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GREEN PRODUCTIVITY IMPLICATIONS ON LONG RUN SUSTAINABLE ECONOMIC GROWTH

ABSTRACT

PURPOSE

This study aims to explain the integration of innovation and climate with economic growth that was awarded the Nobel Prize in economics in 2018 in terms of the concept of Green Productivity (GP). This is drawn from the integration of two important developmental strategies, viz. productivity improvement and environmental protection. Productivity provides the framework for continuous improvement while environmental protection provides the foundation for sustainable development. Therefore, GP is a strategy for enhancing productivity and environmental performance for overall socio-economic development.

DESIGN/METHODOLOGY

Three variations of framework and econometric model were developed to measure green total factor productivity, green labour productivity, and green capital productivity, and their contributions to green productivity and sustainable development; these were based on extensive and intensive growth theories.

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The 2018 Nobel Prize rewarded the design of the models and methods used to address some of the most fundamental and pressing questions regarding the importance and significance of today's economic issues. These issues involve the long-running development of the global economy and the welfare of its citizens. Paul M. Romer (1986, 1987a, b, 1990, 1993) developed new tools for understanding how long-run technological change is determined in a market economy, while William D. Nordhaus (1974, 1975, 1977, 1994a, b, 2013, 2014, 2017, 2018) pioneered a framework for understanding how the economy and climate of our planet are mutually dependent on each other.

FINDINGS

It is likely that the sustainability of higher economic growth will continue to be productivity driven. This will be through the enhancement of Total Factor Productivity (TFP) as a technological progress of the nations that combined the three dimensions of sustainable development (economic development, environmental protection, and social sustainable development via human capital development). Such enhancement needs to put an emphasis on the quality of the workforce, demand intensity, economic restructuring, capital structure, technical progress and environmental standards.
It should be recalled that green productivity through green TFP demonstrates the sustainable development concept of progressing technologically. It will ensure the rights of future, as well as current, generations to enjoy better life.

ORIGINALITY

The study fills the gaps in growth theories by developing three variations of frameworks and econometric models, and internalising pollutants emissions as private and unpriced inputs in the three models. Further, the green capital productivity model is the sole contributing model developed in this paper; it has not been thought about in any previous studies.

In his focus on the fundamental endogeneity of technological change, Romer (1986, 1987a, b, 1990, 1993) emphasised how the economy can expand the boundaries, and thus the possibilities, of its future activities. In his focus on the fundamental challenges of climate change, Nordhaus (1974, 1975, 1977, 1994a, b, 2013, 2014, 2017, 2018) stressed the importance of the negative side, and thus the restrictions, of the endeavours in bringing about future prosperity. Both Romer and Nordhaus emphasise that the market economy, while a powerful engine of human development, has important imperfections; their contributions have thus overfed insights into how government policy could potentially enhance our long-run welfare. In this respect, this study combined the fundamental findings of both scholars' research findings in developing frameworks and models to measure the green productivity that should be used in measuring long-term sustainable economic growth in its dual dimensions (sustainable technological progress and environmental sustainability).

The United Nations Environment Programme (UNEP) reported that sustainable development (SD) is likewise frequently well-defined as development that improves health care, education, and social well-being. Such human development is now recognised as critical to economic development. Some authors have expanded the definition of sustainable development further to include a rapid transformation of the technological base of industrial civilisation. They point out that new technology that is cleaner (green technology), more efficient, and more sparing of natural resources is needed in order to reduce pollution, help stabilise the climate, and accommodate growth in populations and economic activity. Sustainable development is a process requiring concurrent global progress in a variation of dimensions: economic, human, environmental, and technological progress.

Prior to the 1950s, the common business response to environmental pollution was to ignore such problems. This was possible when problems were relatively small in nature and the awareness of health and environmental impact was not high. In the 1960s, a common approach to pollution was to disperse concentration of the pollutants, for example, by constructing tall smokestacks and extending pipelines into the sea to dilute water pollutants. It was soon realised that many pollutants are toxic even at small concentrations, and some chemicals retain their toxicity for a very long period. These diluted pollutants accumulate in soil and water and eventually find their way into the food chain. When industries and communities began to exceed the capacity of the environment to assimilate their waste, there were efforts to establish environmental standards to regulate the discharge of pollutants. In the 1970s, this resulted in the use of treatment systems to ensure the discharge from industries and other enterprises met stipulated environmental quality standards (Ahmed, 2012).

