationship in developing countries. For example, the EY nexus is examined for the Economic Community of West African States (Ouedraogo, 2013), Liberia (Wesseh and Zoumara, 2012), Pakistan (Shahbaz et al., 2012; Mirza and Kanwal, 2017), Lebanon (Dagher and Yacoubian, 2012), Greece (Dergiades et al., 2013), Tunisia (Jebli and Youssef, 2017) and South Africa (Bekun et al., 2019). There are also studies that analyze and compare results across different country groups. For instance, Joyeux and Ripplé (2007, 2011) employ panel data techniques to analyze the influence of energy consumption on standard of living for 7 East Indian Ocean countries, and the causal relations between income and three energy consumption series for 30 OECD and 26 non-OECD countries, respectively.

Within the multivariate modeling framework, researchers have tried to include new variables in their model to circumvent possible problems associated with omitted variables in their analysis. For instance, Nasreen and Anwar (2014) include trade openness in their study using data of 15 Asian countries and found bi-directional causality between economic growth, energy consumption, and trade openness. Omri and Kahouli (2014) augment the classical growth model by incorporating foreign direct investment and energy consumption to investigate the interaction among foreign direct investment, energy consumption, and economic growth for 65 countries classified into high-, middle-, and low-income groups. More recently, research on this thread continued to grow and studies have included the role of institution, government expenditure and trade openness (Saidi et al., 2020; Le, 2020; Le and Van, 2020). Bi-directional causality is generally found in these latter studies.

In the earlier studies, the econometric approaches employed include (i) the Granger-Sims causality tests as pioneered by Granger (1969) and Sims (1972), (ii) the Engle-Granger/Johansen-Juselius cointegration analysis based on Engle and Granger (1987) and Johansen and Juselius (1990), (iii) the Autoregressive Distributed Lag model (ARDL) and Toda-Yamamoto causality tests set forth by Pesaran et al. (2001) and Toda and Yamamoto (1995), and (iv) the panel cointegration analysis advanced by Pedroni (1999, 2004). Empirical studies have continued to adopt different econometric techniques to examine (or re-examine) the EY nexus in various contexts. In time-series studies, Ajmi et al. (2013)

employed two nonlinear causality tests to examine the energy-growth relationship for the G7 countries and found mixed results both across countries and tests. [Yildirim et al. \(2014\)](#) estimate a trivariate model consisting of GDP per capita, energy consumption per capita and gross capital formation for the Next 11 countries and test for causality amongst these variables using the bootstrapped autoregressive metric approach. [Bozoklu and Yilanci \(2013\)](#) re-examine the energy-growth relationship by comparing the causality results for 20 OECD countries in the frequency domain (high-2.5 years; low-12.5 years). [Araç and Hasanov \(2014\)](#) explore the potential asymmetries in the dynamic relationship between energy consumption and economic growth for Turkey. On the other hand, studies adopting panel data have placed more emphasis on testing and mitigating the impacts of cross-sectional dependence. Recent examples of studies taking this approach include [Chen et al. \(2016\)](#), [Le and Quah \(2018\)](#), [Le \(2020\)](#), [Le and Van \(2020\)](#) and [Cheng et al. \(2021\)](#). These studies commonly applied panel unit root tests (e.g. [Pesaran, 2007](#)), cointegration tests (e.g. [Westerglund, 2007](#)) and estimators (e.g. [Eberhardt and Bond, 2009](#)) that can accommodate cross-sectional dependence.

The research in the present paper extends and enhances the overall thread of the past and recent research by incorporating common factors to the panel cointegration methodologies to account for the influence of unobserved variables not captured in the bi-variate analyses. The appropriateness of using common factors in our study is established by applying convergence analysis methodology to the evolution of both the energy intensity (measured in total final energy consumption per dollar of gross domestic product) for the countries across the region of our study and separately for the share of electricity (measured in gigawatt hours (GWh)) in total final consumption. Having shown the relative convergence of these key energy variables for our diverse and dynamic set of countries, we then proceed with the application of common factors methodology to our panel estimations.

2.2. Economic convergence

Following the founding work of [Solow \(1956\)](#), the concept of economic convergence has gained significant attention in empirical research, with pioneering studies like [Mankiw et al. \(1992\)](#), [Islam \(2003\)](#), [Durlauf and Johnson \(1995\)](#) and [Caselli et al. \(1996\)](#).¹ As noted by [Ulucak and Apergis \(2018\)](#), the convergence hypothesis has been examined widely in areas such as education, health, military, tourism, foreign trade, energy, and environment. Convergence of economic variables means that the influence of transitory shocks on an equilibrium system decreases over time, and the effects of these shocks are eliminated when the system is stable ([Kong et al., 2019](#)). In other words, variables move towards their steady-state equilibrium at a decreasing rate ([Erdoğan and Okumus, 2021](#)).

