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The dynamics of material consumption in phases of the economic cycle for selected emerging countries

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ABSTRACT

Domestic materials are vital for production and consumption patterns and their sustainable use holds a prominent place in supporting a virtuous circle of wellbeing-environment-ecological system. In this context, this study contributes to the comprehension of material use dynamics during different phases of the economic cycle, bringing new insights into the dematerialization process. Therefore, this paper examined the effect of economic cycles on material consumption using a STIRPAT framework for 12 emerging economies for the period 1970–2017. In order to ascertain robustness, our estimation techniques account for (country-specific factors) endogenous economic growth, cross-sectional dependence, and cross-country heterogeneity within a panel framework. Thus, evidence suggests that economic expansion constitutes periods of increase in material consumption mainly due to the consumption side effect of expansion, while the occurrence of recession is associated with economic dematerialization. In addition, we found a moderating effect of material productivity on materials utilization. Based on these insights, we submit that increasing material productivity leads to sustainable practices and patterns of materials utilization. On this note, policymakers should understand the effective mechanisms that are detrimental to achieving the sustainable development goals (SDGs) such as curbing material consumption during the recession and maintain a smooth material consumption balance over economic cycles.

1. Introduction

By economic intuition, the process of making service available alongside the production of goods for human use entails raw material utilization. Across the globe, the varying socioeconomic, environmental among other challenges that currently confront the 21st economies have further provided a platform to query the components and efficiency of the existential material for the production of nations' goods and services. Thus, expanding the production of goods and services is as important as ensuring our safeguarding the required sustainable raw material consumption (or material footprint) processes. It then suffices why the Sustainable Development Goals (SDGs) of the United Nations Development Programme (UNDP, 2020a) noted the importance of "affordable and clean energy" (as SDGs No. 7), "decent work and growth" (as SDGs No. 8), "responsible production and consumption" (as SDGs No. 12), "climate action" (as SDGs No. 13), and other material consumption related goals of the UNDP. In specific, the transition toward attaining a resilient and sustainable economy is a function of how the states' limited natural resources such as the domestic material consumption (DMP) is being managed over a specified period. For instance, the resource efficiency roadmap of the European Union (EU) sustainable development strategy employed the DMP of material flow accounting as sustainability indicators (Wiedmann et al., 2015).

In spite of the limited nature of global natural resources, the world has continued to experience an ever-increasing rate of domestic material consumption. For instance, the DMP which measures the overall (included imported and locally made) direct materials that are employed in producing goods and services for human needs has increased globally to 92 billion metric tons in 2017 (Material Flows, 2019; UNDP, 2020b). The UNDP further inferred that all the regions of the world experienced growth in DMP in 2017 but with an exceptional increase of about 10 billion metric tons more than in 2010 in the Eastern and South-Eastern Asia region. Moreover, between the same period of 2010 and 2017, the other regional growth in DMP were presented by the UNDP accordingly: Europe and Northern America (0.3 billion metric tons), Central and Southern Asia (2.4 billion metric tons), Latin America

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and Caribbean (1.2 billion metric tons), Northern Africa and Western Asia (1.4 billion metric tons), Sub-Saharan Africa (0.6 billion metric tons), Australia and New Zealand (0.04 billion metric tons), and Oceania (0.005 billion metric tons). However, for the DMP per unit of the Gross Domestic Product-GDP (measure in kilogram per dollar), there exists a mix of growth and decline across the aforementioned regions. For instance, while there was no change in the global DMP between 2010 and 2017, growth was only experienced in Northern Africa and Western Asia and the Latin America and the Caribbean, and a decline in the other regions.

The observed dynamics in domestic material consumption across the world regions supposedly presents an interesting perspective. In the case of the Eastern and South-Eastern Asia region, and especially the emerging economies, two major factors are associated with the significant increase in domestic material consumptions. Indicatively, UNDP (2020b) opined that infrastructural development and the material-energy outsourcing from high-income to less resource-efficient economies are the two key indicators responsible for the significant DMP growth among the emerging states. Considering that the DMP is an economy-wide accounting material, other factors such as resource productivity, economic expansion (as a measure of the GDP), and trade activities are consistently linked with the dynamics of the DMP (Kovanda, 2020). As such, trade among the emerging and developing economies have consistently increased in recent times against the old pattern of bilateral trade among the old developed economies (Bloomberg, 2019; Economic Commission, 2019). In the same boat with the aforementioned factors, population growth amidst business cycle experiences among the emerging economies (i.e. China and India) is a probable determinant of both material production and consumption. Specifically, the rapid industrialization of emerging economies especially of the Organization for Economic Co-operation and Development (OECD) members and non-member states reportedly account for the increasing intensity of material used in these countries (OECD, 2018a). In this context, the determinants of material utilization have been illustrated in the extant literature (Considine, 1991; Weisz et al., 2006; de la Cruz et al., 2017; Baynes and Musango, 2018).

In view of the above motivation, the current study is designed to examine the role of resource productivity, trade openness, and economic development in domestic material consumption especially during the phases of the economic cycle. In this case, selected emerging countries (Brazil, Chile, China, Egypt, India, Indonesia, South Korea, Malaysia, Mexico, Peru, The Philippines, and South Africa) were considered for the investigation because of the forecasted socioeconomic trends associated with many of the leading emerging states. In specific, the materials use growth strong projection for the emerging and developing economies between 2011 and 2060 is associated with the countries' economic growth rates in the coming decades (OECD, 2018b). While the current study has potentially contributed to the existing studies on the determinants of domestic material consumption, the novelty of the study is presented in parts. In the first place, changes in domestic material consumption in the panel of 12 selected merging economies are examined over phases of the economic cycle (the episodes of recession and expansion). In addition, the study is posed to offer an interesting perspective and a policy mechanism that further guides the existing high bilateral trade among emerging economies.

