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# Revisiting the Solow-Swan model of income convergence in the context of coffee producing and re-exporting countries in the world

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ABSTRACT

The purpose of this paper is to investigate the Solow-Swan's proposition that poorer countries grow faster than richer countries causing declining income disparities across countries. The role of coffee trade in income convergence is also analyzed to enrich our understanding of whether traditional cash export crops, like coffee, contribute significantly to income convergence. We found that, GDP per capita was growing faster among coffee producers than coffee re-exporters, supporting the Solow-Swan's model. However, coffee export values and shares decreased with convergence for green coffee producers while increasing among re-exporters, implying unequal distribution of benefits along the global coffee value chain.

## 1. Introduction

Over the past few decades, the debate on economic growth and income convergence across countries has attracted several scholars in the economic development literature with $\sigma$-convergence and $\beta$-convergence widely applied as standard concepts of income convergence. The concepts were framed by Barro and Sala-i-Martin [1] based on neoclassical growth model. The debate on economic growth and income convergence has mainly gained momentum since the seminal work of Baumol [2], though it can be traced back to the most classical Solow Model of economic growth, which provided profound insights into the causes of growth bringing into attention the concept of income convergence across countries [3,4]. The Solow-Swan growth model is therefore extensively applied as the standard neoclassical approach to explain growth and income convergence [5–11]. The concept is centered on the hypothesis that the initial conditions of a country have no implications on its long-run per capita income because poor countries will tend to grow faster than the rich and eventually catch up with them, causing disparities in income levels across countries to decline over time [12]. The model predicts more rapid growth when the level of physical capital per capita is low, as a result all economies should eventually converge in terms of per capita income. Developing countries are therefore considered as having the potential to grow at faster rates than developed countries because diminishing returns, in particular to capital, are not as salient as in capital-rich countries.

Among others, the debate on economic growth and income convergence attempts to answer the following two major questions: have developing countries made progress in closing the income gap between themselves and the developed countries? What are the factors which drive the convergence or rather divergence across countries? These questions have been dealt with by numerous scholars, both from inter–regional and international perspectives [1,13–20]. However, the findings which have emerged from these studies tend to be quite polarised with some appearing to strongly reject the hypothesis of the Solow-Swan growth model while others accept it. For example, some studies indicate that developed countries tend to converge in terms of per capita income, but the world as a whole does not [20]. Many studies also indicate that countries with a low to medium-high level of development show signs of convergence, but countries with a medium-high to a very high level of development show signs of divergence (ibid).

The existing paradoxes regarding the concept of income convergence call for more robust empirical research to validate the hypothesis of the

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Solow-Swan model. This is even becoming more important now than ever as the landscape of international trade and value chain governance changes, altering the portfolio of global economy by subscribing to a more heterogeneous nature of economic growth among developing and developed countries. Studying the linkage between international trade and income convergence is also becoming imperative following the wide recognition of trade as a key factor for the 2030 Agenda and the desire to combat poverty and achieve sustainable economic growth [21]. Accordingly, the Sustainable Development Goal (SDG) number 10 and SDG target 17.11 aim to reduce inequality within and among countries and significantly increase the exports from developing countries, and in particular with an initial target of doubling the LDCs' share in global exports by 2020, which has so far proven to be a very ambitious endeavor.

Using a more contemporary approach and time series data spanning from 2001 to 2019, this paper examines the concept of income convergence and its drivers. The study uses the case of coffee producers in developing countries and coffee re-exporters in developed countries to represent the poor and rich countries respectively. The idea is to investigate whether low income green coffee producing countries are catching up (in terms of GDP per capita) with their counterpart richer coffee re-exporting countries in the face of changing global value chain governance, structure and outcomes. Coffee is chosen in this study because of its historical importance as one of the world's largest traded commodities. Over years, coffee has been grown as an important traditional cash crop and a factor of growth in many coffee-producing countries [22]. The available statistics, for example, show that approximately 125 million people worldwide depend on coffee to support and maintain their livelihoods [23] with approximately 60 million people being involved in the annual production of 8.5 million tons of green coffee [24] the majority of which being exported to the United States and Europe [25]. Importantly, coffee is a universally popular drink among consumers, with over US$50 billion in retail sales a year (ibid).

More specifically, our study tests the proposition of the Solow-Swan model that poorer countries grow faster than richer countries and that the distribution of income across economies becomes more equitable over time. Using the case of coffee, we also test the proposition that international trade triggers or at least speeds up income or per capita GDP convergence across countries. The study is imperative and novel due to its peculiar focus on coffee producers in developing countries and re-exporters in developed countries. To the best of our understanding, income convergence studies that focus on international trade in traditional cash export crops such as coffee, cashew, pyrethrum, and others are scarce. Another novelty of our study is the comparison of GDP per capita convergence using the variants of $\sigma$-convergence (the CV-test) and weighted $\beta$-convergence test. Most of the previous studies have used either a single metric [26] or where more than one measures are used, the comparison has mostly centered on the conventional $\sigma$-convergence and un-weighted $\beta$-convergence measures [19,27,28,29]. The advantages of using more than one contemporary measure cannot be overemphasized here. Ram [30] recommends researchers not to rely heavily on one measure of convergence and that they should consider alternative measures for drawing conclusions on income convergence. In line with this, Boyle and McCarthy [31] propose the use of an index of rank concordance in addition to $\sigma$-convergence in testing for $\beta$-convergence. To illustrate the importance of using more than a single measure of convergence, Ram [30] applies two variants of $\sigma$-convergence; CV and standard deviation of logarithms (SDLOG) to test income-convergence for a large cross-country sample covering the period 1960–2010. His findings show that while the two measures yielded qualitatively similar scenarios and indicated income convergence over the period; large differences were observed in the rate of change in income inequality with SDLOG indicating divergence at a much higher rate than CV.

To enrich our analysis, we also run two multiple linear regression models independently for coffee producers in developing countries and re-exporters in developed countries respectively. The second model (coffee re-exporters' model) is purposely added to the analysis to enable the comparison of factors influencing GDP per capita convergence between coffee producers in developing countries (poorer countries) and re-exporters in developed countries (richer countries). This comparison was necessary for testing the proposition and hypothesis of the Solow-Swan model. It was also important for ensuring a more representative analysis of global coffee trade as it includes value addition by coffee re-exporters in developed countries. In the next section, we present and discuss the theoretical as well as empirical frameworks underlying the study, including the previous studies on income convergence and the landscape of key value chain governance structures and outcomes that have occurred in the global coffee industry between 1960s and 2000s. The sources of data and empirical analysis are presented in Section 3, followed by the presentation of empirical results in Section 4. The findings of the study and research implication are discussed in Sections 5 and 6 respectively. The study limitations and areas for future research are presented in Section 7, followed by concluding remarks in Section 8.

## 2. Literature review

### 2.1. Theoretical framework

Our theoretical review of literature indicates a general lack of consensus among economic growth scholars regarding the theory of convergence (i.e. whether regions within an economically integrated area will tend to converge to a common level of per capita income or not). On the one hand, there is the neoclassic economic growth perspective which predicts that factor incomes in all parts of an integration area will eventually converge given that satisfactorily strong adjustment mechanisms within the integration area occur [1–11]. This perspective is grounded on the standard neoclassical assumptions, such as, production technologies are identical and exogenously given across countries, returns to scale are constant, and production factors are imperfect substitutes [32]. As initially suggested by Solow [3] the income convergence theory is based on the following production function:

$$Y = eT^{*}F(K, L) \tag{1}$$

Where $Y$ is the total output, produced with a given quantity of the production factors labor ($L$) and capital ($K$); $eT$ is the total factor productivity variable, representing the technology used in the economy.

The theory assumes that technology spreads rapidly and can therefore be regarded as identical in all countries or regions and changes in the technology variable are exogenously determined. Assuming a Cobb–Douglas production function, the functional form of Eq. (1) can be expressed as follows:

$$Y = eT^{*}K(t)^{a}\ L(t)^{1-a} \tag{2}$$

The specification that $a + (1 - a) = 1$ satisfies the assumption of constant returns to scale (CRS) which means that a doubling of both production factors together exactly doubles the output produced. Independently, however, the production factors yield decreasing returns to scale $(a < 1; (1 - a) < 1)$ [32]. State differently, the more one increases the input of only one factor, the lower is the marginal return from this increase. The assumptions in this model lead to the conclusion that there is an optimal ratio between capital and labor, denoted $k^{*}$. When the expected (optimal) ratio ($k^{*}$) is reached, per capita growth is only possible due to technological progress, which is assumed to be exogenous to the economy. However, there are many concerns regarding the optimal ratio ($k^{*}$) and the observed non-optimal ratio ($k$). If the observed non-optimal ratio ($k$) is smaller than the optimal ratio ($k^{*}$), individuals can optimize $k$ by increasing their savings rate and using these savings for investments. If the observed ratio ($k$) is larger than the expected (optimal) ratio ($k^{*}$), people can reduce savings and investments.

On the other hand, there is a counter-perspective, 'the divergence theory" which predicts increasingly uneven spatial distribution of economic activity due to economic phenomena, such as, increasing returns to scale, positive agglomeration of externalities and transport costs. In line with this school of thought, Wyplosz [33] used the relationship between labor productivity and income per capita to illustrate how elusive convergence is. He highlighted that: "… many exceptions to the Solow model's assumptions can be invoked, including that of market and policy imperfections, such as, national preferences …, skill heterogeneities, welfare protection or presence of the powerful vested interests …" Wyplosz [33] concluded that there are a number of well-known inefficiencies in the labor and goods markets which have contributed to divergence.