Some commonly adopted measures of convergence are (i) beta convergence, (ii) sigma convergence, and (iii) stochastic convergence. Beta convergence takes place when the growth rate of an economic variable is negatively correlated with its initial level, while sigma convergence focuses on cross-sectional variation across time series and whether it diminishes over time ([Barro and Sala-i-Martin, 1991](#)). Stochastic convergence concerns the effects of random shocks on the data series. When the effects of temporary shocks dissipate over time (i.e. the data series does not contain unit root), the series are said to converge stochastically ([List, 1999](#)). The concept of beta convergence can be augmented by variables that control for different initial conditions and dynamics in the economic time-series, leading to the notion of conditional convergence. While each individual time-series approaches a steady-state equilibrium under conditional convergence, these time-series can be grouped by common characteristics, with each group

¹ We would like to thank an anonymous reviewer who provided numerous useful references that helped enrich this part of the literature review.

approaching the same steady-state equilibrium ([Durlauf and Johnson, 1995](#)). This type of convergent behavior is later referred to as club convergence.

[Phillips and Sul \(2007\)](#) (PS hereafter) developed an econometric regression test of convergence that allows for a wide range of time paths and individual heterogeneity. Two series are said to converge when the ratio of them converges to unity. [Phillips and Sul \(2007\)](#) also proposed an algorithm for clustering individuals into convergence clubs. The PS approach has received increasing attention in the energy economics literature, and it has been applied to study the convergence of energy intensity and energy consumption. As noted by [Herrerias and Liu \(2013\)](#), convergence of energy intensity can imply diffusion of technologies and diminishing technological differences across regions. [Herrerias and Liu \(2013\)](#) examine electricity-intensity across Chinese provinces and find convergence within groups of regions. Following the line of [Herrerias and Liu \(2013\)](#), [Zhang and Broadstock \(2016\)](#) focused on energy intensity of total energy consumption. They identify three convergence clubs in China, each with markedly different energy intensity profiles. Instead of analyzing energy intensity, [Herrerias et al. \(2017\)](#) examine the convergence of residential electricity, coal and liquid petroleum gas consumption across 29 provinces in China.

[Yu et al. \(2015\)](#) analyze the convergence patterns of total energy intensity in the world. They find four convergence clubs when they apply the PS club convergence algorithm to the world as a whole. When the same algorithm is applied to country groups (e.g., OECD countries, OPEC countries, EU countries, etc.), the authors find two convergence clubs within most of the country groups. It also appears that different convergence groups show different speed of convergence. [Kim \(2015\)](#) studies the convergence of both electricity intensity and per capita electricity consumption across 109 countries in the world. While there is strong evidence of convergence in electricity intensity overall in the world, the same does not apply to per capita electricity consumption. The clustering pattern of per capita electricity consumption is found to be remarkably similar to that of per capita income.

3. Methodology

3.1. Convergence test

The [Phillips and Sul \(2007\)](#) test is useful for measuring transition of economic time-series towards a long-run growth path or individual transitions over time relative to some common trend. As details of the theory and procedure are well-documented in [Phillips and Sul \(2007\)](#), we only present the necessary equations in illustrating our application of the procedure. The procedure involves the construction of the cross-sectional variance ratio (H_1/H_t), where

Table 1. Growth factors (%) for population (POP), TFC, GDP and EI.

World	Levels	Per Capita
POP	2.01	
TFC	2.34	1.16
GDP	4.97	2.11
EI	0.47	
Asia-Pacific combined	Levels	Per Capita
POP	2.01	
TFC	4.55	2.27
GDP	12.19	6.07
EI	0.37	
Asia-Pacific averages	Levels	Per Capita
POP	2.17	
TFC	6.68	3.09
GDP	12.95	6.61
EI	0.82	

$$H_t = \frac{1}{N} \sum_{i=1}^N (h_{it} - 1)^2, \tag{1}$$

and

$$h_{it} = \frac{E_{it}}{N^{-1} \sum_{i=1}^N E_{it}}. \tag{2}$$

h_{it} traces the transition path of E_{it} for country i in relation to the cross-sectional average at time t . If the E_{it} are converging for all countries, then H_t will converge to zero. Under the convergence hypothesis, $H_t \rightarrow 0$ and $h_{it} \rightarrow 1$ as $t \rightarrow \infty$ for given N . The regression analysis involves estimating the following equation and obtaining a heteroskedasticity and autocorrelation-robust t -statistic for b :

$$\log\left(\frac{H_t}{H_1}\right) - 2 \log L(t) = a + b \log t + u \tag{3}$$

where $L(t) = \log(t+1)$ and $t = [rT], [rT]+1, \dots, T$ with $r > 0$. r is the fraction of data that is excluded in the regression stage of the test. Phillips and Sul (2007) show that a small fraction r of the time series data should be discarded in order to emphasize what happens as the sample size gets larger. Based on their simulation experiments, they recommend a value of 0.3 for r . The null hypothesis of convergence can be tested using a one-sided t -test.