KEYWORDS

Sustainable development;
green productivity; TFP;
labour productivity; capital productivity

Meanwhile, Ahmed (2012) states that Green Productivity (GP) was launched in 1994 in line with the 1992 Earth Summit recommendations, that both economic development and environmental protection would be key strategies for sustainable development. With support from the government of Japan, the Asian Productivity Organization (APO) introduced GP as a practical way of answering the challenge of sustainable development.

The objective of the APO's GP programme is to simultaneously enhance productivity and reduce the negative impacts on the environment. It seeks to realise this objective by propagating GP consciousness. The APO pledges to continue the progress in the Asia-Pacific Region and, through cooperation, extend GP to accelerate an expanding green global marketplace.

Moreover, Ahmed (2012) explains that GP is a forceful strategy to complement economic growth and environmental protection for sustainable development. It tenders small and medium businesses with an approach to achieve a competitive advantage by being better, but using less. It is therefore a realistic strategy to increase productivity and protect the environment at the same time. Conventional techniques of pollution control were not cost effective. The concept of GP promises profitability and resource productivity. Businesses and communities get compound returns in the form of bottom-line savings, value added products and services, and environmental protection.

The concept of GP is drawn from the integration of two important developmental strategies, viz. productivity improvement and environmental protection. Productivity provides the framework for continuous improvement while environmental protection provides the foundation for sustainable development. Therefore, GP is a strategy for enhancing productivity and environmental performance for overall socio-economic development. GP is the application of appropriate techniques, technologies and management systems to produce environmentally compatible goods and services. It is not only applicable to the manufacturing sector, but also other sectors, e.g., the agriculture and services sectors. GP also addresses the interaction between economic activities and community development. In addition, GP is also not only applicable to large industries but also to small and medium-sized industries (SMIs) in mobilising scarce organisation resources to increase productivity and protect the environment (Ministry of International Trade and Industry, 1998).

The GP programme acts as a mechanism for disaster prevention in Asia, while its focus is on enhancing productivity and environmental protection. In the final analysis, the GP programme propagates disaster prevention through sound environmentally friendly production processes. As illustrated in the two cases (enhancing productivity and environmental protection), the GP programme actually enhances productivity by taking a proactive stance in preventing disasters to the environment, as well as to the organisations themselves and society at large. With almost 50 GP related projects in 1998, the concept of GP has been ingrained in the productivity movements of the 18 member countries of the Asian Productivity Organization. Coupled with other environmentally sound practices, such as green accounting and green purchasing, the GP programme is excellent for organisations and governments to become more responsible and accountable in pursuing sustainable development (APO, 2002).

However, the methods used to measure productivity growth generally ignore the pollutants that are produced by the production process. For example, pollutant emissions generated as undesirable output in addition to the main output of production are excluded from the productivity accounting framework. This study attempts to extend productivity measures by taking into account pollutant emissions into production functions as un-priced inputs. The pollutant emissions under consideration include carbon dioxide (CO_2) (which measures air pollution), Biochemical Oxygen Demand (BOD) (which measures organic water pollution), and their combination in the form of total pollutant emissions, which is combined air and water pollutions. However; other pollutants should be considered, such as noise pollution and all other types of pollutants.