In this regard, it is important to briefly revisit the theory developed by Kaldor [33–35] which proposes that "increase in demand induced by export growth affects productivity positively, leading to improvements in the price competitiveness for exports (assuming wages to be constant). According to this theory the latter (improvements in the price competitiveness for exports) will lead to further increases in the rates of growth in exports and GDP" (see also Dixon and Thirlwall, [36]) and the most likely outcome would be one of countries growing at different rates, reflecting differences in structural characteristics, which implies divergence rather than convergence in productivity levels. Along a similar viewpoint, Easterliny [37] made two important conclusions: firstly, convergence of income levels ought not to be held as a definite and predictable result of the process of trade and economic development. Secondly, while trade and free movement of labor may exert some pressure towards convergence of wages and income, there are other dynamic processes that can impede the equilibrating effects of trade in resources and goods.

The proposition that trade and efficient markets ensure long-run equilibrium among regional and international income flows in a changing environment has also been challenged by many scholars, including Eberts [38] who suggested information asymmetry and discrepancy between worker skills and job requirements, as well as, institutional barriers to mobility, often lead to incomplete adjustment in wages and persistent differences in regional income levels. Thirlwall [39] also sees some potential constraints of balanced trade and he argues that export-led growth models may overestimate growth. He concludes that the growth rate of a country's GDP relative to the rest of the world depends on the relation between the demand elasticities for its exports and imports (i.e. structural aspects of the economy). His conclusion implies that a country that produces goods which are in high demand both at home and abroad will grow faster. In fact, Thirlwall [39] argues further that "not only the elasticity of exported and imported goods along with the growth rate of international income matter for the determination of the output growth performance, but also the share of each good in exports and imports." Our paper also tests this proposition by adding the share of coffee exports to GDP as one of the control variables in the convergence models.

### 2.2. Empirical review

#### 2.2.1. Previous studies on income convergence

As for the theories, the previous empirical studies indicate controversial nature, causes and speed of income convergence between developing and developed countries [40]. The study by Johnson and Papageorgiou [41], showed that, as a group, developing countries have not made progress in closing the income gap from the advanced economies though they further agree that global inequality has tended to fall since 2000. Using the Augmented Solow model and a panel analysis of 69 countries covering a period of over 39 years, spanning from 1980 to 2018, a recent study by Mensah [20] also found no evidence of absolute convergence from the test of growth convergence (both absolute and conditional). Yet, she found strong evidence of the presence of conditional convergence across countries and within regions after controlling for investment, population growth, and human capital. Her findings suggest that countries with similar characteristics tend to converge in per capita income in the long run. As a result, poor countries can be made to converge to prosperity if they could adopt or attain the socio-economic structures and productivity levels in rich countries. Mensah's results also show that macroeconomic variables have significant effects on the rate of convergence in income growth rates.

Another relevant finding is reported by Kremer et al. [42] who revisit cross-country convergence patterns over the last six decades and provide evidence that the lack of convergence, as observed in the earlier study, has now been replaced by modest convergence. They furthermore argue that this relationship is driven by convergence in various determinants of economic growth across countries as well as flattening of the relationship between these determinants and growth. However, another recent work by Acemoglu and Molina [43] finds no evidence of major changes in patterns of convergence and, more importantly, no flattening of the relationship between institutional variables and economic growth. Acemoglu and Molina [43] further argue that the results by Kremer et al. [42] were driven by the lack of country fixed effects controlling for unobserved determinants of GDP per capita across countries. They show theoretically and empirically that failure to include country fixed effects will create a bias in convergence coefficients towards zero and this bias can be time-varying, even when the underlying country-level parameters are stable.

Elsewhere, Baumol [2] found a significant negative correlation between initial levels of productivity and productivity growth. His findings supported the existence of absolute $\beta$ -convergence. However, in another study where the sample was extended to include less developed countries, Baumol and Lee [44] found no evidence of convergence. The notable conclusion reached by the two studies was that countries with similar economic, political, and social environments appear to converge with each other, while the world as a whole does not. Baumol's finding was also confirmed by Barro and Sala-i-Martin [1] in their study of convergence across the 48 US states. Using data on personal income and the gross state product over a long-term period of about a century, they found evidence of convergence among the states. However, they argue that their result can be reconciled with the neoclassical model only if diminishing returns to capital set in very slowly. Moreover, they found evidence of conditional convergence when they extended their study to a broad cross-section of countries and included human capital into their econometric model.

#### 2.2.2. The global coffee trade

Overall, the available literature indicates that the global coffee industry has undergone substantial structural changes since early 1960s and 2000s (Fig. 1) that influence trade and income distribution along its global value chain. These changes are characterised, among others, by increasing integration and organisation in the commodity value chain with coordination happening mainly downstream the value chain [45]. The evolution of the global coffee production, harvested area, yield and exports is summarized in Appendix 1.

The following key coffee trade-related governance reforms and outcomes are noted. Firstly is the signing of the first International Coffee Agreement (ICA) by most coffee producing and importing countries in 1962, which is recognized as one of the most renowned reforms in the value chain as it aimed to spread industry knowledge and improve the economic conditions of small-scale coffee farmers. Secondly, the increasing volume of coffee on the market and the steady move towards cheaper imports were observed, which undermined the ICA coordination effort and altered the trade dynamics, at both global and domestic levels, leading to the breakup of the Agreement. Thirdly, the change of global value chain structure from supply and demand fixated to a more buyer-driven chain. In this case, the supply chain became dominated by a small number of large multinational traders and roasters, imposing requirements on the other actors along the chain. Fourthly, the establishment of Association of Coffee Producing Countries (ACPC) between 1993 and 2002 has aimed at reviving some control over coffee production and export flows. Unfortunately, the coordination among

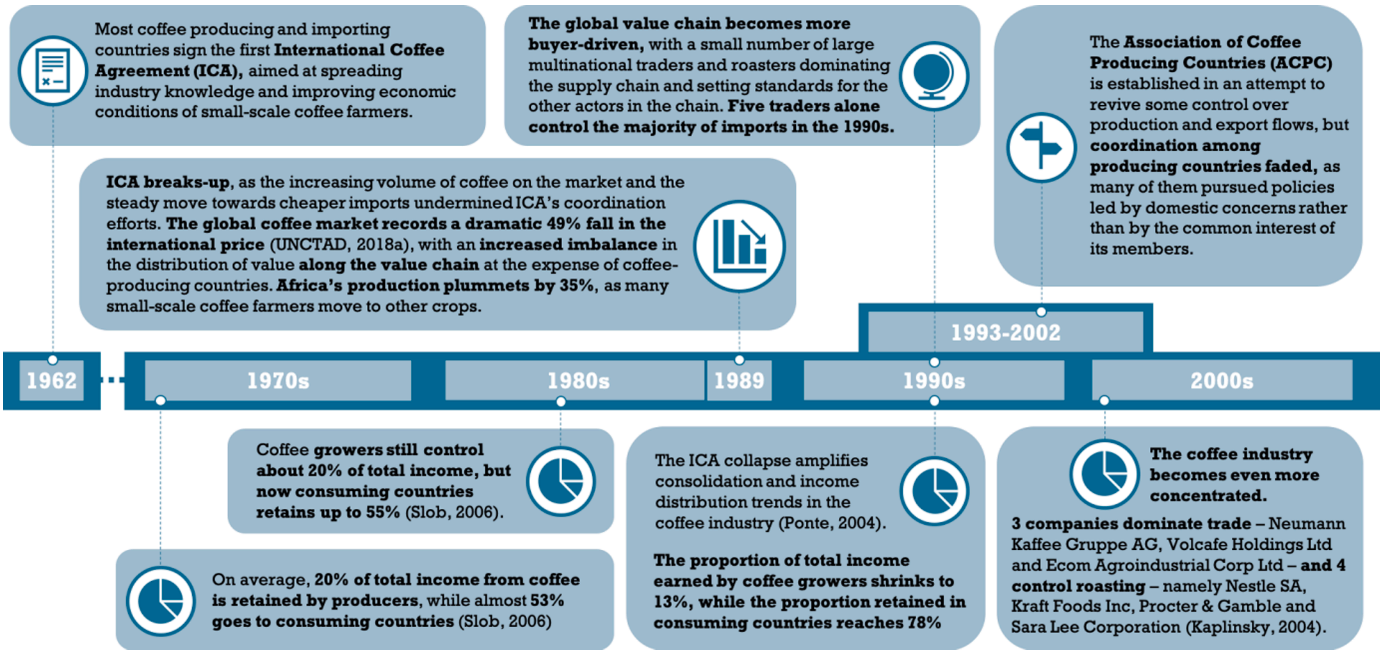



**Fig. 1.** Key global coffee trade governance reforms and outcomes.

producing countries faded as many of them pursued deviating policies led by domestic interests rather than their common economic goals. The key outcomes from these reforms were:

(a) By 1970, an average of 20% of total income from coffee was retained by producers, while the average proportion being appropriated in consuming countries was almost 53% [46].
(b) Between 1980 and 1995, coffee growers controlled about 20% of total income with 55% being retained in consuming countries (ibid).
(c) The global market recorded a dramatic fall in the international coffee price by 49%, following the break-up of ICA in 1989 [45], contributing to an imbalance in the distribution of value along the value chain at the cost of coffee-producing countries, with Africa's production plunging by 35% as a result of many small-scale coffee farmers moving to safer crops (ibid).
(d) Many coffee importing countries abolished import duties on green coffee in an attempt to revive some control over coffee production and export flows, with import taxes for processed coffee varying depending on the types of economic partnership or bilateral trade agreements with producer countries. For example, coffee producing countries in Africa, such as Cameroon, Côte d'Ivoire, Kenya, Papua New Guinea, and Uganda have benefited from partnership agreements with the European Union, which exempt them from import duties for green and processed coffee (see the report by the European Coffee Federation).
(e) The collapse of ICA amplified consolidation in the coffee industry and affected the distribution of total income generated along the coffee value chain between 1989/90 and 1994/95 [47]. During this period, the proportion of total income earned by coffee growers shrank to 13% and the proportion retained in consuming countries increased to 78% (ibid).
(f) By the early 2000s, the trading stage of the coffee chain became more concentrated with just three companies dominating: Neumann Kaffee Gruppe AG (the Germany NK Group); Volcafe Holdings Ltd. (the Swiss Volcafe Group); and Ecom Agro-industrial Corp Ltd. (the Swiss/Spanish Ecom Coffee Group) and four main roasters, namely, Nestlé SA (Switzerland); Kraft Foods Inc (USA); Procter & Gamble (USA); and Sara Lee Corporation (USA) [48].
(g) Global green coffee production has doubled in quantity since 1980, although the total area remained fairly constant (see Appendix 1a).
(h) The top 3 producer countries (Brazil, Vietnam and Colombia) account for almost 55% of the global coffee production in 2019 (see Appendix 1a).
(i) The total area globally devoted to coffee production remained fairly constant over time, oscillating between around 10 and 11 million hectares since 1980 (see Appendix 1b).
(j) Yields have been on a steady upward trend, tripling in some of the top coffee producing countries. Top yields are up to 3 tonnes/ha, compared to a world average of around 1 tonne/ha (see Appendix 1c).
(k) Global coffee exports have more than doubled since 1980; reaching almost 8 million tonnes in 2019 (see Appendix 1d).
(l) The coffee re-exports as a share of total exports for the period 1990–2019 have averaged at 5.4% (see Appendix 1e).