3.2. Panel unit roots tests

In what follows we denote, respectively, by IPS and CIPS* the Im et al. (2003) and the Pesaran (2007) panel unit root tests. The IPS test does not take into consideration possible cross-country dependence, the CIPS* test does. Using a test that allows for cross-country dependence is important since as shown by Baltagi et al. (2007), among others, the IPS test is oversized, which means it over rejects the null at a given nominal level of significance, when dependence is present. Smeekes (2015) uses sequential testing to determine which cross-section units in a panel are stationary. This sequential approach exploits the cross-sectional dimension whereas multiple testing approaches do not. Smeekes (2015) points out that the same approach can be used to test for cointegration (as in Westerlund et al. (2014)). In our analyses, we use the bootstrap sequential quantile test (BSQT) of Smeekes (2015) and the sequential panel selection method (SPSM) of Chortareas and Kapetanios (2009), which is similar to BSQT but not as general and with lower power. We also apply the Romano and Wolf (2005) bootstrap procedure with modified critical values suggested by Smeekes (2015), denoted by RW2.

3.3. Panel cointegration tests

Pedroni (1999) develops panel cointegration tests which allow for heterogeneity in the cointegrating vectors and short-run dynamics. We assume that the cointegrating regression can be written as:

$$y_{it} = \alpha_i + \delta_{1i}t + \beta_{1i}x_{1it} + \dots + \beta_{Ki}x_{Kit} + e_{it} \tag{4}$$

where x_{1it}, \dots, x_{Kit} are K possibly endogenous regressors and e_{it} is the error term. Eq. (4) is the panel representation of the general linear consumption/demand model employed by Joyeux and Ripple (2011), where y is

energy consumption and the x 's are economic variables including income. Their empirical results support the consumption/demand model over the production function model, and we follow this here with the extension to panel data and then to the influence of common factors.

Pedroni (1999) four pooled tests and three group mean tests test the stationarity of the error term in Eq. (4). Common time dummies can be included to allow for cross-section dependence. For the seven tests the null hypothesis is of no cointegration for all countries. The alternatives are different with the group mean tests allowing for a more heterogeneous alternative. If we reject the null hypothesis with the group mean tests, we conclude that a significant percentage of the countries are cointegrated; with the pooled tests we conclude that all the countries are cointegrated.

We also apply the Westerlund and Edgerton (2007) bootstrap panel cointegration tests. Their tests take cointegration as the null. They allow for cross-sectional dependence and heterogeneous autocorrelation. Westerlund et al. (2014) and Pesaran (2012) show that the power of the Pedroni (2004) panel cointegration tests are significantly larger than the nominal levels even in cases where only 10% of the units are cointegrated. They conclude that a rejection of the null cannot be taken as evidence that all units are cointegrated but instead that there is cointegration for at least some units. Pesaran (2012) recommends estimating the fraction of cointegrated units. To this end we follow Westerlund et al. (2014), and we implement the BSQT, RW2 and SPSM estimators to determine which cross-section units are cointegrated.

3.4. Short- and long-run causality

We assume that x and y are two weakly stationary processes such that

$$y_{it} = \alpha_i + \sum_{k=1}^p \gamma_i^{(k)} y_{it-k} + \sum_{k=1}^p \beta_i^{(k)} x_{it-k} + \varepsilon_{it} \tag{5}$$

For each country the error term ε_{it} is assumed to be *i.i.d.* $(0, \sigma_i^2)$ and independent across countries.

To test for short-run causality from x to y we use the Dumitrescu and Hurlin (2012) Homogenous Non Causality (HNC) test. The null hypothesis of HNC is:

$$H_0 : \beta_i = 0 \quad \forall i = 1, \dots, N \tag{6}$$

where $\beta_i = (\beta_i^{(1)}, \dots, \beta_i^{(p)})'$. The alternative hypothesis is:

$$H_1 : \beta_i = 0 \quad \forall i = 1, \dots, N_1 \\ \beta_i \neq 0 \quad \forall i = N_1 + 1, N_1 + 2, \dots, N \tag{7}$$

Under the null there is no causality from x to y for any of the countries, whereas under the alternative causality may be present for a subset, N_1 , of the countries.