The presentation of the other sections of the study is patterned accordingly. In the next section, further description of the employed data and the theoretical framework are both outlined. By employing the systematic procedures, the essential estimations were performed. Moreover, the result presentations, discussion and the conclusion of the study were presented in sections 4, 5, and 6 respectively.

2. Data, theoretical framework, and model construction

Our chief aim is to investigate the impact of different phases of the economic cycle captured by economic expansion and economic contraction on the dynamics of material consumption in emerging countries. We use a two-stage procedure to estimate the impacts of economic growth on material consumption in emerging countries. Firstly, we decompose the economic growth pattern into episodes of expansion and contraction. Secondly, we estimate the dynamics of the effects of economic growth on material consumption during episodes of economic expansion and contraction.

2.1. Data

The analysis exploits annual data for 12 emerging countries, including Brazil, Chile, China, Egypt, India, Indonesia, South Korea, Malaysia, Mexico, Peru, The Philippines, and South Africa over the period 1970–2017. Indicatively, the country selection is limited to 12 because of data availability and since we have considered the material consumption profile of the emerging economies, especially both the OECD member and non-member states. In addition, the authors believe that this sample is sufficiently long enough and contains enough information to capture various cycles in economic growth.[1] The per capita material consumption data from the EuroStat database based on the material flow analysis. The material consumption data has been applied in a wide range of applications, ranging from material management (Baninla et al., 2019; Wang et al., 2012), resource efficiency (Baninla et al., 2020; Chiu et al., 2017; Rieckhof et al., 2015), and the environmental impact of material consumption through the Material Kuznets Curve (Focacci, 2005; Grabarczyk et al., 2018; Jaunky, 2012, 2014). In this study, the domestic material consumption is used as an indefectible analysis indicator to track the materials consumption associated with economic activities (production and consumption), industrial construction minerals, metal ores, biomass as well as fossil energy systems. It is computed as the sum of raw material extracted from the domestic natural environment and imports minus exports (Wang et al., 2012). This indicator can be considered as an effective way to monitor and track the ecological assets and resource flows for sustainable resource policies, particularly in the context of the global resource supply chain (Ulucak et al., 2020). Thus, domestic material consumption can be the channel through which economic growth impacts the environment.

Our main variable of interest is economic growth, which is expressed by real GDP per capita. The data for real GDP per capita was gathered from the World Development Indicators database. Theoretically, a rise in income is expected to drive domestic material consumption in an upward direction (Kates, 2000). In order to monitor the possible omitted variable bias in our analysis, we used several control variables such as population (POP), trade openness (TR), and productivity (RP). It is important to emphasize that these variables enable us to follow the STIRPAT model specification widely used in the material consumption literature (Chiu et al., 2017; Martinico-Perez et al., 2017; Ulucak et al., 2020). Population size is a point of special concern in emerging countries as the growth of its size is closely related to raw material demand and anthropogenic emissions (Birdsall, 1992). It is expected that population size has a positive impact on individual material consumption attributable to material demand-induced affluence (Davis and Lopez-Carr, 2010). Another important component of the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) framework is technology. By following (Schandl et al., 2018; Schandl and West, 2012), we used material productivity as a measure of technology parameter. This measure of productivity is defined as the economic output produced per unit of domestic material consumed. Thus, the change in resources is directly applied to the added value of the output, which represents the productivity management index. Mathematically, the resource productivity index is the ratio of resource consumption to GDP (Dong et al., 2017). Theoretically, it is expected

[1] The country selection is based on data availability over the period under investigation.

that resource productivity negatively affects domestic material consumption when decoupling between material consumption and GDP is maximized so that effective productivity management policy and technological enhancement play an important role in slowing the use of domestic material (Shah et al., 2020). Finally, we account for the degree of trade openness as the growth dynamic of material flows has been closely linked to international trade. As a result of the international trade, physical imports and exports of goods have become the fastest-growing component of materials use (Ulucak et al., 2020; Welsch, 2007). The trade openness series is obtained from the World Development Indicators database.

2.2. Theoretical framework and model construction

Although the study of Baynes and Musango (2018) aligned the DMP with standard MFA national accounting, the study further noted the link between the determinants of DMP and socio-ecological systems. However, for the regression analysis, Baynes and Musango (2018) examined the determinants of DMP from the framework of STIRPAT which is an augmentation of the IPAT (Impact = Population × Affluence × Technology) framework of Ehrlich and Holdren (1971). In specific, the IPAT theoretical framework has been widely applied in the research field of material/resource use, sustainability science, and environmental assessment. Here, we followed the IPAT framework to analyze the contribution of the main triggers of domestic material consumption. The IPAT identity can be specified as:

$$I = PAT \tag{1}$$

where, I represents the environmental impact stemming from population P; affluence or economic activity A and technological enhancement T. Here, I, P, A and T were defined as domestic material consumption per capita, population, real GDP per capita, and DMP per GDP, which is also named material productivity/intensity, respectively. Moreover, Dietz and Rosa, 1997 extended the IPAT framework to include a stochastic component that is called the STIRPAT and is specified as:

$$I_{it} = \alpha_0 P_{it}^{\alpha_1} A_{it}^{\alpha_2} T_{it}^{\alpha_3} e_{it} \tag{2}$$

where i denotes individual cross-section dimension, t represents the time dimension, e is the error term of the model, α_0 is the intercept term and the parameters α_1, α_2 and α_3 are the exponents of the underlying variables. In this study, we used an augmented version of the STIRPAT model by including trade openness in addition to the impact of socio-ecological systems in terms of population and economic development. By taking the natural logarithm on both sides, we obtained the following specification:

$$DMP_{it} = \alpha_0 + \alpha_1 POP_{it} + \alpha_2 GDP_{it} + \alpha_3 RP_{it} + \alpha_4 TR_{it} + e_{it} \tag{3}$$

with $RP_{it} = \frac{GDP_{it}}{DMP_{it}}$

Equation (3) allows us to quantitatively measure the implication of population, real GDP per capita, domestic material efficiency/productivity, and trade openness for the dynamic of domestic material consumption. Equation (3) is estimated as our baseline model and it does not take account of the possible asymmetry in the material consumption patterns during episodes of economic expansion and contraction. To estimate the asymmetric models, we decomposed real GDP per capita into episodes of economic recession and expansion, corresponding to years of GDP downscaling and upscaling, respectively.[2] We define episodes of economic cycles as follows:

$$GDP_{it}^{+} = \sum_{k=1}^{t} \Delta GDP_{ik}^{+} = \sum_{k=1}^{t} \max\left(\Delta GDP_{ik},\ 0\right) \tag{4}$$

$$GDP_{it}^{-} = \sum_{k=1}^{t} \Delta GDP_{ik}^{-} = \sum_{k=1}^{t} \min\left(\Delta GDP_{ik},\ 0\right) \tag{5}$$

where, GDP_{it}^{+} is the sum of the actual changes in GDP if positive or zero otherwise up to the current date, corresponding to episodes of economic expansion. GDP_{it}^{-} is the sum of the actual changes in GDP (if negative) or zero (otherwise) up to the current date, then it is a negative quantity, corresponding to episodes of economic contraction. To empirically test the pattern of material consumption over business cycles, the following regression is estimated:

$$DMP_{it} = \lambda_0 + \lambda_1 GDP_{it}^{+} + \lambda_2 GDP_{it}^{-} + \lambda_3 RP_{it} + \lambda_4 TR_{it} + \lambda_5 POP_{it} + v_{it} \tag{6}$$

This specification implies that the coefficients λ_1 and λ_2 measure the effects of economic growth on material consumption in the cases of positive changes in income (expansion) and negative changes in income (recession), respectively. Equation (6) allows resource productivity, trade openness, and population size to enter linearly in the model.

3. Methodology

Following the second-generation panel time-series estimation techniques, first, we examine the possibility of cross-sectional dependence and slope heterogeneity across panel members. Next, the stochastic properties of the series are investigated through advanced panel unit root tests. After that, cointegration analysis among the variables is conducted. Lastly, the employed advanced panel estimation techniques to estimate the long-run parameters. The econometric methodology followed in this study is discussed below in detail.

3.1. Preliminary tests: cross-sectional dependence and slope homogeneity

A battery of cross-sectional dependence tests was performed. Firstly, we employed the Lagrange Multiplier (LM) test developed by (Breusch and Pagan, 1980), This test is based on the average of squared correlation between residuals. For the exposition, we assume the following panel model:

$$y_{it} = a_i + \beta_i' x_{it} + \varepsilon_{it} \tag{7}$$

for cross-section dimension ($i = 1,\dots N$) and time dimension ($t = 1,\dots.T$), x_{it} is a $m \times 1$ vector of explanatory variables. a_i and β_i' represent intercepts and slope coefficients. The LM test is based on the following statistic:

$$LM = T\Sigma_{i=1}^{N-1}\Sigma_{j=i+1}^{N}\widehat{\varphi}_{ij}^{2} \quad \sim \chi^2_{N(N-1)/2} \tag{8}$$

where, $\widehat{\varphi}_{ij}$ is the average of squared correlation between residuals obtained from individual ordinary least squares estimation of Equation (7).

Secondly, we used the cross-sectional dependence test developed by (M H Pesaran, 2004), which is a scaled version of the LM test as given in Equation (8).

$$CSD_{(LM)} = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\varphi}_{ij}\right) \sim N(0,1) \tag{9}$$

$CSD_{(LM)}$ is based on the pairwise correlation of the residuals rather than the average squared correlation used in the LM test. Under the null hypothesis the LM and $CSD_{(LM)}$ tests assume that there is no cross-sectional dependence ($H_0: Cov(\varepsilon_{it}\varepsilon_{jt}) = 0\ for\ all\ t,\ i \neq j$), whereas the alternative hypothesis assumes the presence of CSD across panel members ($H_1: Cov(\varepsilon_{it}\varepsilon_{jt}) \neq 0\ for\ at\ least\ one\ period,\ i \neq j$).