Overall, there are a huge and growing number of empirical studies which confirm that the global (international) coffee trade has been characterized by existence of unequal share of benefits along its value chain. The United Nations Statistical Division [49] for example, reported coffee sales to amount to 19 billion US$ in 2017 but there have been significant imbalances in the financial flows between producing and importing countries since early 2000s with only a small percentage of the purchase price for green coffee remaining in producing countries [50,51]. Even where coffee is sold via sustainability arrangements and certification (which constitutes about 25% of total coffee traded globally according to Lernoud et al. [52]), this often does not improve small-holder farmers' livelihoods [53], but rather benefits roasters or retailers [54–56].

The study of global coffee value chain by Ponte [47] and many others, such as, UNCTAD [45] and Slob [46] actually attribute these outcomes to lack of a strong amalgamation and power among coffee producers, especially after the collapse of ICA, which trigger dramatic decreases in coffee prices at the international market. This in turn has increased imbalance in the distribution of benefits along the value chain at the cost of coffee exporting countries: the proportion of total income earned by coffee growers in developing countries shrinks while the share retained in consuming countries grows.

Export diversification could be one of the options for producing countries to reduce reliance on coffee exports. Unfortunately, this is known to decrease with economic growth [57,58]. Ksenija et al. [57] for example, investigated export market concentration for developed, developing, and transition countries for the period between 1948 and 2016 using the standard HH index. Their study suggests a decreasing trend in market concentration of global merchandise exports with the importance of developing and transition countries increasing while developed countries preferring mutual trade instead. Lee and Zhang [58] investigated the potential linkage between the export structure and economic growth and its volatility in low income countries (LICs) and small states using a range of indices of export concentration differing in the coverage of industries. Their study shows that the economic benefits of export diversification differed by country size and income level and that there were bigger benefits for relatively large and poor countries within the group of LICs and small states. They conclude that export diversification may promote economic growth and reduce economic volatility in these countries.

### 2.3. Conceptual framework

Based on the theoretical and empirical review of economic growth models and the role of international trade on economic growth we develop a conceptual framework which shows the links between coffee international trade and per capita income convergence (Fig. 2). In particular, we investigate if international trade in coffee has any role in triggering or at least speeding up income or per capita GDP convergence across countries. It should be noted here that the mainstream theories of trade and economic growth tend to suggest that trade can cause income convergence by positively impacting the growth rate of income in various ways. Firstly, trade leads to efficient allocation of resources; and scale efficiency due to greater access to expanded markets and greater capacity utilisation [59–62] which in turn leads to higher income and rate of domestic savings. Secondly, trade induces capital inflow and thus causes higher real return to capital in unskilled labour abundant countries that exploit their comparative advantage [63–65]. It is believed that international trade brings about increased factor mobility, encourages diffusion of new products and technology and structural and organisational improvements which in turn lead to per capita income convergence among the countries with low income countries catching up with the high-income countries. Thirdly, trade liberalisation can mediate international flow of technology and knowledge spillover [2, 66–71]. The different levels of technologies prevalent in different countries can be transfused between the countries by means of trade. This flow of technology will in turn trigger changes in factor prices and per capita income.

## 3. Data sources and analysis

### 3.1. Data sources

Our paper draws from different open data sources, including the World Bank's meta-data of the World Development Indicators (for per capita GDP, population growth rates, land resource endowment, as well as some of the trade indicators, such as, trade logistics performance, export documentary and border compliance costs). In addition, the paper uses the Human Development Index (HDI), Gini coefficient, and Concentration index (export) obtained from the Human Development Reports of the United Nations Development Programme (UNDP) as well as the coffee export data compiled by the World's Top Exporters and Observatory of Economic Complexity (OEC) and FAOSTAT. The data were filtered to drop missing observations and trend analyses were carried out using only countries for which the required data were

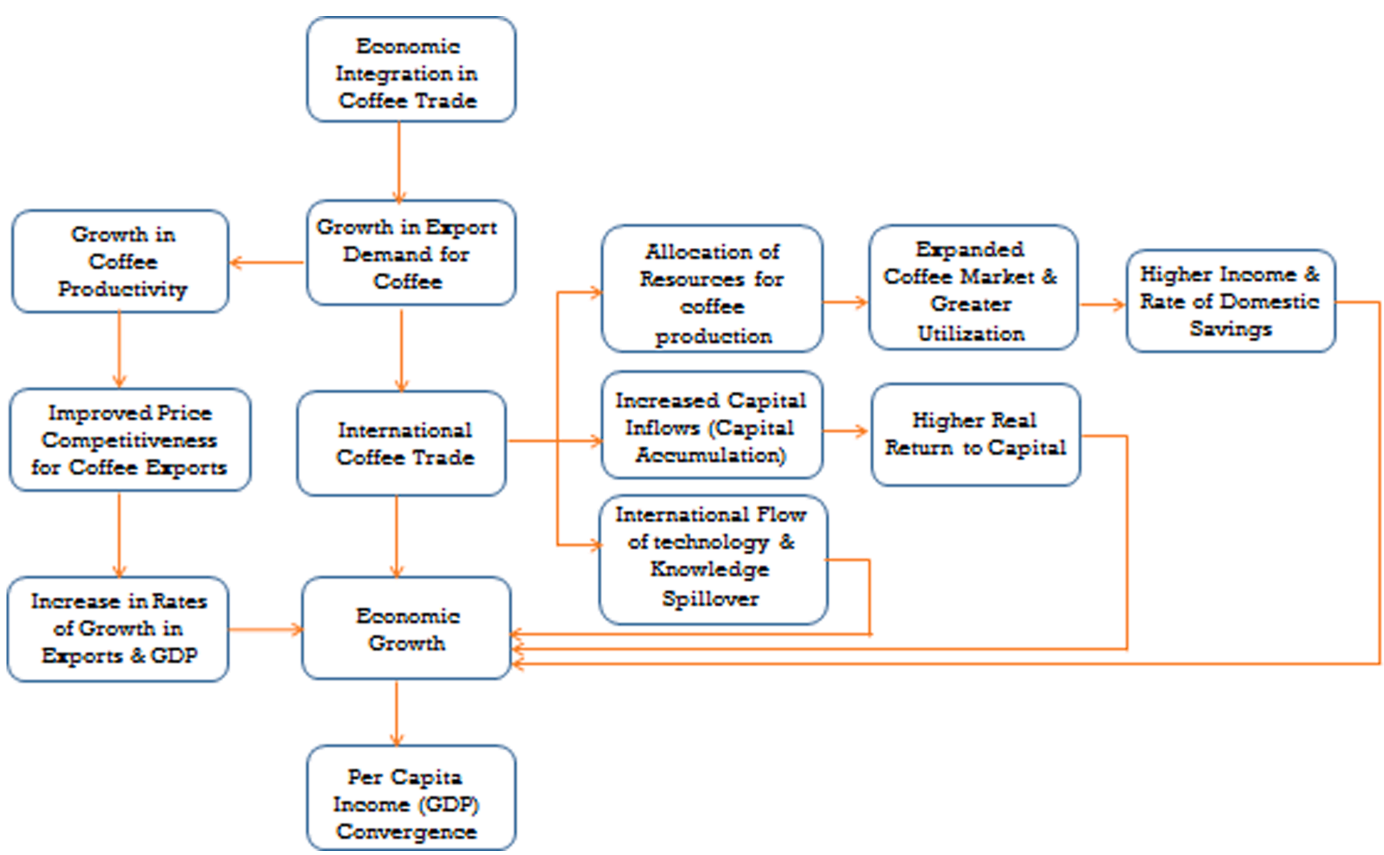



**Fig. 2.** The conceptual framework of international trade in coffee and per capita income convergence.

available for at least eight or more consecutive year intervals. The list of coffee exporting countries covered by the study is given in Appendix 2.

### 3.2. Empirical analysis

The GDP per capita convergence and evolution of convergence speed are tested for two terms: 2001-2019 (long term) and 2010-2019 (the short to medium term) using CV and weighted $\beta$ measures. We provide a summary of the theoretical framework which underpins the Solow-Swan model and its variants in Appendix 3. Specifically, we calculate the CV using the expression provided in Eq. (6) of Appendix 3. The dispersion and evolution of convergence speed are also evaluated using weighted $\beta$ as an alternative test which enables ascertaining weight of each country and the influence of its growth on the overall convergence process using weighted GDP per capita averages for the period 2001–2019. The idea is to take into consideration and attempt to address the inherent challenge in CV test of responsiveness to changes in the upper end of distribution [72]. To estimate the weighted $\beta$, the annual changes in GDP per capita are first calculated for each country and weighted using the average value for all countries, and then the following simple linear model (Eq. (3)) is run:

$$\Delta y_{i,t} = \alpha + \beta\left(y_{i,t-1}\right) + \mu_{i,t} \tag{3}$$

where; $y_{i,t}$ and $\Delta y_{i,t}$ are representing the level and weighted growth rate of per capita GDP in region $i$ at time $t$; $\mu_{i,t}$ is the standard error term; and $\alpha$, $\beta$ and $\Delta$ are the parameters to be estimated.