One of the attractive features of model (5) is that the coefficients of the VAR may differ across countries under both the null and the alternative hypotheses. The test statistic is computed as the cross-sectional average of the individual countries Wald statistics. Letting T tend to infinity first and then N this statistic converges to a normal distribution under the null. Dumitrescu and Hurlin (2012) prove that there is a gain in power in using their panel test compared to Wald tests on the individual countries. In what follows we use their standardized statistic, $Z_{N,T}^{HNC}$. The Dumitrescu and Hurlin (2012) test is suitable for the case where we have no common factors included since we found that cointegration was not present in that case.

Firstly, if cointegration is found in the panel dataset, we estimate, for each country, the cointegrating relationship between y and x using Fully Modified Ordinary Least Squares (FMOLS). Second, for each country, we estimate the error correction model (ECM) using the estimated residuals \hat{e}_{it} from the FMOLS regressions:

Table 2. Growth factors ranges for per Capita TFC and GDP.

	Average	Maximum	Minimum
TFC	3.09	8.54	0.18
GDP	6.61	32.52	0.76

$$\begin{aligned}\Delta y_{it} &= c_{1i} + \lambda_{1i} \widehat{e}_{it-1} + \sum_{j=1}^p \gamma_{11ij} \Delta y_{it-j} + \sum_{j=1}^p \gamma_{12ij} \Delta x_{it-j} + \varepsilon_{1it} \\ \Delta x_{it} &= c_{2i} + \lambda_{2i} \widehat{e}_{it-1} + \sum_{j=1}^p \gamma_{21ij} \Delta y_{it-j} + \sum_{j=1}^p \gamma_{22ij} \Delta x_{it-j} + \varepsilon_{2it}\end{aligned}\quad (8)$$

for each country i , where ε_{it} is the error term. Since the estimates of the coefficients of the cointegrating relationship between y and x are superconsistent, we can replace the error correction term with its estimates and test whether there is no long-run causation from x to y (or from y on x) by following the approach adopted by Canning and Pedroni (2008) and using a group mean test computed as:

$\bar{t}_{\lambda_s} = \frac{\sum_{i=1}^N t_{\lambda_{si}}}{N}$, where $t_{\lambda_{si}}$ is the t -test on λ_{si} , for $s = 1, 2$. \bar{t}_{λ_s} is asymptotically normally distributed under the null. A potential problem with this test is that significant negative t -ratios could cancel out with significant positive t -ratios and the average t might be insignificant. Therefore, as an additional panel statistic we compute the lambda-Pearson statistic equal to $P_{\lambda_s} = -2 \sum_{i=1}^N \ln p_{\lambda_{si}}$, which is computed from the sum of the log of the p -values of the individual countries t tests. This statistic is distributed as a χ^2 with $2N$ degrees of freedom under the null that $\lambda_{si} = 0$ for all i .

4. Data and empirical results

4.1. Total final consumption of energy, gross domestic product, and energy intensity

In the empirical analysis we adopt annual data of total final consumption of energy (in Mtoe), gross domestic product (in billions of 2015 USD-PPP) and electricity consumption (in GWh) spanning 1971 to 2018.² All data come from the IEA World Energy Statistics and Balances of the OECD iLibrary online database.³ We begin by examining the transition of total final consumption of energy (TFC), gross domestic product (GDP) and energy intensity (EI = TFC/GDP). This includes tabular and graphical representations, as well as rigorous convergence testing to evaluate the commonality of trend of these energy-income-related economic characteristics. Over the past several decades we have observed significant changes in energy consumption and income characteristics of the 20 Asia-Pacific countries under study in this paper. Individual country changes have not occurred in a vacuum. These changes have occurred within the context of changing regional and world energy consumption patterns. And the dynamics of these changes have also driven changes in energy intensity. Table 1 reports growth factors for the period 1971–2018, as measured by 2018 values divided by 1971 values.

Table 2 reports growth factors for per capita TFC and per capita GDP across the 20 Asia-Pacific countries included in our study. In addition to the differences seen between the Asia-Pacific countries and the world in Table 1, Table 2 shows that wide ranges are also observed with the 20 Asia-Pacific countries. The countries representing the extremes are worth identifying. For TFC per capita, it is interesting to note that the maximum increase is South Korea, and the minimum increase is North Korea. And, it should not be too surprising that the maximum increase in per capita GDP is China, while the minimum increase occurred in Brunei.