It should be recalled that, in 2018, the Nobel Prize for Economic Sciences was shared between William D. Nordhaus and Paul M. Romer for research undertaken in the 1970s. That research addressed negative externalities, such as pollutant emissions, in achieving long term economic growth through green development that sustains long term economic growth. In this respect, Ahmed (2006, 2007, 2012) stated that the most obvious deficiency in the growth accounting models used in previous studies was found to be the exclusion of externalities, such as the pollutant emissions, that were generated by the manufacturing and other economic sectors. Ahmed's studies aimed to contribute to the available literature on the growth accounting method and econometric method, in that the research drew together both methods to calculate the total factor productivity (TFP) and TFP per unit of labour growth as residuals. This followed Solow (1956, 1957) by internalising the pollutant emissions together with the input terms used in conventional production functions. Consequently, TFP and TFP per unit of labour growth became indicators of green productivity.This takes into account economic development and environmental protection such as those in studies by Pittman (1983), Gollop and Roberts (1983), Baumol and Oates (1988), Chaston et al., 1997, Gollop and Swinand (1998), Gollop and Swinand (2001) and Harchaoui et al. (2002). Ahmed (2017) stated that:

> "It has been documented in the Solow (1956, 1957) empirical work on economic growth that after accounting for physical and human capital accumulation, something else accounts for the bulk of output growth in most countries. Together, physical and human capital accumulations are definitely critical for economic growth. The development becomes more complex with the role of knowledge in the economic growth procedure".

METHODS AND ESTIMATIONS PROCEDURES

This research reviews the studies undertaken on green productivity issues around the globe. Several methods have been used to measure green productivity issues; these include descriptive analysis, non-parametric analysis (such as Data Envelope Analysis (DEA)), Input Output (I-O) analysis, and Dynamic Computable General Equilibrium (DCGE). To fill the gap in measuring GP, this research intends to use parametric analysis based on a combined method of parametric analysis. This method combines both growth accounting, that is non-parametric, and econometric and non-parametric estimation. This method will be applied in two steps: the first step is an econometric estimation to calculate the parameters (coefficients) of the variables, and the second step plugs these parameters into the model to calculate the productivity indicators. In this respect, three variation models have been used, extensive growth and intensive growth (labour productivity and capital productivity), as explained by Ahmed (2009, 2010, 2017, 2018). In this research, a Cobb-Douglas production function estimation model and Solow's residual model were used as a modified model; this is to fill the gaps in both models that cast doubts on the results generated.

The framework (Figure 1) is a presentation of extensive growth theory for Model 1. The output (green Gross Domestic Product) is the dependent variable, and capital, labour, carbon dioxide emissions (CO_2) for air pollution and biochemical oxygen demand (BOD) for organic water pollution are the explanatory variables based on their quantity. Moreover, the framework presents green total factor productivity (GTFP) that is expressed in the combined contribution of the quality of the inputs (explanatory variable).

Meanwhile, the production function for an economy can be represented as follows:

$$GGDP_{t,i} = F(K_{t,i},\ L_{t,i},\ CO_{2t,i},\ BOD_{t,i}, T_{t,i}) \tag{1}$$

where Country $i = 1, 2, \ldots$ in Years t, output real green Gross Domestic Product (GGDP) is a function of real fixed physical capital input K, labour input L, CO_2 and BOD, that proxies for pollutants emissions and time T, that proxies for GTFP as a technological progress of the economies and sustainable development indicator.