Where per capita GDP convergence is detected, the "half-life" is calculated using the first order law of integrated rate presented in Eq. (4).

$$ln(y_t) = -\beta T + ln(y_0) \tag{4}$$

By rearranging Eq. (4), Eq. (5) is obtained.

$$\begin{aligned} & ln(y_t) - ln(y_0) = -\beta t \\ & = ln\left(\frac{y_t}{y_0}\right) = -\beta t \\ & = ln\left(\frac{1}{2}\right) = -\beta t_{1/2} \\ & t_{1/2} = \frac{0.693}{-\beta} \end{aligned} \tag{5}$$

Two multiple linear regression (MLR) models are then run (for coffee exporters in developing countries and coffee re-exporters in developed countries) to predict the growth in per capita GDP using various control variables, including population growth rate, size of agricultural land, average growth in Human Development Index (HDI), deviation in income distribution among individuals in a country (Gini coefficient), overall logistics performance, export cost (documentary and border compliance costs), as well as, the value and share of coffee to total country exports. The last two control variables (value and share of coffee to total exports) were added to enable the testing of the hypothesis that international trade significantly promotes economic development [73, 74]. Many studies which have investigated the impact of foreign trade on economic growth argue that international trade encourages technology transfer and promotes new levels of consumption [75]. They view foreign trade as a tool for sustainable economic growth, as it makes it possible to generate products and services more economically by shifting the demand for more competitive output [76–80]. However, there also exists an array of counter arguments claiming that foreign trade inflicts competitive environments, leading to divergence of the market structure from perfect competition and a decline in the resource productivity, see Tapşin [73] for a detailed review on this.

The regression analysis enables the testing for statistical significance of each explanatory or independent variable. It is important to note that in the regression model output, the unstandardized coefficients indicate how much the dependent (response) variable varies with an independent variable when all other independent variables are held constant. Initially, more independent variables were specified than the ones described in the previous paragraphs but some were dropped after conducting statistical testing, including the diagnostics of normally distributed errors, creating a matrix of scattered plots, correlation matrix, and collinearity statistics. The independent (regressors or explanatory) variables were correlated to check for multicollinearity. For pairs of variables found to have correlation coefficient ($r$) of equal to or greater than 0.8, one of the variables was removed from the specification [81]. The new specification was tested by computing the Variance Inflating Factors (VIFs) and all the two models yielded values of less than 1.5 confirming the absence of multicollinearity problem. VIFs greater than 10 would imply the presence of a multicollinearity problem [82].

We use the R-squared ($R^2$) and $F$-statistics to measure the model's goodness-of-fit (i.e. whether the set of independent variables statistically significantly predict the dependent variable). In addition, the Akaike Information Criterion (AIC) is also used to complement the evaluation of how well the regression models fit the data they are generated from [83–85]. According to the AIC, the best-fit model is the one that explains the highest amount of disparity using the fewest possible independent variables (ibid). Thus, lower AIC scores are better, and AIC punishes models that apply more parameters. So if two models explain the same amount of disparity, the one with fewer parameters will have a lower AIC score and will be the better-fit of the model. The unstandardized coefficients are used to measure how much the dependent (response) variable varies with a one-unit increase in an independent variable when all other independent variables are held constant. The Durbin Watson ($DW$) statistic is also used to test for autocorrelation in the residuals of the regression models. This statistic has a value between 0 and 4. The value of 2.0 means absence of autocorrelation in the data and the values from 0 to less than 2 indicate positive autocorrelation, while the values from 2 to 4 indicate negative autocorrelation. When the hypothesis that the instrument is uncorrelated with the second-stage residual is rejected, this implies that the estimates only reflect a correlation between inequality and GDP per capita and not a causal effect of the former variable on the latter. That correlation gives a novel contribution to literature as it describes a phenomenon about how transitional growth is related to inequality that is not caused by variation in countries' average incomes. In fact, such a procedure has the objective to ensure that estimates are not biased due to reverse causality running from higher GDP per capita to less inequality [86]. However, it should also be noted that this approach may not be suitable for providing an estimate of a causal effect of inequality on GDP per capita in a richer model where the distribution of income is driven by social policies or changes in trade policy – all of which may directly affect economic growth and are hard to measure in a cross-country time-series context.

## 4. Empirical results

### 4.1. GDP per capita convergence

The results of CV and weighted $\beta$-convergence tests for green coffee producers and exporters in developing countries and coffee re-exporters in developed countries are summarised in Table 1. The cases of converging GDP per capita are shaded in light black. The two tests consistently show that the GDP per capita was converging among coffee producers and exporters in developing countries (cases with negative gradients in Table 1). However, the two tests provide contradicting results for coffee re-exporters in developed countries: the CV-test shows a converging trend of GDP per capita while the weighted $\beta$- test reveals a diverging trend. The CV-test yields half-lives of 41, 68 and 462 years for green coffee producers in developing countries, coffee exporters in developing countries and coffee re-exporters in developed countries respectively. The weighted $\beta$-test indicates relatively longer half-lives of 385 and 187 years for green coffee producers and coffee exporters in

**Table 1**
Summary results of per capita GDP convergence tests (2001 – 2019).

| Test | N | Convergence | Gradient | Half-life |
|---|---|---|---|---|
| (a) Coefficient of variation (CV) | | | | |
| Green coffee producers in developing countries | 45 | Yes | -0.0167 | 41 |
| Coffee exporters in developing countries | 67 | Yes | -0.0102 | 68 |
| Coffee re-exporters in developed countries | 30 | Yes | -0.0015 | 462 |
| (b) Weighted $\beta$ | | | | |
| Green coffee producers in developing countries | 45 | Yes | -0.0018 | 385 |
| Coffee exporters in developing countries | 67 | Yes | -0.0037 | 187 |
| Coffee re-exporters in developed countries | 30 | No | 0.0165 | |

developing countries respectively.

Fig. 3 presents the results of CV- and weighted $\beta$-tests disaggregated by country income groups. The results of CV test indicated that the GDP per capita were converging for all the four country income groups with gradients of -0.003, -0.0186, -0.0325, and -0.004 for low income countries (LICs), low middle income countries (LMICs), upper middle income countries (UMICs), and high income countries (HICs) respectively. The results of weighted $\beta$ test showed GDP per capita convergence only among LICs (gradient = -0.0175) and LMICs (-0.0016). For converging cases, the gradients of CV and weighted $\beta$ values were consistently larger for green coffee producers and exporters in developing countries than those of coffee re-exporters in developed countries supporting the proposition of Solow-Swan model that poorer countries grow faster than richer countries and that the distribution of income across economies becomes more equitable over time. However, as also already noted, the results of weighted $\beta$-test did not provide sufficient evidence to support this proposition for coffee re-exporters in developed countries.

The results of GDP per capita convergence tests as well as the trends of values and shares of coffee to total exports of goods and services for green coffee producers and coffee re-exporters in developing and developed countries are summarized in Table 2. The findings indicate that, in the short to medium term, the average coffee export values and shares of coffee to total exports were decreasing with GDP per capita

**Table 2**
Trends of GDP per capita, values and shares of coffee to total exports of goods and services, 2010-2019.

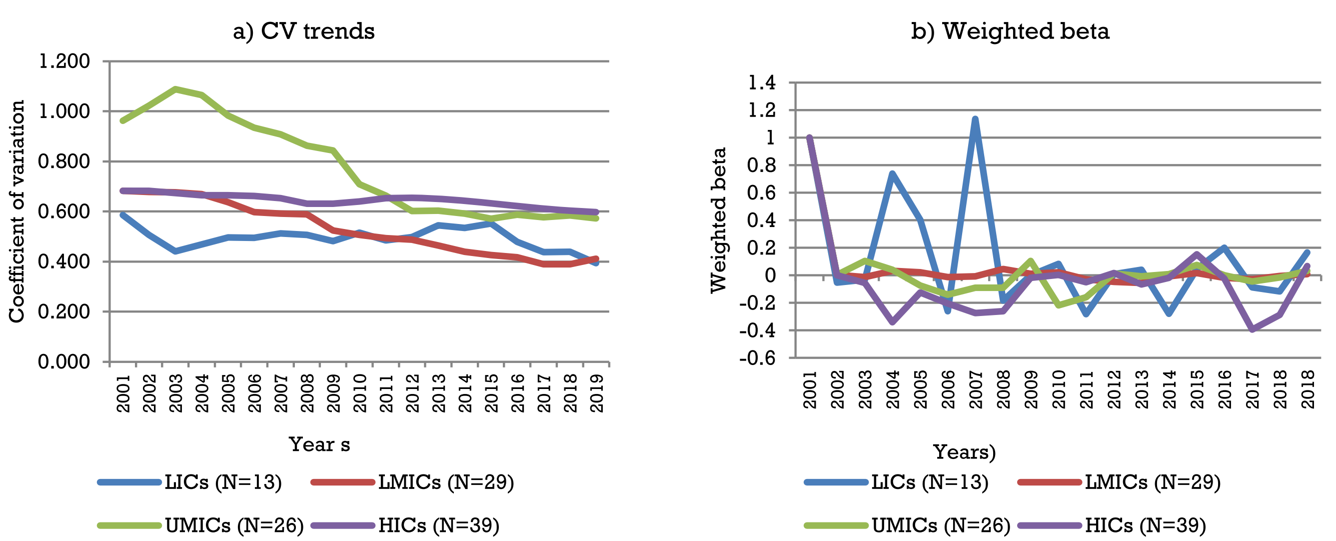
| Test | N | Trend function* | | |
|---|---|---|---|---|
| | | Convergence (Y) | Coffee value (V) | Coffee share (S) |
| (a) Coefficient of variation (CV) | | | | |
| Green coffee producers in developing countries | 45 | -0.0144x + 29.935 | -2.6564x + 5667.1 | -0.0133x + 0.4013 |
| Coffee re-exporters in developed countries | 30 | -0.0051x + 10.951 | 0.0116x - 22.99 | 0.001x + 0.1185 |
| (b) Weighted $\beta$ | | | | |
| Green coffee producers in developing countries | 64 | -0.0024x + 4.7576 | -2.6564x + 5667.1 | -0.0133x + 0.4013 |
| Coffee re-exporters in developed countries | 30 | -0.0317x + 63.652 | 0.0116x - 22.99 | 0.001x + 0.1185 |

*Shaded cells represent converging cases of GDP per capita

convergence for green coffee producers in developing countries. For the same term, the values and shares of coffee re-exports to total value of exports were increasing with GDP per capita convergence for coffee re-exporters in developed countries. In the short to medium term, we also note an interesting trend: both the results of CV and weighted $\beta$-tests show converging GDP per capita.