A result of these dynamics is that energy intensity has evolved substantially over this period for the economies of Asia-Pacific. The energy intensities for the 20 Asia-Pacific economies under study all improved, with the sole exception of Brunei Darussalam. The average energy intensity in 2018 was 82% of that in 1971, as shown in Table 1. China's

energy intensity improved by far the most with 2018 being just 11% of the level in 1971. Brunei, on the other hand, the sole economy to show deterioration, was over 6 times more energy intensive in 2018 than in 1971. It appears that the reason for the contrary path for Brunei is due to a combination of its very small size and low TFC in 1971 and its move toward using more energy domestically to produce higher value-added refined products for export and domestic use. The oil and gas sector is said to account for about two-thirds of Brunei's GDP.

During our study period, China became the largest energy consumer in the world. Its energy intensity peaked in 1977 at 0.78, just one year prior to the beginning of China's economic reforms, known as "Socialism with Chinese Characteristics", when its share of world primary energy consumption was just 5.8%. Since then, China's economy has grown substantially and energy intensity has shown nearly continual improvement, arriving at an EI in 2018 of 0.09. This represents an 88% improvement compared to 53% for the world.

Much of China's improvements pre-date its noted energy policy commitment to reduce its energy intensity by 16% between 2010 and 2015; this commitment was rolled into the IEA's projections in its World Energy Outlook; the realized improvement was 17.4%. Clearly its 86% improvement was from a very, very high base, but even this massive reduction left it 16.9% above World energy intensity in 2018. Nonetheless, this is a substantial improvement over China's relative position in 1971 when its energy intensity sat at 375% above the World value.

This overview provides the background for the economic and energy consumption evolution in these countries over the period under study. While growth in both energy consumption and GDP have differed to some degree among the countries of the region over the period, the evolution of energy intensity across the region may be characterized as exhibiting underlying commonalities. However, we want to more rigorously examine the degree of convergence of the underlying energy-income-related characteristics as further evidence in support of employing common factors methodology to enhance our panel data analyses.

4.2. Convergence results

Figure 1 shows the relative transition parameters (h_{it}) for the members of the convergence club for energy intensity, while Figure 2 reports the same for the share of electricity in TFC. We can see that for energy intensity, a majority of the transition parameters oscillate around the value of 1, while a number of the countries show clear sign of convergence towards this value (e.g., Brunei, China, Myanmar, North Korea, etc.). A somewhat similar pattern can also be observed for electricity's share in TFC. With the exception of Nepal, most of the transition parameters are either around or moving towards the value of 1.

Turning to the convergence regression, the estimated coefficient for b is 0.9620, with t -statistic of 18.2532 for the energy intensity test, and b is -0.1425 with t -statistic of -3.9679 for the share of electricity in TFC. Therefore, the null hypothesis of convergence is not rejected for our sample for energy intensity but rejected for the share of electricity in TFC. Applying the club convergence algorithm proposed by Phillips and Sul (2007), the estimated b coefficient is 0.4865, with a t -statistic of 12.8713 for the group of all countries except Myanmar and Nepal. We conclude that our 20 countries comprise a single convergence club for energy intensity, and for the share of electricity in TFC we find a convergence club consisting of all countries but Myanmar and Nepal.

The foregoing provides a solid foundation for moving forward with our planned methodology of employing panel data augmented by common factors. We proceed now to analyze the causal relationships between energy consumption and GDP per capita across our 20 Asia-Pacific countries from 1971 to 2018. The first steps of our analyses apply panel cointegration techniques to study the relationships between per capita GDP and per capita total final consumption of energy. These analyses are carried out employing panel time series methodologies to take advantage of the increased explanatory powers of combining the cross-

² The data and program code can be obtained from the corresponding author upon request.

³ https://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en.