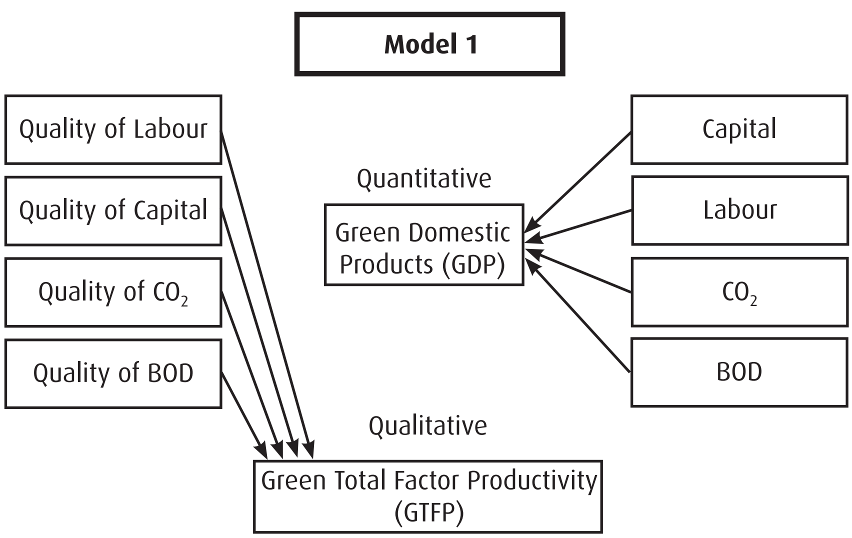

FIGURE 1 **Green Productivity Framework, Extensive Growth Theory**

Source: Modified from Ahmed, 2018

Extensive growth theory

This subsection presents the extensive growth theory based on Green Gross Domestic Product (GGDP) that is decomposed into physical capital, employment CO_2 and BOD. The present study attempts to close this gap by developing this model into a parametric model, and providing statistical analysis for it in the first step as follows:

$$\Delta \ln GGDP_{t,i} = a + \alpha.\Delta \ln K_{t,i} + \beta.\Delta \ln L_{t,i} + \lambda.\Delta \ln CO_{2t,i} + \theta.\Delta \ln BOD_{t,i} + \varepsilon_{t,i} \quad (2)$$

t = Number of years and i is the number of the countries

where

- α is the green output elasticity with respect to capital
- β is the output elasticity with respect to labour
- λ is the output elasticity with respect to CO_2 emissions
- θ is the output elasticity with respect to biochemical oxygen demand emissions
- a is the intercept or constant of the model[1]
- ε is the residual term[2]
- ln is the logarithm to transform the variables
- Δ is the difference operator denoting proportionate change rate

Since the intercept (a) in Equation 2 has no position in the calculation of the productivity growth indicators, a second step was proposed. This step calculates the growth rates of productivity indicators, transforming Equation 2 as an extension of the basic growth accounting framework. The Cobb-Douglas production function is specified in the parametric form of the above equation as follows:

$$\Delta \ln GTFPit = \Delta \ln GGDPit - [\alpha.\ \Delta \ln Kit + \beta.\ \Delta \ln Lit + \lambda.\ \Delta \ln CO_2it + \theta.\ \Delta \ln BOD_{t,i}] \quad (3)$$

where the weights are given by the average value shares as follows:

- $\Delta \ln GGDPit$ is the growth rate of green output
- $\alpha.\Delta \ln Kit$ is the contribution of the aggregate physical capital
- $\beta.\Delta \ln Lit$ is the contribution of the aggregate labour
- $\lambda.\Delta \ln CO_2it$ is the contribution of the CO_2 emissions
- $\theta.\Delta \ln BOD_{t,i}$ is the contribution of the BOD emissions
- $\Delta \ln GTFPit$ is the green total factor productivity growth

[1] The intercept term, as usual, gives the mean or average effect on dependent variables of all the variables excluded from the model.
[2] The residual term proxies for the total factor productivity growth that accounts for the technological progress of the economy through the quality of input terms.

The framework decomposes the growth rate of GGDP into the contributions of the rates of growth of the aggregate physical capital, labour, CO_2 emissions and biochemical oxygen emissions, plus a residual term typically referred to as the growth rate of GTFP.

Intensive growth theory (labour productivity)

The second framework (Figure 2) is a presentation of intensive growth theory (labour productivity) for Model 2, the labour productivity or output per labour (Gross Domestic Product/labour) is the dependent variable, and capital per labour, CO_2 emissions per labour and biochemical oxygen demand emissions per labour are the explanatory variables based on their quantity. Moreover, the framework presents the green total factor productivity per labour (GTFP/L) that is expressed as the combined contribution of the quality of the inputs (explanatory variable).