### *4.2. GDP per capita growth models*

The results of regression analysis for coffee exporters in developing countries and coffee re-exporters in developed countries (models 1 and 2) are summarised in Table 3. The AIC statistics show that model 2 yields better results in terms of fitness with data than model 1 (cf. AIC of 222.069 versus 484.603 respectively). Model 1, which represents coffee producers and exporters in developing countries, show a *DW* value of 2.104 (which is approximately equal to 2.00) and a statistically significant *F*-value of 3.919 ($p = 0.000$). The second model yields a *DW* value of 2.219 which is also close to 2.00, and a statistically significant *F*-value of 2.879 ($p = 0.023$). These statistics provide adequate evidence for absence of autocorrelation in the data and that the independent variables (regressors) statistically significantly predicted the dependent (response) variable in both models.




LICs = Low income countries; LMICs = Low middle income countries; UMICs = Upper middle income countries; and HICs = High income countries

**Fig. 3.** CV and weighted $\beta$-convergence plots disaggregated by income groups.

**Table 3**
Results of regression analysis.

| Variable | Model 1 ($N = 67$) | | Model 2 ($N = 30$) | |
|---|---|---|---|---|
| | Unstd. Coeff. (B) | Std. Error | Unstd. Coeff. (B) | Std. Error |
| Constant | 0.002 | 0.052 | 0.06 | 0.089 |
| Average Per capita GDP (2001 – 2019) | -0.000003* | 0.000 | 0.0000003 | 0.000 |
| Size of agricultural land, 2001–2018 (sq. km) | 0.00000001* | 0.000 | 0.00000001 | 0.000 |
| Logistics performance index (overall) | 0.030* | 0.013 | -0.021 | 0.017 |
| Cost to export: Documentary compliance costs (US $) | 0.00004 | 0.000 | 0.000 | 0.000 |
| Cost to export: Border compliance costs (US $) | 0.00001 | 0.000 | -0.00006 | 0.000 |
| HDI annual growth (1990–2019) | 0.004 | 0.008 | 0.063 | 0.058 |
| Gini coefficient (2010–2018) | -0.001** | 0.000 | 0.00007 | 0.001 |
| Population growth rate (2001–2019) | -0.016*** | 0.004 | -0.023* | 0.01 |
| Share of coffee exports to total exports, 2010–2019 (%) | 0.000 | 0.001 | 0.005 | 0.019 |
| Value of coffee exports, 2010-2018 (mean '000 US$) | 0.000000000002 | 0.000 | 0.00004 | 0.000 |
| Concentration index (exports) (2001–2019) | 0.008 | 0.029 | 0.031 | 0.122 |
| Diversification index (exports) (2001–2019) | 0.088* | 0.047 | 0.074 | 0.114 |
| Green coffee production, 2001–2019 (average'000 MT) | | | | |
| *Statistics* | *Value* | | *Value* | |
| *F*-statistic | 3.919*** | | 2.879* | |
| R-Square | 0.465 | | 0.670 | |
| Adjusted R-Square | 0.347 | | 0.437 | |
| *DW* value | 2.104 | | 2.219 | |
| AIC value | 484.603 | | 222.069 | |

Dependent variable: Average annual change in GDP per capita (2001-2019)
Model 1: Coffee exporting developing countries ($N = 68$), and Model 2: Coffee re-exporting developed countries ($N = 30$).
*Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$; ***Significant at $p \leq 0.001$.

The results of regression in model 1 (for coffee producers and exporters in developing countries) show that, the average GDP per capita and size of agricultural land have marginally affected the average change in annual GDP per capita. The former has negatively influenced the change in annual GDP per capita while the latter (size of agricultural land) has positively influenced it with p–values of 0.091 and 0.080 respectively. Income inequality and population growth rate have negatively influenced the average change in annual GDP per capita (p–values of 0.008 and 0.001 respectively). The average change in annual GDP per capita has also increased with overall logistics performance ($p = 0.027$) and marginally with export diversification ($p = 0.06$). The negative relationships between income inequality and population growth versus the predicted or response variable (average change in annual GDP per capita) in model 1 suggests that coffee producers and exporters in developing countries which had lower levels of income inequality and population growth rates were growing economically faster than their counterpart countries with higher levels of income inequality and population growth. The results of regression in the second model (coffee re-exporters in developed countries) also support the assertion that population growth has negative influence on GDP per capita and was the only explanatory or controlled variable which showed statistically significant effect in model 2 (*p*-value of 0.035).

## 5. Discussion

In the long-term scenario, the results of CV and weighted $\beta$–tests consistently show converging GDP per capita for green coffee producers and exporters in developing countries (Table 1). However, the two tests show different trends of GDP per capita for coffee re-exporters in developed countries for the same scenario: the CV-test shows a converging trend while the weighted $\beta$-test shows a diverging trend.

Because of contradictory results between CV and weighted $\beta$–convergence tests in Table 1, our study did not find enough evidence to conclude converging GDP per capita among coffee re-exporters in developed countries. Remarkable perhaps are the results of CV-test (in Table 2), which indicate that in a short to medium term scenario, the per capita GDP among coffee re-exporters in developed countries was also converging though at relatively slower rate (gradient of 0.0015) compared with that of green coffee producers in developing countries (gradient of 0.0144). As such, these results support both the hypothesis of the Solow-Swan model that the distribution of income across economies becomes more equitable over time and the proposition that poorer countries grow faster than richer countries. It is also interesting to note that in the short to medium term, GDP convergence among green coffee producers and exporters in developing countries, increased with green coffee production ($y = 2.7752x - 5401.2$) and coffee re-exportation by developed countries ($y = 2.8567x - 5681.1$).

To a large extent, the trends of GDP per capita in both the long and short to medium terms (Tables 1 and 2) seem to be mirroring the dynamics in the landscape of global coffee value chain governance and key outcomes that have occurred since early 2000s (Fig. 1 and Appendix 1). Ponte [87] specifies these dynamics and outcomes as including among others deregulation, new consumption patterns, and evolving corporate strategies. He sees the global coffee value chain to have considerably shifted from what he describes as "a balanced contest between producing and consuming countries within the politics of International Coffee Agreements, power relations to the advantage of transnational corporations which implies a remarkable shift from relatively stable institutional environment where proportions of generated income were fairly distributed between producing and consuming countries into one that is more informal, unstable, and unequal." This is clearly illustrated by the trends of coffee values and shares to total income in Table 2, which are decreasing for green coffee producers and exporters in developing countries and increasing for coffee re-exporters in developed countries. Weber and Wiek [88] view this shift as continuing to cause significant economic inequalities and negative impacts on human well-being.

The declining trends of coffee export values and shares of coffee in total export among green coffee producers and exporters in developing countries might have also triggered a more export diversification trend amongst these countries. This argument is supported by the results of regression (Table 3) for coffee producers and exporters in developing countries (model 1) which show that export diversification modestly influenced the average change in annual GDP per capita (*p*-value = 0.067). It should be noted that export diversification is inversely related with export concentration [89,90] and the latter is measured as an index that traces the changes in a country's export structure, to assess the extent of export diversification [91].

Our study also found robust negative relationships between the average change in per capita GDP and income inequality (as measured by Gini coefficient) in model 1 ($p = 0.008$), as well as, population growth rate in both model 1 ($p = 0.001$) and model 2 ($p = 0.035$). Similar relationship is also reported by Jianu et al. [92] who found income inequality among developed EU member states to be positively linked to economic growth. However, income inequality was found to be detrimental to growth among developing EU countries (ibid). Causa et al. [93] found insignificant association between the GDP growth in many OECD countries and growing income disparities though the potential drivers of these changes were not certain. They furthermore argue that inequality in different parts of the income distribution can affect GDP differently. In developing countries, inequalities in the upper end of the distribution are sometimes associated with positive effects on GDP, while inequalities in the bottom end can induce negative effects. They conclude that higher levels of inequality can reduce GDP per capita and the magnitude of the effect is similar, regardless of whether the rise in inequality takes place mainly in the upper or lower half of the distribution.

We found population growth rate to be negatively related with GDP per capita ($p \leq 0.001$). High rates of population growth can lead to increased income inequality because most of the workforce tends to work under low wages, especially in the traditional sectors in the economies of developing countries [94,95]. Importantly, we found the relationships between per capita GDP and value of coffee exports as well as its share to total country exports to be insignificant in both models.