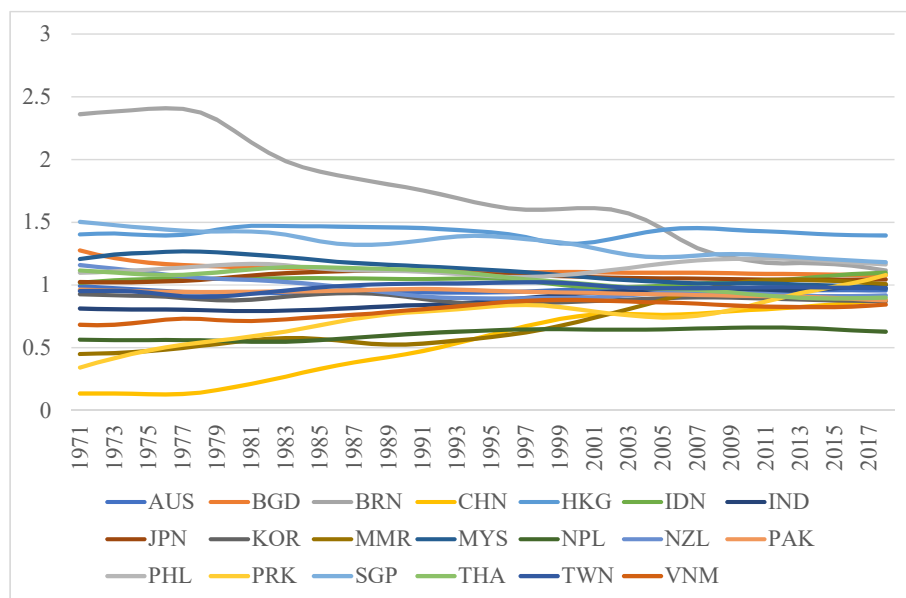


Figure 1. Relative transition parameters for energy intensity.

section and time-series dimensions of the available data. In the cross-section dimension the panel includes the 20 economies across Asia-Pacific, and in the time series dimension it ranges over the 48-year period. The conventional cointegration and causality analyses are then augmented by including common factors for the 20 countries. All variables are analyzed in natural log.

4.3. Panel unit root results

Results from the IPS and CIPS* tests are presented in Table 3 for the variables in levels and first differences. They show that the TFC and the GDP per capita series in levels have a unit root. Their first differences display stationarity. The two series can therefore be assumed to be $I(1)$. The BSQT, RW2, and SPSM results show that for the two variables in levels we do not reject the null of a unit root for any country and in differences we reject the null for at least 75% of the countries.⁴

4.4. Panel cointegration results

Given that we are estimating energy demand models including only one explanatory variable, the log of GDP per capita, it is expected that there are missing relevant variables common to all countries. These common factors would be variables related to world demand for energy. As in Westerlund et al. (2014) and Pesaran (2006), we proxy these common factors by using the cross-section averages of all the observable variables (including the dependent variable). These averages are included in the cointegrating regression as additional regressors. The results are presented in Table 4.

The Pedroni tests do not reject the null of no cointegration when no common factors are included. The Westerlund and Edgerton (2007) tests do not reject the null of cointegration even at the 10% level. Once we include proxies for the common factors the Pedroni tests all reject no cointegration at the 5% level. The Westerlund and Edgerton (2007) do not reject the null of cointegration with a p -value of 0.995. These results also concur with the sequential cointegration tests BSQT, RW2, and SPSM presented in Table 5. In all cases, we still find cross-section units for which we do not have cointegration. These results are important for the

causality tests and the long-run elasticities estimations which follow. We should use panel tests for long-run cointegration only with a panel for which all the cross-section units present cointegration. Moreover, we can only estimate the long-run elasticities using panel estimators when all the units in the panel are cointegrated. For Nepal, Philippines, Thailand we find that TFC-PC and GDP-PC are not cointegrated using the RW2 test. When estimating long-run elasticities we present the results with and without those 3 countries included.

4.5. Causality results

We apply the Dumitrescu and Hurlin (2012) test to the differenced energy consumption and GDP variables since they were found to have a unit root. We report in Table 6 the p -values of $Z_{N,T}^{HNC}$ for the first differences of our variables. The numbers in brackets are the percentages of countries for which non-causality is rejected with individual Wald tests at the 5% level. The countries listed are the ones for which the null hypothesis of non-causality is rejected using individual Wald tests. Since we have 48 time series observations, we can expect the Wald tests on the individual countries to have lower power than the panel tests.

We reject the null hypothesis of HNC from GDP-PC to TFC-PC at 5% significance level. We also find feedback from TFC-PC at the 5% level. If we consider the Wald tests for the individual countries, we find that rejection of non-causality at the 5% level occurs for at least 15% of the countries in all instances. If there really were no causality, we would expect to reject no causality in 5% of the countries. Consequently, there is evidence of feedback between TFC-PC and GDP-PC using the individual Wald tests as well. Note that we also implemented the test including common factors and reached the same conclusions.

Since we have found cointegration for 85% of the countries using the RW2 test between GDP-PC and TFC-PC, we estimate the error correction models for each country. The results for the long-run causality tests are presented in Table 7. We find causality running from GDP-PC to TFC-PC with the Lambda-Pearson test using a 5% significance level. There is no feedback according to the Lambda-Pearson test between GDP-PC and TFC-PC.

4.6. Long-run elasticities

We estimate the long-run elasticities with the group-mean Panel DOLS estimates proposed by Pedroni (2001). They have been shown to

⁴ We thank Joakim Westerlund for providing the Gauss codes for the BSQT, RW2, and SPSM methods.