This subsection demonstrates the decomposition of labour productivity into capital deepening, increased usage of CO_2 per unit of labour, and BOD per unit of labour. Moreover, following Dollar and Sokoloff (1990), Wong (1993), Felipe (2000), and Ahmed (2006, 2007), when constant returns $\beta=(1-\alpha-\lambda)$ to scale is imposed, Equation 2 becomes:

$$\ln GDP_{t,i} = a + \alpha.\ln K_{t,i} + \lambda.\ln CO_{2t,i} + \theta.\ln BOD_{t,i} + (1-\alpha-\lambda-\theta).\ln L_{t,i} + \varepsilon_{t,i} \quad (4)$$

t=Number of years and i is the number of the countries

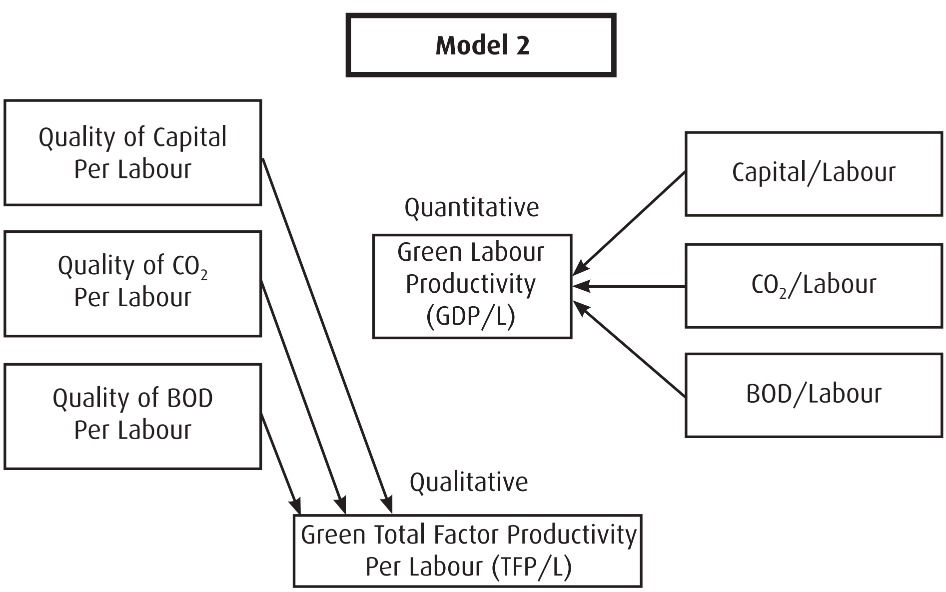

FIGURE 2

Green Total Factor Productivity per Worker Framework, Intensive Growth Theory

Source: Modified from Ahmed, 2018

However, there are two options for dividing the variables by L:

1. Dividing the variables (data) by L before the analysis, in which the equation is given as: $\ln(GGDP/L)_T = a + \alpha \ln(K/L)_T + \lambda \ln(CO_2/L)_T + \theta.\ln(BOD_2/L)_T$

   This will not be used in this study.

2. Dividing the variables by L during the analysis through programming the variables: this will be used in this study, as follows:

$$\ln(GGDP/L)_T = a + \alpha_1 \ln(K/L)_T + \alpha_2[\ln(K/L)_T]^2 + \lambda_1 \ln(CO_2/L)_T + \lambda_2[\ln(CO_2/L)_T]^2 + \theta_1 \ln(BOD_2/L)_T + \theta_2[\ln(BOD/L)_T]^2$$

The output elasticity is calculated with respect to capital deepening and biotechnology intensity, i.e. $\alpha = \alpha_1 + \alpha_2$, $\lambda = \lambda_1 + \lambda_2$ and $\theta = \theta_1 + \theta_2$, respectively. This follows Dollar and Sokoloff (1990) and Ahmed (2006). The production function can be in the form:

$$\Delta\ln(GGDP/L)_{t,i} = a + \alpha_1 \Delta\ln(K/L)_{t,i} + \alpha_2 [\Delta\ln(K/L)_{t,i}]^2 + \lambda_1 \Delta\ln(CO_2/L)_{t,i} + \lambda_2 [\Delta\ln(CO_2/L)_{t,i}]^2 + \theta_1 \Delta\ln(BOD/L)_{t,i} + \theta_2[\Delta\ln(BOD/L)_{t,i}]^2 + \varepsilon_{t,i} \quad (5)$$

t=Number of years and i is the number of the countries

Then, it follows that:

