Are bio-economy dimensions new stream of the knowledge economy?

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Abstract

Purpose – The purpose of this paper is to explain bio-economy dimensions as a new stream of knowledge-based economy that exists in the new era of the information and communications technology.
Design/methodology/approach – Bio-economy refers to the production of a wide range of goods and services from plant, animal and forest-based material. It is more than just grain-based bio-fuels or bio-diesel as extensively highlighted in Latin America. It is related to biotechnology and other bio-activities based on knowledge generated from the bio-activities and extension of the knowledge-based economy.
Findings – The main concern of developing bio-economy is the environmental damage caused through the undesirable output produced by the bio-economy activities. Bio-economy is centred on research and development (R&D) collaborations across different sectors, including the public and private sectors, in order to breakthrough new products through invention and innovation.
Originality/value – For bio-economy to be realised and put into practice, it should have a well-developed regulatory framework as a platform in order to run and work smoothly.

Keywords Knowledge-based economy, Environment, R&D, Regulatory framework, Bio-economy

Paper type Conceptual paper

Introduction

The knowledge-based economy replaced the information economy; this was done through the introduction of information and communications technology (ICT) that provided advanced hardware and software applications that facilitate the economic activities and bridged the digital divide around the globe. It should be recalled that the term "bio-economy" was first used by the Biomass Research and Development Board in 2001 to describe a revolution and technological return to a sustainable past through the implementation of a new model of economic development, as stated by Pavone (2013). The bio-economy refers to the production of a wide range of goods and services, from plant, animal and forest-based material. It is more than just grain-based bio-fuels or bio-diesel.

According to Johnson and Altman (2014), the term bio-economy includes counterparts for everything for which petroleum is currently used, and for other things as well. In the bio-economy, we will replace petroleum (as well as coal and natural gas) with biomass-based material. So, plastics, nutraceuticals, pharmaceuticals, and all kinds of bio-manufacturing will be part of the bio-economy (Brown, 2003).

OECD (2009) explained that the bio-economy is a transformation of the entire economy, and perhaps even social structure. Meanwhile, the utmost extensive definition is that of the OECD "the aggregate set of economic operations in a society that use the latent value incumbent in biological products and processes to capture new growth and welfare benefits for citizens and nations".

Moreover, Morrison (2012) said that, in re-writing the past, the bio-economy concept became a comprehensive interpretative framework through time for understanding and swaying the present and the future simultaneously. The bio-economy has become a standpoint on society and its relationship with nature (Pavone, 2013).

According to the OECD (2009), several definitions of bio-economy explain that the common factor is that technology provides answers for the major problems of mankind if it

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progress over time. In this respect, the focus is displaced from social causes of problems to technological solutions. These technological solutions can be applied to leading production, health and industry. It should be noted that biotechnology offers technological solutions for numerous global health and resource-based problems facing the world.

Furthermore, Pavone (2013) mentioned that regardless of the correctness or fallaciousness of such thoughts, bio-economy can be anticipated not only as a vision but also as a powerful political scheme. In addition, this explanation renewed the key-stone for the design of public policy pointing at promoting the development and growth of biotechnology-based industries by several government institutions. It should be recalled that gaining full reimbursement for the bio-economy will need a purposive goal-oriented policy to put in place the structural conditions required to realise success, such as locating regional and international agreements (OECD, 2009).

It should be noted, as stated by Benner and Löfgren (2007) and Heinz *et al.* (2010), that neoliberalism was the philosophical ground of this political scheme. Benner and Löfgren (2007) also explained that the idea of the knowledge-based economy was stimulated in this second period, connecting competitiveness and innovation. In this respect, and in order to maintain the competitiveness of OECD and EU countries in relation to emerging economies as mentioned by Pavone *et al.* (2011) and Pavone (2013), the new model of growth is based on the commercialisation of scientific and technological innovations. This is looking at the fact that the bio-economy is a tangible form of this knowledge-based economy in which biotechnology, in addition to natural and biological resources, plays a vital role in creating values.