## 6. Research implication

The gradient of GDP per capital convergence among green coffee producers and exporters in developing countries was larger than that of coffee re-exporters in developed countries implying that the former countries were growing faster than the latter causing declining disparities in income levels across coffee producing and richer coffee re-exporting countries in the world. However the CV and $\beta$ tests yielded different results for coffee re-exporters in developed countries making it difficult to conclude convergence in GDP per capita among these countries. Just as important, the negative relationship between mean change in GDP per capita and Gini coefficient implies less income inequality among the relatively richer coffee re-exporters in developed countries than among relatively poorer green coffee producers and exporters in developing countries. Just as important, the trends of coffee values and shares to total income were declining for green coffee producers and exporters in developing countries while the same were increasing amongst coffee re-exporters in developed countries. This implies unequal sharing of benefits in the global coffee trade which is contrary to SDG number 10 and SDG target 17.11 that aim to reduce inequality within and among countries and significantly increase the exports from developing countries. Specifically, SDG number 10 aims at reducing economic inequality within and between countries by targeting more rapid income growth at the bottom of the income distribution, as well as more equal opportunities and less unequal outcomes. Achieving this goal requires that national and international efforts have to adequately integrate elements of trade policy into packages aimed at meeting SDG 10 objectives. Well thought national and multilateral policies can mitigate negative effects of trade on intra- and inter-country inequality or even reduce inequality.

Among coffee producers and exporters in developing countries the average change in annual GDP per capita was modestly influenced by export diversification which is inversely related with export concentration. Thus, increased diversification among coffee producers and exporters in developing countries would also imply lower export concentration ratios. Countries with lower export concentration ratios (i.e. countries with more diversified exports) have exports that are comprised of a larger number of products and that trade with a larger number of trading partners. Given the risks associated with export concentration, policies to promote export diversification, especially among coffee producers and exporters in developing, can also be relevant and should be given considerable attention. Reliance on a narrow range of exports gives rise to risks associated with the lack of diversification thereby aggravating a country's vulnerability to economic shocks. Export diversification can mitigate these risks, which include among others the volatility and instability in export earnings which in turn cause adverse macro-economic effects on growth, employment, investment planning, export capacity, foreign exchange reserves, inflation, capital flight and, inter alia, debt repayment [96]. By providing a broader base of exports, diversification can lower instability in export earnings, expand export revenues, upgrade value added, and enhance growth through several channels [97]. Thus, national coffee trade policies should also be complemented by regional and international cooperation efforts that strengthen export diversification and by a trade environment that focuses on trade facilitation and market access for coffee exports from developing countries. Importantly, policies to promote export diversification should purely depend on a comprehensive analysis of the country's specific position in the international trade (i.e. its position in the global supply chain and the prospects of world demand). Classically, the policy reforms necessary to foster export diversification require a multifaceted approach bridging trade, investment and industrial policies, as well as institutional reforms.

Our study found non-significant relationships between GDP per capita and value of coffee exports as well as its share to total country exports implying that coffee production and exportation was not a major factor influencing economic growth among coffee producers and exporters in developing countries. In the context of agro-based economies, this would also support the phenomenon of "progression from traditional to other, non-traditional exports" [98] which simply implies that there is a shift in the landscape of global agricultural commodity trade, especially among green coffee producers and exporters in developing countries, from exporting traditional cash crops, (coffee in this case), to non-traditional commodities, which did not constitute the major items in the basket of agricultural export commodities in the past decade.

## 7. Limitations and future research

While the current study contributes substantially to the debate on GDP per capita or income convergence and the role of coffee trade in the convergence, it has some limitations that need to be discussed here. One of the important limitations is that our study is based on a horizontal interrelation between developing countries that produce and export coffee, and developed countries which re-export coffee (on an aggregate level) and not on a country-specific level. For reasons of data availability, we are also not able to deepen the analysis to capture all the factors we present in our conceptual framework (Fig. 2). A more informative approach would be the use of more complex dynamic models that capture changes in different economic variables happening over time, including the growth in export demand, productivity, price competitiveness, allocation of resources, capital inflows, international flow of technology and knowledge spillover, the resultant rate of domestic savings and real return to capital, just to mention some. Capturing technological progress, institutional and policy aspects such as policy differences among countries, market forces and competition that works in favor of, or against convergence, channels of convergence (e.g. imitation, competition, state competition and enforcement) is important because per capita convergence can be bunged due to institutional factors. The idea is to trace the path of change or the movement of these economic variables towards equilibrium (i.e. how these variables are changing with time). This requires the use of dynamic economic models which are becoming popular not only in business fluctuations but also in the determination of income growth models. Unfortunately, there are still some key limitations regarding the use of dynamic economic models. Firstly, the models entail a complex approach to study economic variables based on time elements. Secondly, dynamic economic analysis is not fully developed though many economists, such as, Samuelson [99] and Harrod [100–103] have formulated their theories through dynamic economic analysis. Yet their models of economic analysis have not been fully developed due to the fact that factors affecting economic variables change very soon and dynamic approach is not developing at the speed at which economic factors change. This constitutes one of important areas for further research in income convergence and its relationship with international trade in traditional cash export crops like coffee and others.

## 8. Conclusions

This paper contributes to the debate on GDP per capita convergence among developing and developed countries using the case of coffee producing and exporting countries in the world. Specifically, the paper tests the income convergence proposition of the Solow-Swan model that poor countries grow faster than rich countries and that the distribution of income across economies is becoming more equitable over time using the variants of $\sigma$-convergence test (the CV-test) and $\beta$-convergence (weighted $\beta$- tests). In addition, the paper constructs a conceptual framework which links international trade in coffee and GDP per capita convergence. The paper also explores the factors which influence GDP per capita using two multiple linear regression models (the first representing coffee producers and exporters in developing countries and the second representing coffee re-exporters in developed countries). The scope of the paper is interesting and novel due to its peculiar focus on coffee producers in developing countries and re-exporters in developed countries. Studies that focus on international trade in traditional cash crops such as coffee, cashew, pyrethrum, and others are scarce. Another novelty of our study is the comparison of GDP per capita convergence using the variant of $\sigma$-convergence (the CV-test) and weighted $\beta$-convergence. Most of the previous studies have used either a single metric or where more than one measures are used, the comparison has mostly centered on the conventional $\sigma$-convergence and un-weighted $\beta$-convergence measures.

We find that, in the long run, the CV and weighted $\beta$-tests yielded consistently converging trend of GDP per capita for green coffee producers and exporters in developing countries. However, we also find contradictory results for coffee re-exporters in developed countries: the results of CV-test show a converging trend while that of weighted $\beta$-test show a diverging trend. Furthermore, the CV-test yields relatively lower half-lives than the weighted $\beta$-test. In the long term, the gradients of CV functions are consistently smaller for coffee re-exporters in developed countries than those of coffee producers and exporters in developing countries. This supports the proposition of Solow-Swan model that poorer countries grow faster than richer countries and that the distribution of income across economies becomes more equitable over time. The results of weighted $\beta$-test do not support this proposition. In the short to medium term, the results show converging GDP per capita for both tests. However, the weighted $\beta$-test yields lower rates of convergence for green coffee producers and exporters in developing countries than those of coffee re-exporters in developed countries. This again disagrees with the proposition of poorer countries growing faster than richer countries.

In the long term, green coffee production and exportation by developing countries and coffee re-exportation by developed countries have both increased with GDP per capita convergence. However, in the short to medium term, coffee export values and shares have continued to decrease with GDP per capita convergence for green coffee producers and exporters in developing countries. The same have continued to increase with GDP per capita convergence among coffee re-exporters in developed countries. This suggests existence of disparities in the distribution of benefits along the global coffee value chain. In addition, we found GDP per capita to be positively associated with the country's size of agricultural land among coffee producers and exporters in developing countries. The GDP per capita was negatively associated with population growth and levels of income inequality for coffee producers and exporters in developing countries. Trade-related factors were also equally important. For example, GDP per capita was positively related with overall logistics performance and marginally, with export diversification. Conclusively, we argue that green coffee production and exportation have not contributed to economic growth in a statistically significant way, especially in developing countries. However, coffee re-exporters among developed countries were faring relatively better in the global coffee value chain due to value addition which is mostly limited among green coffee producers and exporters in developing countries.