$\Delta\ln(GGDP/L)_{t,i}$ is the labour productivity contribution (output per worker)

$\overline{\alpha}\, \Delta\ln(\overline{K/L}) = \alpha_1.\Delta\ln(K/L)_{t,i} + \alpha_2[\Delta\ln(K/L)_{t,i}]^2$ is the contribution of the capital deeping

$\overline{\lambda}.\Delta\ln(\overline{CO_2/L}) = \lambda_1.\Delta\ln(CO_2/L)_{t,i} + \lambda_2.[\Delta\ln(CO_2/L)_{t,i}]^2$ is the contribution of the CO_2 emissions intensity

$\overline{\theta}.\ \Delta\ln(\overline{BOD/L}) = \theta_1.\Delta\ln(BOD/L)_{t,i} + \theta_2[\Delta\ln(BOD/L)_{t,i}]^2$ is the contribution of the BOD emissions intensity

$\varepsilon_{t,i}$ is the residual term that proxies for GTFP intensity growth ($\Delta\ln(GTFP/L)_{t,i}$)

Δ is the difference operator denoting proportionate change rate

Again, as has been mentioned in extensive growth theory, the intercept (a) has no position in the calculation of the productivity growth rate indicators. Therefore it becomes:

$$\Delta\ln(GGDP/L)_{t,i} = \overline{\alpha}.\Delta\ln(\overline{K/L})_{t,i} + \overline{\lambda}.\Delta\ln(\overline{CO_2/L})_{t,i} + \overline{\theta}.\Delta\ln(\overline{BOD/L})_{t,i} + \Delta\ln(GTFP/L)_{t,i} \quad (6)$$

Where $\overline{\alpha}$, $\overline{\lambda}$ and $\overline{\theta}$ denote the shares of capital deepening, CO_2 emissions intensity, BOD emissions intensity, and GTFP/L is the translog index of GTFP intensity growth as an indicator of green productivity and sustainable development.

Further, to calculate the average annual growth rate of GTFP intensity, as well as the contribution of other productivity indicators in the model, Equation 6 becomes:

$$\Delta\ln(GTFP/L)_{t,i} = \Delta\ln(GGDP/L)_{t,i} - [\overline{\alpha}.\Delta\ln(\overline{K/L})_{t,i} + \overline{\lambda}.\Delta\ln(\overline{CO_2/L})_{t,i} + \overline{\theta}.\Delta\ln(\overline{BOD/L})_{t,i}] \quad (7)$$

Thus, Equation 7 expresses the decomposition of green labour productivity growth into the contributions of capital deepening, increasing the production rate of CO_2 emissions intensity, and BOD emissions intensity. Production is by product or unpriced products in addition to the main products, as well as the combined contribution of the quality of input terms. This is expressed as GTFP per unit of labour (intensity) contribution.

Intensive growth theory (capital productivity)

The third framework (Figure 3) is a presentation of intensive growth theory (green capital productivity) for Model 3, the green capital productivity or output per capita (Green Gross Domestic Product/capital is the dependent variable), and labour per capita, CO_2 emissions per capita, and BOD emissions per capita are the explanatory variables based on their quantity. Moreover, the framework presents the green total factor productivity per capita (GTFP/K) that is expressed as the combined contribution of the quality of the inputs (explanatory variables).

This subsection has shown the capital productivity decomposition into labour, CO_2 emissions and BOD emissions per unit of capital, as presented in Ahmed (2017, 2018). When constant returns to scale [$\alpha(1-\beta-\lambda-\eta)$] have been imposed, Equation 2 becomes:

$$\ln(GGDP)_{t,i} = a + (1-\beta-\lambda).\ln K_{t,i} + \beta \ln L_{t,i} + \lambda \ln CO_{2t,i} + \delta .\ln BOD_{t,i} + \varepsilon_{t,i} \quad (8)$$

t = Number of years and i is the number of the countries

For the purposes of this study, Equation 8 has been transformed by dividing each term by K (capital input). The output elasticity was then calculated with respect to labour deepening,