Another important issue in macro panel time-series analysis is cross-

[2] Similar decomposition of variables has been used in several previous studies including (Kassouri and Altıntaş, 2020; Nakajima, 2020).

sectional heterogeneity. Given the structure of our panel data model (large T and N), we used the delta ($\tilde{\Delta}$) tests developed ed by (Hashem Pesaran and Yamagata, 2008). This test is valid and provides robust results in panel data with large T and N. The test statistics developed by (Hashem Pesaran and Yamagata, 2008) is computed as follows:

$$S = \Sigma_{i=1}^{N}(\beta_i - \beta_{WFE})' \frac{x_i' Z_r x_i}{\sigma_i^2}(\beta_i - \beta_{WFE})$$

$$\Delta = \sqrt{N}\left(\frac{N^{-1}S - k}{\sqrt{2k}}\right) \tag{10}$$

The bias adjusted version of the Δ test is computed as follows:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}S - k}{\sqrt{\frac{2k(T-k-1)}{T+1}}}\right) \tag{11}$$

It is important to highlight that $\tilde{\Delta}$ is obtained from the modified version of the S test developed by (Swamy, 2006). β_i and β_{WFE} are the pooled OLS and weighted fixed effect pooled estimators, respectively. Z_r is the identity matrix of order r, x_i is the explanatory variables matrix. σ_i^2 is the estimate of σ_i, k is the number of regressors. The null hypothesis of slope homogeneity ($H_0 : \beta_i = \beta$ for all i), while the alternative hypothesis assumes slope heterogeneity ($H_0 : \beta_i \neq \beta$ *for* i $\neq j$).

3.2. Panel unit root tests

Given the low power of traditional panel unit root tests in the presence of cross-sectional dependence, we test for unit roots using advanced panel unit root tests developed by (Pesaran, 2007a,b) extended the standard Dickey-Fuller test and introduced the cross-sectionally augmented Dickey-Fuller (CADF) to accommodate the issue of cross-sectional dependence and heterogeneity across panel members and test the null hypothesis of unit root against the alternative that at least one-panel member's series is stationary. The CADF statistic is computed as follows:

$$\Delta z_{it} = \alpha_i + \beta_i z_{it-1} + d_i \bar{z}_{t-1} + \sum_{j=0}^{p}\theta_{ij}\Delta\bar{z}_{t-j} + \sum_{j=1}^{p}\phi_{ij}\Delta z_{it-j} + e_{it} \tag{12}$$

where, $\Delta\bar{z}_{t-j}$ and $\bar{z}_{t-j}$ are the cross-sectional averages of the first differences and lagged levels of z_{it}, respectively. e_{it} is the random error term. The CIPS statistic is derived as follows:

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \tag{13}$$

where $CADF_i$ is the t-statistics of β_i from Equation (12).

3.3. Panel cointegration tests

In order to analyze the presence of a long-run equilibrium relationship among the underlying variables, we employ the panel cointegration test proposed by (Westerlund, 2007a). (Westerlund, 2007a) developed the error correction-based panel cointegration test to tackle the issue of cross-sectional dependence across panel members. This test is composed of four different statistics, namely two pooled panel statistics (P_S, P_a) as well as two groups mean statistics (G_S, G_a). The group statistics test the null hypothesis that there is no cointegration relationship for at least one of the cross-sections, while the panel statistics test the null of no cointegration for all the cross-section units. The mean group and panel statistics are derived from the following error correction equation:

$$\Delta y_{it} = \pi_i' d_i + \delta_i(y_{i(t-1)} + \zeta_i' z_{i(t-1)}) + \Sigma_{j=1}^{r}\delta_{ij}\Delta y_{i(t-j)} + \Sigma_{j=0}^{r}\alpha_{ij}\Delta z_{i(t-j)} + v_{it} \tag{14}$$

where δ_i is the adjustment parameter indicating the speed by which the system adjusts back to the long-run equilibrium. Based on Equation (14), (Westerlund, 2007a) derived the following statistics:

$$G_s = N^{-1}\sum_{i=1}^{N}\frac{\delta_i}{SE\left(\widehat{\delta}_i\right)} \tag{15}$$

$$G_a = N^{-1}\sum_{i=1}^{N}\frac{T\delta_i}{\delta_i'(1)} \tag{16}$$

$$P_s = \frac{\widehat{\delta}_i}{SE\left(\widehat{\delta}_i\right)} \tag{17}$$

$$P_a = T\widehat{\delta}_i \tag{18}$$

On the one hand, the group statistics (G_s, G_a) use the individual weighted-average process and individual *t-statistic,* respectively. On the other hand, the panel statistics (P_s, P_a) are computed under the assumption of common error-correction parameters across cross-sections.

3.4. Panel long-run estimates

To correct for bias resulting from the model with slope heterogeneity and cross-sectional dependence, we estimate the continuously updated fully modified ordinary least squares (CUP-FM) and continuously updated bias-corrected (CUP-BC) estimators proposed by Bai et al. (2009). These estimators well behaved under cross-sectional dependence, serial correlation, endogeneity, parameter heterogeneity, and the mixture of I (0) and I (1) variables, as well as heteroscedasticity. We consider the following panel data model with CSD:

$$z_{it} = a_i + bx_{it} + e_{it} \tag{19}$$

$$\text{For} \quad e_{it} = \eta_i' F_t + u_{it} \tag{20}$$

The CUP-FM and the CUP-BC estimators can be defined as follows:

where $\widehat{z}_{it}^{+} = z_{it} - (\widehat{\eta}_i'\widehat{\Omega}_{F\varepsilon i} + \widehat{\Omega}_{u\varepsilon i})\widehat{\Omega}_{\varepsilon i}^{-1}\Delta x_{it}$, and $\widehat{\Omega}_{F\varepsilon i}$ and $\widehat{\Omega}_{u\varepsilon i}$ are the estimated long-run covariance matrices and $\widehat{\Delta}_{F\varepsilon i}^{+}$ and $\widehat{\Delta}_{u\varepsilon i}^{+}$ are estimated one-sided long-run covariance. Following (Bai et al., 2009) the CUP-FM and CUP-BC estimators are obtained by repeatedly estimating long-run covariance and loading factor until convergence is reached.