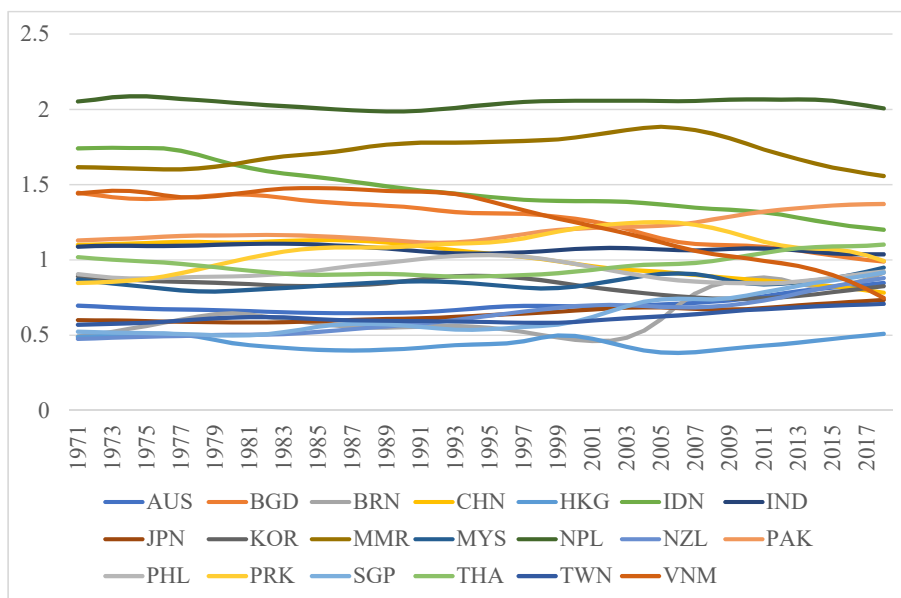


Figure 2. Relative transition parameters for share of electricity in TFC.

outperform other panel estimators when a single cointegrating relationship exists and in the presence of cross-section dependence and cross-unit cointegration (Wagner and Hlouskova, 2010). The long-run coefficients panel DOLS estimates are presented in Table 8 for two panels: the full panel including all the countries, and a 17-country panel where the countries for which we did not find cointegration between TFC-PC and GDP-PC with the RW2 test (i.e., Nepal, Philippines and Thailand) have been excluded. The long-run estimated coefficients are estimated elasticities of the energy consumption variable with respect to per capita GDP.

The elasticities estimated including common factors are much smaller than when they are not included, as expected. The TFC-PC elasticities with common factors are roughly half of those estimated without common factors, and the estimates are not markedly different between the full and the 17-country panels. Our estimation results point out that omitting relevant variables when estimating elasticities can distort

Table 3. Panel unit root tests.

Levels	With constant and trend	
	TFC-PC	GDP-PC
IPS-ADF ⁽¹⁾	1.000	0.999
CIPS ^{*(2)}	0.955	0.990
BSQT ⁽³⁾	0.000	0.000
RW2 ⁽³⁾	0.000	0.000
SPSM ⁽³⁾	0.000	0.000
1 st Difference	With Constant	
	TFC-PC	GDP-PC
IPS-ADF ⁽¹⁾	0.000	0.000
CIPS ^{*(2)}	0.010	0.010
BSQT ⁽³⁾	0.700	0.800
RW2 ⁽³⁾	0.700	0.850
SPSM ⁽³⁾	0.650	0.700

Notes:

(1) *p*-value of the *W* bar statistic. Maximum 3 lags in levels and 2 in first differences.

(2) *p*-value; maximum 3 lags in levels and 2 in first differences.

(3) Fractions of countries for which the null of a unit root is rejected at the 5% significance level.

results considerably. Of course, it would be preferable to include the relevant variables themselves rather than proxies if they were available, but data limitations persist.

5. Discussion and conclusion

The literature examining the causal relationship between energy consumption and economic growth itself continues to grow, but there is a lack of consensus on the causal relationship. As noted by Payne (2010) and Ozturk (2010), and more recently by Omri (2014), Isa et al. (2015) and Waheed et al. (2019), these conflicting results may arise from the differences in data set, variables included, econometric methodology, varying energy consumption pattern, structure and stages of economic development, etc. To further contribute to the rich literature on this topic, Payne (2010) suggests that future studies should differentiate and group countries according to energy consumption patterns and/or stages of economic development, fully understand the causal relationship by examining also the sign and magnitude of the relationship, and investigate the relationships using several econometric approaches, preferably in a panel framework in the case of multi-country analysis.

Table 4. Panel cointegration tests: GDP-PC as independent variable.