## 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.

## Acknowledgments

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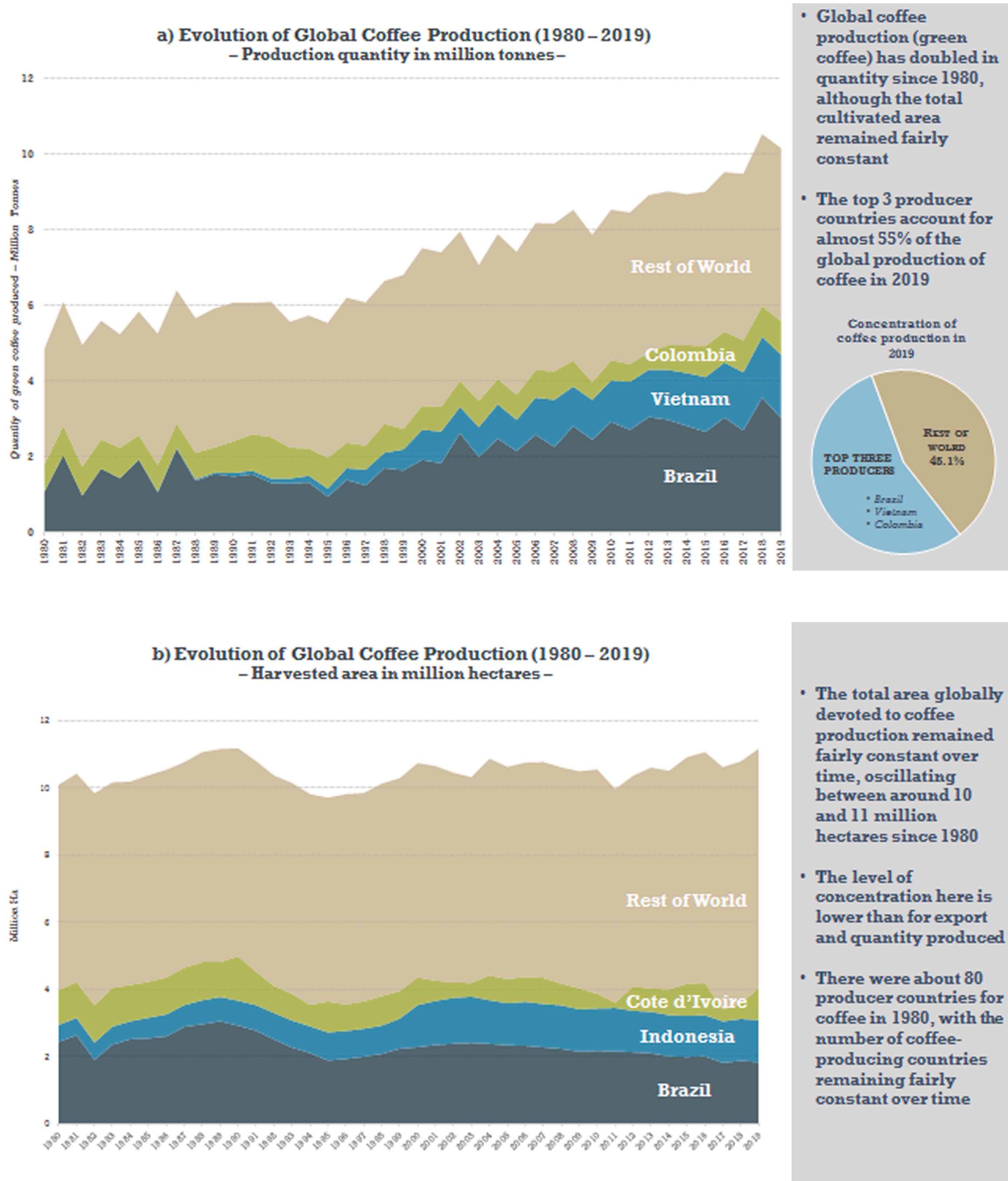
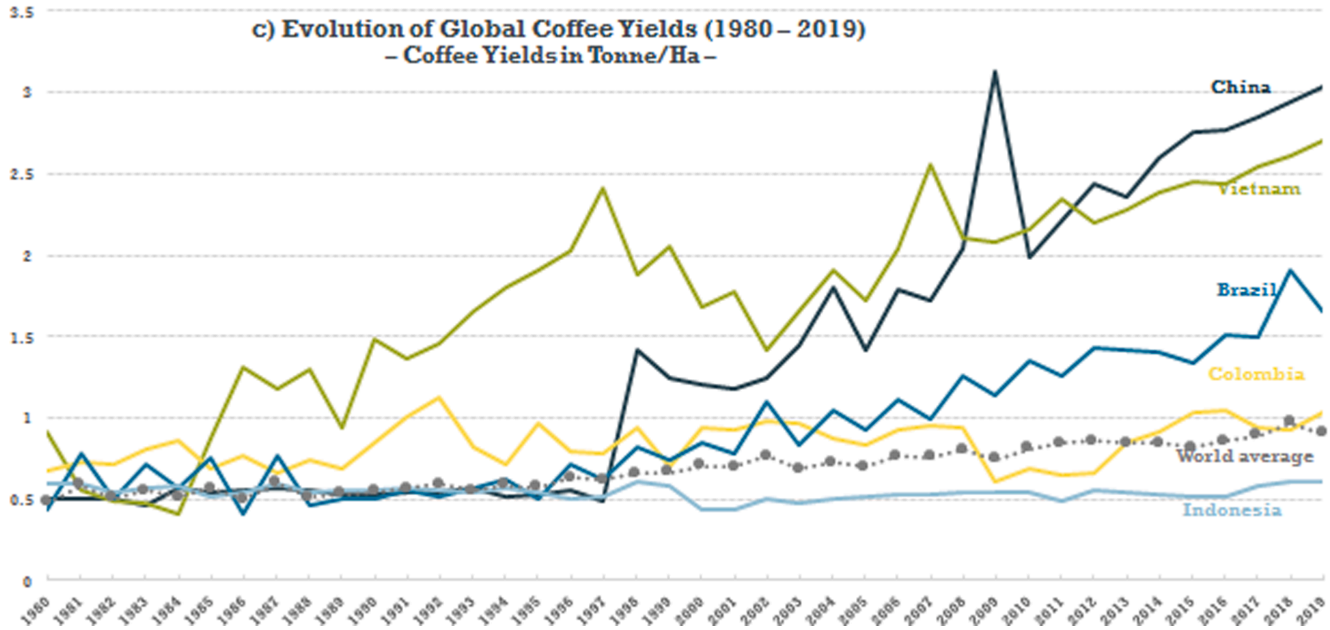
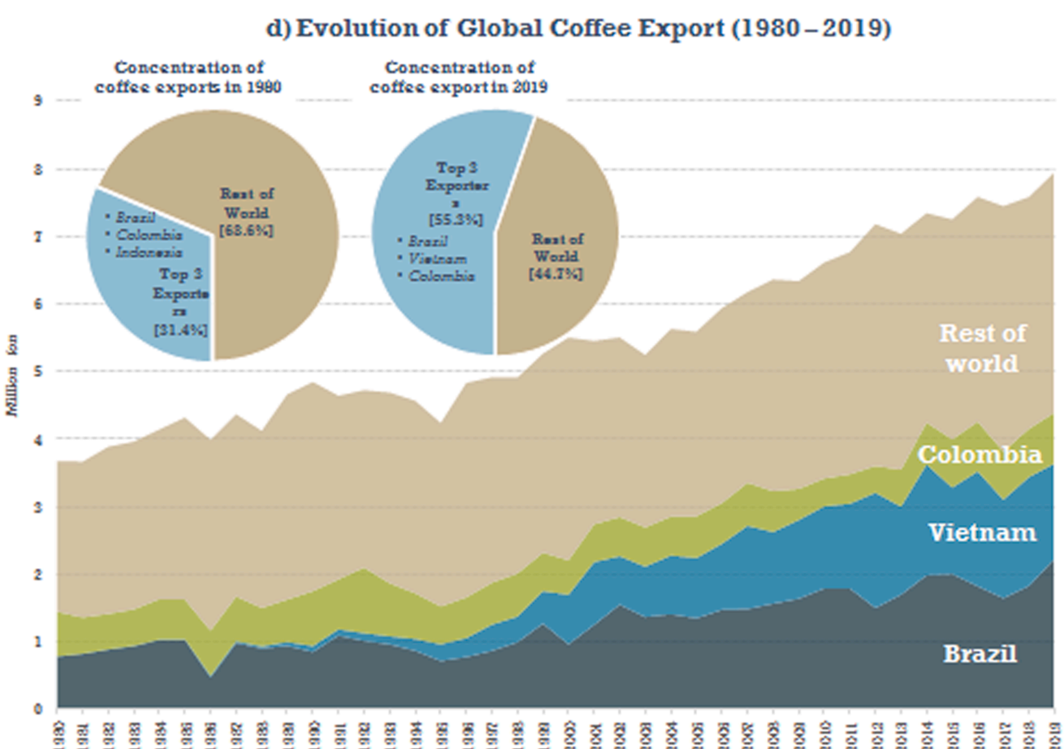
**Appendix 1: Evolution of global coffee production, harvested area, yield and export volumes**


a) Evolution of Global Coffee Production (1980 – 2019)
– Production quantity in million tonnes –
Quantity of green coffee produced – Million Tonnes
Rest of World
Colombia
Vietnam
Brazil
Global coffee production (green coffee) has doubled in quantity since 1980, although the total cultivated area remained fairly constant
The top 3 producer countries account for almost 55% of the global production of coffee in 2019
Concentration of coffee production in 2019
TOP THREE PRODUCERS
Brazil
Vietnam
Colombia
REST OF WOLRD 45.1%
b) Evolution of Global Coffee Production (1980 – 2019)
– Harvested area in million hectares –
Million Ha
Rest of World
Cote d'Ivoire
Indonesia
Brazil
The total area globally devoted to coffee production remained fairly constant over time, oscillating between around 10 and 11 million hectares since 1980
The level of concentration here is lower than for export and quantity produced
There were about 80 producer countries for coffee in 1980, with the number of coffee-producing countries remaining fairly constant over time

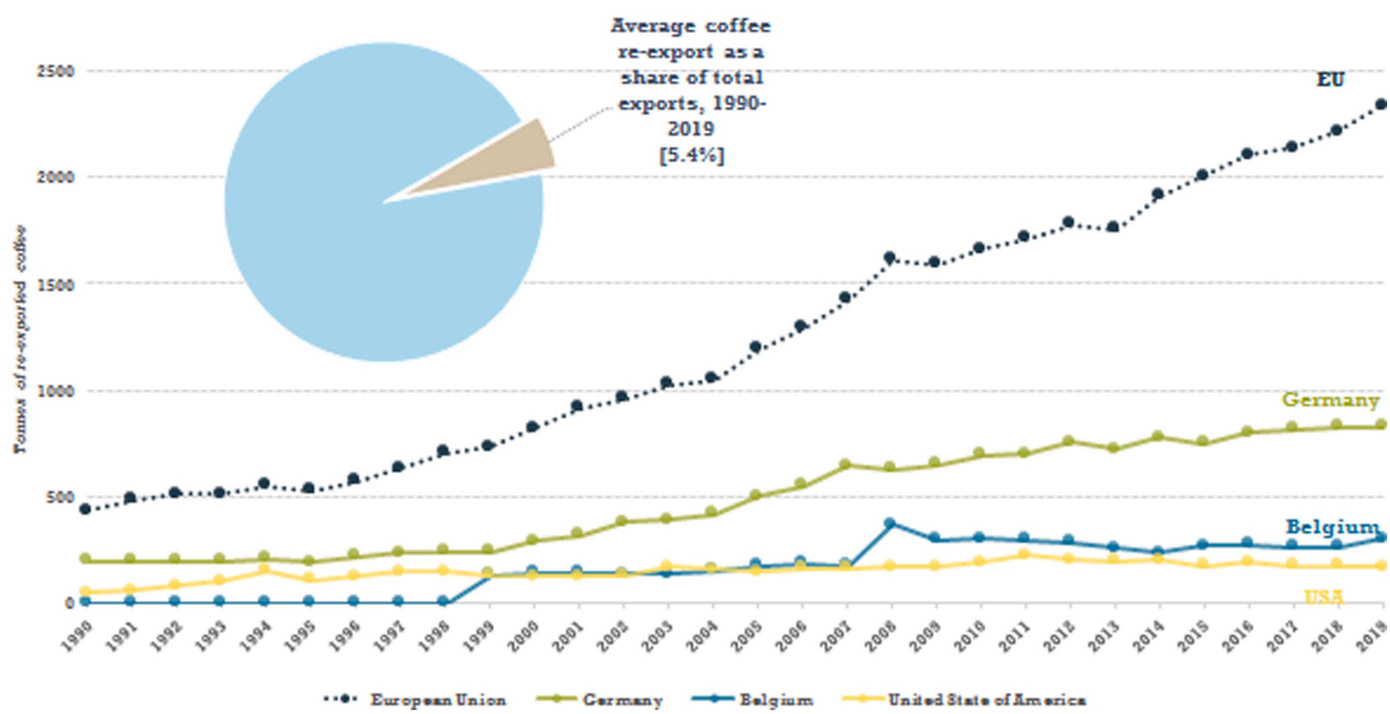
- Top yields are up to 3 tonnes/ha, compared to a world average of around 1 tonne/ha
- Yields have been on a steady upward trend, tripling in some of the top producing countries