4. Results and discussion

4.1. Descriptive statistics

Table 1 displays the basic statistics of the variables under investigation for each country. One observation is that China is the highest domestic material consumer per capita (pc), followed by Peru, and

$$\widehat{b}_{Cup} = \left[\sum_{i=1}^{N}\left\{\Sigma_{t=1}^{T}\widehat{z}_{it}^{+}\left(\widehat{b}_{Cup}\right)\left(x_{it}-\bar{x}_i\right)' - T\left(\eta_i'\left(\widehat{b}_{Cup}\right)\widehat{\Delta}_{F\varepsilon i}^{+}\left(\widehat{b}_{Cup}\right) + \widehat{\Delta}_{u\varepsilon i}^{+}(b_{Cup})\right)\right\}\right] \times \left[\sum_{i=1}^{N}\sum_{i=1}^{T}\left(x_{it}-\bar{x}_i\right)\left(x_{it}-\bar{x}_i\right)'\right]^{-1} \tag{21}$$

Table 1
Descriptive statistics of the underlying variables.

	DMP	GDP	MP	OPEN	POP
Brazil					
Mean	2.095	9.046	4.391	2.994	18.836
Std. Dev.	.291	.210	0.558	0.222	0.237
Min	1.489	8.456	3.640	2.666	18.375
Max	2.556	9.392	5.713	3.390	19.152
Chile					
Mean	1.993	8.919	2.909	3.967	16.437
Std. Dev.	0.506	0.448	0.343	.283	0.190
Min	2.358	8.257	2.498	3.123	16.096
Max	3.725	9.600	3.563	4.391	16.731
China					
Mean	3.122	7.009	3.816	3.225	20.853
Std. Dev.	.721	1.121	0.894	.720	0.155
Min	.945	5.433	2.774	1.593	20.522
Max	3.206	8.896	5.745	4.166	21.049
Egypt					
Mean	1.650	7.363	4.588	3.864	17.889
Std. Dev.	.309	.415	0.696	0.247	0.306
Min	1.094	6.593	3.781	3.404	17.356
Max	2.071	7.943	6.040	4.310	18.384
India					
Mean	1.256	6.562	5.316	3.064	20.627
Std. Dev.	.228	0.506	0.530	.598	0.269
Min	.966	5.944	4.440	2.036	20.134
Max	1.710	7.594	6.153	4.0216	21.014
Indonesia					
Mean	1.592	7.517	4.841	3.910	19.037
Std. Dev.	.309	.472	0.646	.206	.244
Min	1.169	6.649	3.822	3.356	18.558
Max	2.128	8.323	6.187	4.566	19.393
Korea					
Mean	2.266	9.093	4.216	4.920	17.579
Std. Dev.	.549	0.835	0.896	.316	.136
Min	1.151	7.503	3.282	4.295	17.288
Max	2.896	10.173	6.626	5.395	17.754
Malaysia					
Mean	2.449	8.558	3.557	3.630	16.769
Std. Dev.	.393	.516	0.413	.234	0.331
Min	1.695	7.557	3.084	3.115	16.195
Max	2.946	9.369	4.458	4.067	17.258
Mexico					
Mean	1.937	9.003	4.696	4.160	18.269
Std. Dev.	.209	.162	0.466	.302	.257
Min	1.485	8.616	4.152	3.667	17.756
Max	2.206	9.240	5.804	4.684	18.642
Peru					
Mean	2.299	8.227	3.624	3.950	16.923
Std. Dev.	0.295	.238	0.383	0.148	0.253
Min	1.910	7.859	3.066	3.624	16.415
Max	2.757	8.750	4.187	4.288	17.263
Philippines					
Mean	1.453	7.432	5.159	4.138	17.991
Std. Dev.	0.137	.201	0.516	.271	.326
Min	1.291	7.136	4.172	3.483	17.393
Max	1.756	7.967	5.844	4.700	18.471
South Africa					
Mean	2.786	8.775	3.170	3.608	17.449
Std. Dev.	.226	.094	0.277	0.484	.284
Min	2.417	8.615	2.756	2.794	16.909
Max	3.171	8.933	3.688	4.346	17.858
Total					
Mean	2.075	8.125	4.190	3.786	18.222
Std. Dev.	0.649	1.005	0.942	0.633	1.376
Min	0.945	5.433	2.498	1.593	16.096
Max	3.725	10.173	6.626	5.395	21.04

Note: Std Dev.: Standard Deviation; Min: Minimum; Max: Maximum.

South Korea. India and Indonesia are the lowest domestic material consumer with an annual average value of 1.256 per capita (pc) and 1.592 pc, respectively. Although, considerable quantities of material or resources are consumed in China, Peru, and South Korea, however, rising real GDP per capita can be considered as a substantial driver of the demand for material in these countries. Interestingly, real GDP per capita has the highest annual average value among all the variables under consideration.