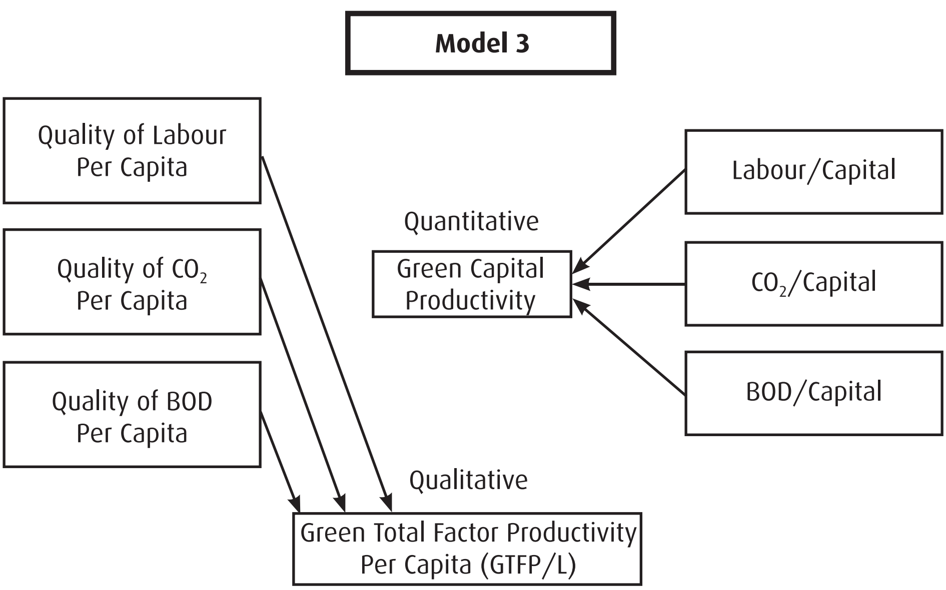

FIGURE 3 **Green Capital Productivity Framework, Intensive Growth Theory**

Source: Modified from Ahmed, 2018

CO_2 emissions per capita (intensity) and BOD emissions intensity, i.e. $\beta=\beta1+\beta2$, $\lambda=\lambda1+\lambda2$, $\delta=\delta_1+\delta_2$, respectively. According to Ahmed (2017, 2018), the production function can be in the form:

$$\begin{aligned}\Delta\ln(GGDP/K)_{t,i} = a &+ \beta_1\Delta\ln(L/K)_{t,i} + \beta_2[\Delta\ln(L/K)_{t,i}]^2 + \lambda_1\Delta\ln(CO_2/K)_{t,i}\\ &+\lambda_2[\Delta\ln(CO_2/K)_{t,i}]^2 + \delta\Delta\ln(BOD/K)_{t,i}\\ &+\delta\Delta \ln[\Delta\ln(BOD/K)_{t,i}]^2\varepsilon_{t,i}\end{aligned} \tag{9}$$

t = Number of years and i is the number of the countries

It then follows that:

$\Delta\ln(GGDP/K)_{t,\,i}$ is the green capital productivity contribution (output per capital)

$\overline{\beta}\Delta\ln(\overline{L/K})=\beta_1\Delta\ln(L/K)_{t,i}+\beta_2\,[\Delta\ln(L/K)_{t,i}]^2$ is the contribution of the labour deeping (labour per unit of capital)

$\overline{\lambda}\Delta\ln(\overline{CO_2/K}) = \lambda_1\Delta\ln(CO_2/K)_{t,i}+\lambda_2[\Delta\ln(CO_2/K)_{t,i}]^2$ is the contribution of the CO_2 emission intensity (CO_2 per unit of capital)

$\overline{\delta}\Delta\ln(\overline{BOD/K}) = \delta_1\Delta\ln(BOD/K)_{t,i}+ \delta_2[\Delta\ln(BOD/K)_{t,i}]^2$ is the contribution of the BOD emissions intensity (BOD per unit of capital)

$\varepsilon_{t,i}$ is the residual term that proxies for GTFP intensity (GTFP per unit of capital) growth $(\Delta\ln(GTFP/K)_{t,i})$

Δ is the difference operator denoting proportionate change rate.