	Without Common Factors	With Common Factors
<i>Pedroni</i> ⁽¹⁾		
panel <i>v</i> -stat	-0.71	3.45**
panel <i>rho</i> -stat	0.64	-1.67**
panel <i>pp</i> -stat	0.64	-2.72**
panel <i>adf</i> -stat	-0.08	-3.12**
group <i>rho</i> -stat	0.19	-1.15
group <i>pp</i> -stat	-0.24	-3.22**
group <i>adf</i> -stat	-0.15	-3.40**
<i>Westerlund (p-value)</i> ⁽²⁾	0.083	0.995

Notes:

(1) The panel variance test is a one-sided normal right tail test and the other six are normal left tail tests. ** indicates rejection at 5% or lower. An intercept is included in the cointegrating regressions.

(2) An intercept is included in the cointegrating regressions. The null hypothesis is cointegration.

Table 5. Fractions of cointegrated countries.

Without Common Factors		
Test	Fraction ⁽¹⁾	Countries with cointegration
BSQT	0.000	
RW2	0.000	
SPSM	0.000	
With Common Factors		
Test	Fraction ⁽¹⁾	Countries without cointegration
BSQT	0.900	<i>Nepal, Philippines</i>
RW2	0.850	<i>Nepal, Philippines, Thailand</i>
SPSM	0.750	<i>Japan, Myanmar, Nepal, Philippines, Thailand,</i>

Notes:

(1) Fractions of countries for which the null of no cointegration is rejected.

Table 6. Dumitrescu-Hurlin short run panel causality tests.

Causal Direction	p-value
TFC-PC → GDP-PC	0.002 (0.20) <i>Brunei, Hong Kong, New Zealand, Vietnam.</i>
GDP-PC → TFC-PC	0.000 (0.15) <i>Australia, Indonesia, Malaysia.</i>

Notes:

(1) p-values of $Z_{N,T}^{HNC}$.

(2) Numbers in brackets are the percentages of countries for which the null of non-causality is rejected with individual Wald tests at the 5% level. The countries listed are the ones for which the null of non-causality is rejected using individual Wald tests.

Table 7. Long-run causality tests.

Causal Direction	Group mean t test	Lambda-Pearson test
TFC-PC → GDP-PC	0.748	0.175
GDP-PC → TFC-PC	0.104	0.000

Notes:

(1) For all tests one lag was used.

(2) p-values are reported.

We endeavor to heed this advice in this paper. Our study is confined to Asia-Pacific countries, but it should be noted that these countries are in different stages of economic/social development, and we cannot preclude the possibility that the energy-income relationships are different across these countries. However, our convergence test results provide evidence that the countries included in our panel do show convergence over the period under study for key energy sector variables. To circumvent the possible heterogeneity problem and deal with the fact that long-run relationships may only occur in a subset of countries in our analysis, we take on board the latest developments and considerations in panel data econometrics advanced by studies like [Westerlund et al. \(2014\)](#), [Dumitrescu and Hurlin \(2012\)](#), and [Smeekes \(2015\)](#). We also estimate

Table 8. Panel DOLS elasticity estimates.

	Without Common Factors	With Common Factors
Panel 20 countries	0.877*	0.386*
Panel 17 countries	0.815*	0.301*

Notes:

(1) Two lags were used in the panel DOLS estimation.

(2) * Indicates significance at 5% level or lower.

long-run income elasticity of TFC-PC to facilitate more concrete recommendations for energy policy.

In general, our panel cointegration results show that the inclusion of (unobserved) common factors is required for the establishment of a cointegrating relationship between energy consumption and income in our panel of Asia-Pacific countries. The sequential cointegration tests (BSQT, RW2, and SPSM) help further reveal the set of countries where cointegration is detected. These results display (i) the potential influence of omitted variables on the energy-income relationship and (ii) the importance of country grouping and heterogeneity in multi-country panel studies.

The results of our analysis tend to provide support for the original policy conclusions put forward by [Kraft and Kraft \(1978\)](#). They concluded that with causation running from income to energy consumption the energy conservation policies then being promoted would not have adverse effects on economic growth. The causality results reported herein find causality flowing from GDP-PC to energy consumption, albeit with feedback. This suggests that current energy policies across Asia-Pacific aimed at reducing energy intensity, and thereby reducing CO₂ emissions (or at least their rate of growth), should not adversely affect economic growth across the region. And we believe that the modeling of unobserved common factors was key to fully understanding this relationship across this economically diverse region.

The panel DOLS income elasticity results of 0.386 for TFC-PC when common factors are included, compared to 0.877 when they are not, emphasizes their importance. When common factors are accounted for the long-run income elasticities are found to be far smaller than the 1-to-1 relationships often suggested for developing countries.

Declarations

Author contribution statement

Raymond Li, Roselyne Joyeux & Ronald D. Ripple: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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