Coming to material productivity (expressed as economic output created per unit of material consumption), we report that India (5.316) and The Philippines (5.159) have the highest material productivity annual average value per capita. This finding indicates considerable improvements in terms of decoupling between economic growth and material consumption in India and The Philippines.

Conversely, South Africa, and Chile have the lowest material/ resource productivity per capita, with an annual average value of 3.170 and 2.909, respectively. This highlights the fact that increasingly more material consumption translates into lesser economic output in these countries. However, for other emerging countries, we observe a stable annual average of material productivity.

Table 2 reports the correlation matrix among variables. The output implies a significant, positive, and high-level (highest) correlation of ($r = 0.778$) between real GDP per capita and domestic material consumption per capita. In addition, we report a positive and significant correlation between trade openness and material consumption as well as between population size and material consumption, with the following correlation coefficients $r = 0.289$ and $r = 0.166$, respectively. As expected, we observe a negative and highly significant correlation between resource productivity and material consumption. The correlation matrix yields preliminary relationships among variables; however, we need to perform a formal analysis to confirm/contradict these outcomes.

4.2. Cross-sectional dependence (CSD) and slope homogeneity tests

The presentation in Table 3 shows that the null of no cross-sectional dependence is strongly rejected at 1% level of significance for the *LM* test developed by (Breush and Pagan, 1980) as well as the scaled version of *LM* test proposed by (M.Hashem Pesaran, 2004). As expected, this outcome implies that a shock occurring in one country is translated to other emerging countries mainly due to trade and financial linkages between emerging market countries (see Table 3).

In addition, Table 3 highlights the findings from the slope homogeneity tests. In this study, we found that the slope homogeneity tests advanced by (Pesaran et al., 2008) strongly reject the null hypothesis of slope homogeneity, supporting the occurrence of slope heterogeneity across panel members.

4.3. Panel unit root tests

Evidence for slope heterogeneity and CSD imply that the application of conventional panel unit root techniques are not valid in the present study due to low statistical power of these tests. Consequently, we employed the second-generation panel unit root tests developed by (Pesaran, 2007a,b) namely, i.e. CADF and CIPS panel unit root tests.

The empirical results from the CADF tests indicate that only resource productivity and population size are stationary at level with intercept and trend, whereas all the variables become stationary at first difference. Turning to the CIPS unit root tests, we find that all the variables contain unit root problem at level with intercept and trend, suggesting that the variables are integrated at I (1). These outcomes as indicated in

Table 2
Correlation matrix.

	DMP	GDP	MP	OPEN	POP
DMP	1				
GDP	0.778[c]	1			
MP	−0.723[c]	0.414[c]	1		
OPEN	0.289[c]	0.470[c]	0.138[c]	1	
POP	0.166[c]	−0.508[c]	−0.605[c]	−0.373[c]	1

a $p < 0.05$.
b $p < 0.01$.
c $p < 0.001$.

Table 3
CSD and slope homogeneity tests.

Test	Statistic	
Cross-sectional dependence tests		
LM	1097.651[a]	(0.000)
CD_{LM}	88.749[a]	(0.000)
Homogeneity tests		
Δ	22.650[a]	(0.000)
$\tilde{\Delta}$	28.610[a]	(0.000)

Note.
[a] Denotes significance level at 1%.

Table 4
CADF and CIPS unit root tests.

Test	CADF		CIPS	
	Level	1st Diff.	Level	1st Diff.
DMP	−2.024	−4.299[a]	−1.894	−5.756[a]
GDP	−1.977	−3.622[a]	−1.370	−4.323[a]
MP	−2.173[c]	−4.035[a]	−1.619	−5.344[a]
OPEN	−1.807	−4.440[a]	−1.652	−5.665[a]
POP	−2.421[a]	−3.597[a]	−1.777	−2.709[a]

Note: −2.140, −2.250, and −2.440 are critical values at 10%, 5% and 1% level, respectively.

Table 5
Results from panel cointegration tests.

Stat	Value	Asymp p-value	Bootstrap p-value
Gs	−3.592[a]	0.000	0.000
Ga	0.053	0.521	0.147
Ps	−3.916[a]	0.010	0.000
Pa	−2.280[a]	0.029	0.000

Note: [a], [b] represent a significance level at 1% and 5%, respectively.

Table 4 allow us to investigate the cointegration relationship among variables in the next sub-section.

4.4. Panel cointegration

The illustration in Table 5 depicts the empirical results of (Westerlund, 2007a,b) cointegration test. This cointegration test can effectively control parameter heterogeneity as well as CSD in the long-run relationship through bootstrapping. From Table 5, we observed that the bootstrap (p-value) is statistically significant at the conventional levels, which supports the evidence that there exists a long-run relationship among domestic material consumption, economic growth, material productivity, trade openness, and population size.

4.5. Long-run estimations

4.5.1. Linear model

In Table 6, the linear estimation results for emerging countries is illustrated. For the sake of robustness, we employed both the CUP-FM and CUP-BC estimators. As expected, economic growth captured by real GDP per capita increases the consumption of material in emerging countries. From the CUP-FM and CUP-BC results, we discovered that a 1% increase in economic growth will lead to an increase in domestic material consumption by 0.612 and 0.566, respectively. These relatively high levels of economic-material coupling in emerging countries show that the current modes of economic development in these countries are fundamentally unsustainable. This outcome is in line with our argument that the richer a country gets, the more materials it consumes. By this finding, it means that economic growth is a key driver of material/resource consumption in emerging countries, which is in line with several previous papers (Agnolucci et al., 2017; Dong et al., 2017; Schaffartzik et al., 2014; Steinberger et al., 2013).