It should be noted that the intercept (a) has no position in the calculation of the productivity growth rate indicators. Therefore it becomes:

$$\Delta\ln(GGDP/K)_{t,i}=\overline{\beta}\,.\Delta\ln(\overline{L/K})_{t,i}+\overline{\lambda}.\Delta\ln(\overline{CO_2/K})_{t,i}+\overline{\delta}.\Delta\ln(\overline{BOD/K})_{t,i}+\Delta\ln(GTFP/K)_{t,i} \tag{10}$$

Where $\overline{\beta}$, $\overline{\lambda}$ and $\overline{\delta}$ denote the shares of labour per unit of capital, CO_2 emissions per unit of capital, BOD emissions per unit of capital, and (GTFP/K) is the translog index of GTFP per unit of capital growth.

To calculate the average annual growth rate of GTFP per unit of capital, as well as of other productivity indicators' contributions in the model, Equation 10 becomes:

$$\Delta\ln(GTFP/K)_{t,i}=\Delta\ln(GGDP/K)_{t,i}-[\overline{\beta}.\Delta\ln(\overline{L/K})_{t,i}+\overline{\lambda}.\Delta\ln(\overline{CO_2/K})_{t,i}+\overline{\delta}.\Delta\ln(\overline{BOD/K})_{t,i}] \tag{11}$$

Thus, Equation 11 expresses the decomposition of green capital productivity growth into the contributions of labour per unit of capital, increasing production of CO_2 emissions per unit of capital, and BOD emissions per capital as by or unpriced products as well as the GTFP per unit of capital contribution based on the quality of inputs, including private inputs (CO_2 and BOD emissions).

DATA SOURCES

The data for this paper were collected from various sources. Real Gross Domestic Product (GDP) in US dollars millions, real fixed physical capital in US dollars millions, numbers of employment, were collected from the Asian Development Bank: Key indicators of developing Asia and Pacific countries, Statistical and Data Systems Division, and international financial statistics of the International Monetary Fund and World Development Indicators online database system. Due to a lack of data on man-hours of work, the labour input index was constructed based on the number of persons employed. Data of CO_2 emissions CO_2 (in kilo tonne (Kt)) and BOD (Kilogram (Kg)) were found to match with the time series data of the other variables of the study for the period of 1965–2006 at the World Development Indicators online database.

CONCLUSIONS AND IMPLICATIONS

This study combined the fundamental findings of Nordhaus and Romer's (2018) research findings. They were awarded the Nobel Prize in economics 2018 for suggesting frameworks and models to measure long-term sustainable economic growth through developing frameworks, and models to measure green productivity to be used in measuring long-term sustainable economic growth in its dual dimensions (sustainable technological progress and environmental sustainability).

The concept of Green Productivity (GP) is drawn from the integration of two important developmental strategies, viz. productivity improvement and environmental protection. Productivity provides the framework for continuous improvement, while environmental protection provides the foundation for sustainable development. Therefore, GP is a strategy for enhancing productivity and environmental performance for overall socio-economic development.

Green productivity is a forceful strategy that can complement economic growth and environmental protection for sustainable development. It tenders small and medium businesses with an approach to achieve a competitive advantage by being better but using less. It is therefore a realistic strategy to increase productivity and protect the environment concurrently.

This study fills the gaps in growth theories by developing three variations' frameworks and econometric models, and internalising the pollutants' emissions as private and unpriced inputs (CO_2 and BOD emissions). Further, the green capital productivity model is the sole contribution of this study to the body of knowledge that has not been thought about in any study so far. Moreover, this study closed the gap of growth accounting theory model by providing statistical analysis in a parametric form that removed the doubt in the results generated. Further, the econometric model gap that did not calculate the productivity indicators used in the growth accounting studies has been filled in this study.

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