- Global coffee exports have more than doubled since 1980, reaching almost 8 million tonnes in 2019
- There is a ongoing concentration process in coffee export: in 1980 the top 3 exporters accounted for less than 1/3 of the total export, while in 2019 the top 3 exporters accounted for more than 55% of it
- In total, 38 countries exported coffee in 1980. They were over 100 in 2019

e) Evolution of Global Coffee Reexport (1990 – 2019)




## Appendix 2: List of coffee producing and exporting countries used in the study

| Developing countries | | | Developed countries |
|---|---|---|---|
| (a) Green coffee producers ($N = 45$) | (b) Coffee exporters ($N = 67$) | | (c) Coffee re-exporters ($N = 30$) |
| Bolivia | Burundi | Botswana | Austria |
| Brazil | Central African Rep. | Brazil | Belgium |
| Burundi | Congo, Dem. Rep. | Bulgaria | Croatia |
| Cameroon | Haiti | China | Cyprus |
| Central African Rep. | Malawi | Colombia | Czech Rep. |
| China, Mainland | Mali | Costa Rica | Denmark |
| Colombia | Mozambique | Dominican Rep. | Estonia |
| Congo, Dem. Rep. | Niger | Ecuador | Finland |
| Congo, Rep. | Rwanda | Gabon | France |
| Costa Rica | Sierra Leone | Guatemala | Germany |
| Cote d'Ivoire | Togo | Indonesia | Greece |
| Dominican Rep. | Uganda | Jordan | Hungary |
| Ecuador | Yemen, Rep. | Kazakhstan | Ireland |
| El Salvador | Bolivia | Malaysia | Italy |
| Gabon | Cameroon | Mexico | Japan |
| Ghana | Congo, Rep. | Namibia | Latvia |
| Guatemala | Cote d'Ivoire | Paraguay | Lithuania |
| Haiti | Egypt, Arab Rep. | Peru | Luxembourg |
| Honduras | El Salvador | Russian Fed. | Malta |
| India | Ghana | South Africa | Netherlands |
| Indonesia | Honduras | Thailand | Norway |
| Kenya | India | Turkey | Poland |
| Lao PDR | Kenya | | Portugal |
| Malawi | Kyrgyz Rep. | | Romania |
| Malaysia | Lao PDR | | Slovak Rep. |
| Mexico | Moldova | | Slovenia |
| Nicaragua | Morocco | | Sweden |
| Myanmar (Burma) | Myanmar (Burma) | | Switzerland |
| Nepal | Nepal | | United Kingdom |
| Papua New Guinea | Nicaragua | | United State of America |
| Paraguay | Pakistan | | |
| Peru | Papua New Guinea | | |
| Philippines | Philippines | | |

(continued on next page)

(*continued*)

| Developing countries | | Developed countries |
|---|---|---|
| (a) Green coffee producers ($N = 45$) | (b) Coffee exporters ($N = 67$) | (c) Coffee re-exporters ($N = 30$) |
| Rwanda | Sao Tome and Principe | |
| Sao Tome and Principe | Senegal | |
| Sierra Leone | Sri Lanka | |
| Sri Lanka | Tanzania | |
| Tanzania | Tunisia | |
| Thailand | Ukraine | |
| Togo | Vietnam | |
| Uganda | Zambia | |
| Vietnam | Zimbabwe | |
| Yemen, Rep. | Albania | |
| Zambia | Argentina | |
| Zimbabwe | Armenia | |

## Appendix 3: A summary of the Solow-Swan model and its extensions

The Solow-Swan model assumes diminishing returns implying higher (lower) marginal productivity of capital in a capital-poor (rich) economy, and thus, a negative correlation between the initial income level and the subsequent growth rate [104]. Accordingly, Barro and Sala-i-Martin [3] derive the following equation to show the relationship between the average GDP growth rate and the initial income level (Eq. (1)).

$$\left(\frac{1}{T}\right) ln\left(\frac{y_T}{y_0}\right) = \alpha - \frac{(1-e^{-\beta T})}{T} ln(y_0) + \omega_t \tag{1}$$

where, $(1 - e^{-\beta T})/T$ is the coefficient on initial income. Jena and Barua [105] modified this $\beta$-convergence formula into a regression model presented in Eq. (2).

$$\left(\frac{1}{T}\right) ln\left(\frac{y_T}{y_0}\right) = \alpha_0 + \alpha_1 ln y_0 + \varepsilon_t \tag{2}$$

where $\beta$ is the convergence parameter, $\alpha_1$ is the coefficient on initial income, which equals $(1 - e^{-\beta T})/T$ in Eq. (1); $y_0$ and $y_T$ are income per capita in the initial year, and the final year, respectively; $T$ is the length of time period and $\varepsilon_t$ is the random error. A negative and significant value of estimated coefficient $\alpha_1$ would validate the existence of $\beta$-convergence. In this case, the speed of convergence to a steady-state can be calculated as in Eq. (3) [105].

$$\beta = -\frac{1}{T} ln(1 + \alpha_t T)_t \tag{3}$$

Jena and Barua [104] calculated the time $\tau$ taken to move half way to the balanced steady state using the formula expressed in Eq. (4). This time parameter is also known as the "half-life" measure of convergence [78]. It measures the time that a representative economy would need to halve the distance between its initial position and its long-run equilibrium.

$$\tau = -\frac{1(0.5)}{\beta} \tag{4}$$

Thus, from $-(1 - e^{-\beta T})/T$, Eq. (3) is obtained. For a small $T$, regression coefficient $\alpha_1$ tends to convergence parameter $\beta$ because if $T$ tends to zero the expression $(1 - e^{-\beta T})/T$ approaches $\beta$.

From a metric perspective, analyses of $\sigma$-convergence commonly estimate the standard deviation (SD) of the log of GDP per capita and evaluate it at multiple periods of time (ibid). When a systematic reduction in the SD is observed, then a process of $\sigma$-convergence is taking place. Income convergence (the $\sigma$-convergence) is usually tested using the trend line of dispersion in income levels and can be estimated using the expression given in Eq. (5) [105].

$$SD(y_t) = \alpha_0 + \alpha_1 t + \mu_t \tag{5}$$

where $SD$ is the standard deviation, $t$ is time. Again, a negative and statistically significant coefficient $(\alpha_1)$ would suggest the existence of $\sigma$-convergence.

Friedman [106] recommends the use of simple trend in the CV of per capita GDP as it provides an unbiased estimate of $\beta$-convergence. CV is a variant of sigma convergence and it can simply be defined as the ratio between the SD and the mean of all regions. Higher CV values are statistical expressions for inter-regional disparities and vice versa. The measure allows us to take into consideration the time dimension of cross-country or cross-regional convergence [107]. The measure can be calculated as in Eq. (6).

$$CV = \frac{\sqrt{\sigma^2}}{\overline{Y}} \tag{6}$$

where, $\overline{Y}$ is the mean per capita income, and $\sigma^2$ is the variance of per capita income. When dealing with log transformed data, the CV can be calculated as in Eq. (7).

$$\sqrt{e^{\sigma^2} - 1} \tag{7}$$

The CV is often preferred to the SD which has no interpretable meaning on its own unless the mean value is also reported [108]. The CV indicates the degree of variability only in relation to the mean value.

The $\beta$-convergence test generally involves estimating a growth equation in the following form:

$$ln\left(\Delta y_{i,t}\right) = \alpha + \beta ln\left(y_{i,t-1}\right) + yZ_{i,t} + \mu_{i,t} \tag{8}$$

where; $y_{i,t}$ and $\Delta y_{i,t}$ are respectively the level and the growth rate of per capita GDP in region $i$ at time $t$; $Z_{i,t}$ includes all other factors supposedly affecting the growth rate; $\mu_{i,t}$ is the standard normal error term; $\alpha$, and $\beta$ are the parameters to be estimated and $\Delta$ is an operator of growth rate.

A negative relationship between the growth rate $(\Delta y_{i,t})$ and the initial level of GDP per head $y_{i,t-1}$, that is, a significant and negative $\beta$ is the sign of a convergence process. The estimated value of $\beta$ also indicates the rate at which regions approach their steady-state and hence the speed of convergence. Based on this value, one can also calculate the "half-life" or the time span which is necessary for current disparities to be halved using the expression given in Eq. (9).

$$\frac{-ln2}{ln(1+\beta)} \tag{9}$$

If the value of $y$ is restricted to 0, absolute convergence is assumed [109–112], while if it is freely estimated, conditional convergence is assumed [113,114]. Note that, the same specification can be used to test the existence of a convergence process on other economic variables such as GDP per worker or labor productivity.

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