Among the drivers of domestic materials use, we find that improving material/resource productivity through technological enhancement and innovation negatively and significantly affects material consumption per capita. As expected, we report that a rise in material productivity is a necessary condition for reducing material consumption and the overall environmental pressures associated with the use of materials. This outcome matters for sustainable development in the context of the dematerialization of the global economy. A negative impact of technological enhancement on material consumption was as well revealed in previous studies (Shah et al., 2020; Ulucak et al., 2020). In addition, we report that international trade openness is responsible for a much larger domestic material consumption in emerging countries. This finding implies that trade liberalization increases primary material flows across countries, thus causing potentially disastrous environmental consequences. As evidenced by (Schütz et al., 2004), in the course of trade liberalization, primary material use increases through policies to promote the imports of materials/resources from the developing countries in order to shift environmental burdens related to material extractions on to the developing countries. Surprisingly, we find that population size does not significantly influence domestic material consumption in emerging countries across both specifications.

Overall, our baseline results from the linear specification are consistent with the expectations and with previous evidence. However, the baseline outcome does not yield evidence about the behavior of domestic material use across economic cycles. Building on the theoretical framework of Modigliani's life cycle hypothesis, one may expect that the dynamics of economic over the life cycle can significantly shape the pattern of material consumption in emerging countries (Ando and Modigliani, 1963; Spiro, 1962). We expand this theoretical framework by examining the possible asymmetric in the dynamics of material consumption over episodes of economic expansion and contraction in emerging countries.

Table 6
Linear effects of economic growth on DMP.

$DMP_{it} = \lambda_1 GDP_{it} + \lambda_2 RP_{it} + \lambda_3 OPEN_{it} + \lambda_4 POP_{it} + e_{it}$

	CUP-FM	*t-statistic*	*CUP-BC*	*t-statistic*
λ_1	0.612[a]	7.500	0.566[a]	4.005
λ_2	−0.057[a]	−11.190	−0.063[a]	−17.836
λ_3	0.338[a]	7.526	0.309	1.035
λ_4	0.005	0.221	0.011	0.233

[c], [b], [a] denote significance level at 10%, 5%, and 1%, respectively.

4.5.2. Nonlinear model

Table 7 shows the results for the nonlinear model by computing the effects of economic expansion and economic recession on domestic material consumption. It is important to bear in mind that negative changes (GDP^{-}) capture a slowdown in economic growth and positive changes in GDP (GDP^{+}) capture episodes of ascending economic growth.

Table 7
Nonlinear effects of economic growth on DMP.

$DMP_{it} = a_1 GDP^{+}_{it} + a_2 GDP^{-}_{it} + a_3 RP_{it} + a_4 OPEN_{it} + a_5 POP_{it} + e_{it}$

	CUP-FM	*t-statistic*	*CUP-BC*	*t-statistic*
a_1	0.118[a]	4.396	0.140[c]	1.989
a_2	0.016[a]	6.160	0.005[b]	2.261
a_3	−0.018	−1.101	−0.030[a]	−6.575
a_4	0.016	1.223	0.072[a]	6.513
a_5	0.003[a]	2.452	0.001[a]	4.180

[c], [b], [a] denote significance level at 10%, 5%, and 1%, respectively.

With this background, positive changes in GDP (GDP^{+}) will be a positive quantity, and a positive (negative) estimated coefficient associated with GDP^{+}implies a positive (negative) impact on domestic material consumption, respectively. Conversely, during episodes of recession (GDP^{-}) will be a negative quantity and a positive (negative) value of the estimated coefficient associated with GDP^{-} means a decrease (increase) in material consumption, respectively.

The findings show that the occurrence of expansion positively and significantly influences material consumption, while episodes of descending movements in economic growth negatively affect material consumption. This outcome is robust across both specifications CUP-FM and CUP-BC. One observation is that the increase in material consumption during an economic expansion is greater than the decrease in material consumption triggered by the economic recession. As a result, material consumption tends to react more strongly to positive changes in economic growth in emerging countries. This finding again confirms our baseline outcomes regarding the high levels of economic-material coupling in emerging countries. Thus, emerging countries have not reached the level of economic development able to decouple their economic development from primary material consumption (Zhang et al., 2017). The negative effect (even close to zero) of economic recession on materials use in emerging countries provides evidence in favor of the lower degree of dematerialization during the recession. Similar conclusions have been found by (Wu et al., 2019), who showed that material consumption tends to react less strongly during episodes of economic contraction mainly because of the predominance of biomass in their primary materials.

Concerning the drivers of domestic material consumption, one may claim that the effects of material productivity, trade openness, and population size are consistent with our baseline model. Specifically, we find a statistically significant decrease in material consumption due to improvements in material productivity, suggesting the moderating effect of material productivity on materials use. However, this moderating effect of RP is not sufficient enough to offset the increase in material consumption observed during economic expansion. In addition, we find that trade openness and population size positively and significantly influence materials used in emerging countries. The impact of trade openness is not robust across both specifications, while the positive impact of population size on materials consumption is marginal (close to zero). This is indicative that population size is not a key driver of material consumption in emerging countries.

5. Discussion

Dematerialization of the global economy has become a major concern for all countries and international institutions. In this study, we sought to understand the dematerialization of economic development by examining the patterns of material consumption with respect to economic cycles in 12 emerging countries over the period 1970–2017. We applied the consumption-income theoretical framework to investigate the sensitivity of materials use to income shocks from a linear and nonlinear perspective.

We found a strong relationship between material consumption and economic growth, and across panel members, there is also evidence that economic growth significantly increases material consumption. The empirical outcomes provided support for high levels of economic-material coupling in emerging countries (Table 6). The implication of our finding is that the current modes of economic development in the sample of emerging countries are fundamentally unsustainable. This conclusion is shared by (Canas et al., 2003; Zhang et al., 2017). In addition, we examined the possible nonlinearity in material consumption dynamics over economic cycles. In doing so, we decomposed economic cycles into episodes of recession and expansion and studied the sensitivity of material consumption to economic cycles. Overall, the analysis proves the presence of asymmetry in the patterns of material consumption in response to positive and negative changes in economic growth.

The empirical outcomes are in concordance with the lower degree of dematerialization during the economic recession while episodes of economic expansion are coupled with higher levels of material consumption in emerging countries. A salient feature of this outcome is that during economic recessions, emerging countries cut their demand for raw materials and stimulates the export to improve the economy. In addition, economic expansion fosters material stock demand from a consumption side, which can be explained by the current level of developmental stage in the emerging countries under investigation. As discussed by (Ulucak et al., 2020), in the initial stages of economic development the material use increases as a result of scale effect, however, after a certain threshold of economic growth, the dematerialization of the economic systems occurs mainly due to sustainable materials use policies and technological enhancements.

Improving material productivity is shown to provide a strong foundation for mitigating material consumption. This argument was shared by several papers (Shah et al., 2020; Ulucak et al., 2020), and as such, policymakers should consider this component as a way to curb materials use and promote sustainable development simultaneously. However, we revealed that the moderating effect of material productivity is not sufficient enough to offset the increase in material consumption observed during economic expansion. Concerning the drivers of domestic material consumption, trade openness seems to be an important driver of material consumption, while the effect of population size is relatively small or close to zero.

6. Conclusion and policy mechanism

This study examined the dynamic patterns of material consumption with respect to economic cycles in 12 emerging countries over the period 1970–2017. This study is innovative and contributes to the literature by examining those dynamics through linear and nonlinear frameworks. The nonlinear model allows the nature of the effects of both economic recession and expansion on domestic material consumption dynamics. This is of sound importance for policymakers, given that they can effectively implement material management policies in accordance with the phase of the economic cycle.

The prevailing cross-sectional dependence, endogeneity, and parameter heterogeneity are addressed by the estimation techniques. More specifically, we employed the continuously updated fully modified ordinary least squares (CUP-FM) and continuously updated bias-corrected (CUP-BC) estimators proposed by Bai et al. (2009). In this study, we investigated the triggers of material consumption, from the perspectives of potential dematerialization of economic growth, improvements in resource productivity, trade openness, and population size. The adoption of the panel time-series approach enabled us to estimate the stochastic properties as well as the cointegration relationship between material consumption and the underlying variables.

Our analysis using a STIRPAT framework indicated that increasing economic growth made the most important contribution to increasing material consumption. In particular, we shed light on the understanding of material consumption dynamics during episodes of recession and expansion. Economic expansion constitutes periods of increase in material consumption mainly due to the consumption side effect of expansion, while economic recessions curb the levels of material consumption and lead to a new adjustment to reduce imports of materials/resources. Our study confirms that, under this situation, the occurrence of an economic recession is associated with economic dematerialization.

Indicatively, policymakers should understand the dynamics of material consumption during different phases of the economic cycles, thus ensuring a sustainable and attitudinal change in line with the material consumption during the stage of economic expansion. The implementation of policy that enhances resource efficiency in order to enable a more balanced material consumption during the economic cycle is essential for shaping sustainable development in emerging countries.

This is because the current evidence posited that improvements in material productivity lead to a relative decoupling, thus reducing the levels of material consumption. Effectively, the current finding provides evidence against the Jevons paradox which holds that a technology that enhances productivity does not necessarily lead to less consumption of material resources (Wu et al., 2019). Then, from a policy perspective, policymakers can adopt policies to improve material productivity. For instance, ambitious environmental policies to improve material innovation and reuse materials and recycling. Turning to socio-economic determinants, population size has a marginal effect on material consumption, whereas trade openness significantly promotes the consumption of material in emerging economies. Another application of these results is that policymakers can consider the effects of these socioeconomic drivers of material consumption when implementing material management policies. Considering that China previously employed a strict population engineering policy in response to the country-specific population trend, population education among other mechanisms could be employed to dissuade cultural and attitudinal misperceptions. In addition, as opined by Alola (2019a & b), trade policies that incorporate environmental guidelines and innovative standardization from the raw material production to the end-product utilization of goods and services could ensure a sustainable domestic material consumption.

CRediT authorship contribution statement

Yacouba Kassouri: Data curation, Writing - original draft, Conceptualization, Formal analysis, Investigation, Methodology. **Andrew Alola:** Writing - review & editing, Visualization, Corresponding. **Savaş Savaş:** Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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