Additionally, the political mission of bio-economy was, from the outset, intended as a global project, to be embraced by all countries, including those have potential to progress in bio-economy. It should be noted that the potential economic and environmental benefits of biotechnology have shaped a rising strategic interest in the bio-economy in both OECD and non-OECD countries. Not only will the bio-economy be global, but it will also be the main market for biotechnology in primary production (agriculture, forestry and fishing) and resource-based industries in developing countries (OECD, 2009).

In the case of Latin American countries, Benner and Löfgren (2007) stated that the concept of bio-economy is not always specified in Latin American state policy programmes. Different Latin American Governments have combined the schemes, and the region has converted into the main global provider of genetically modified (GM) commodities. In this respect, Latin American Governments encouraged and promoted the bio-economy through a range of interventions that were rather diverse from other industrial policies. It should be noted that diverse national and international policies helped meet the financial and scientific needs of the biotechnological industry and produce a new normative and social shape. Pavone *et al.* (2011) mentioned that government institutions encouraged resource mobilisation towards biotechnology through supportive incentives such as a flexible taxation system and subsidies, and stimulated the interest of corporations and the scientific community. At the same time, governments and international organisations had to introduce new science-based regulatory frameworks. It should be mentioned that for private commercialisation and appropriation of biotechnology products, the right social environment for biotechnology had to be refined and preserved.

In addressing national strategies and policies of Organisation for Economic Cooperation and Development (OECD) countries, Staffas *et al.* (2013) demonstrated the purpose of their article as to stretch a comparative analysis of a sample of national strategies and policies on the bio-economy (BE) and bio-based economy (BBE). The paper discussed the difference between the BE and BBE in different operationalisations. As cited, the BE term is predominantly used when referring to the biotechnological and life science part of an existing economy, whereas the term BBE is used for describing an economy which is predominantly based on biomass for food, feed, energy and other purposes, rather than fossil-based resources. The paper differentiates between BE and BBE in that the "bio-economy" is frequently understood as a sector, while the "BBE" refers to a transformation of the economy as a whole. The paper explained that the two terms can also be used interchangeably, and the BE can be considered a part of the BBE, constituting the process part and not encompassing the resource to the same extent as the BBE. The further explained that whether this difference has any implications for a global approach to the challenge of shifting from a fossil-based economy to a BBE is not clear, but it is clear from the work performed here that the purposes with a strategy or vision for a BE or BBE correlate with the term used.

The breakthrough of bio-economy took place on 16 April 2012, when the Obama administration released the National Bioeconomy Blueprint (White House, 2012). This was a new policy directive designed to promote growth of the US bio-economy through basic and translational research, education, regulatory reform and public-private partnerships. It should be noted that the US blueprint does not explicitly define the bio-economy, but implies that it includes most biological-based activities from genetic engineering to biofuel production. In this respect, US President White House (2012) stated that bio-economy is an economy based on the use of research and innovation in the biological sciences to create economic activities and public benefits. Unlike Latin America's, the US bio-economy includes new drugs and diagnostics for improved human health, higher-yielding food crops, emerging bio-fuels to reduce dependency on oil, bio-based chemical intermediates, and several other aspects of biotechnology activities: the bio-economy had been limited to biofuel in Latin America.

It should be noted that the public benefit gained through biological and biotechnology research can be seen through the eyes of patients who receive a critical medication that did not exist decades ago. In addition, the farmers' higher-yield crops are turned into new bio-economy products such as fuels, food, and intermediate chemicals, and for small-business owners, their innovative bio-based products are breaking new ground in manufacturing and services through the invention and innovation of bio-economy technical progress. This has created signif1icant wealth for them compared with traditional methods of business. Moreover, the increasing social needs for food and energy, combined with new knowledge/discoveries in biotechnology and new methods for harnessing biological processes, and have dramatically increased the economic potential of the bio-economy.

In his statement, President Obama explained that current bio-economy rose from several scientific and technological developments that transformed the practice and potential of biotechnology research, including three of particular importance: genetic engineering, Deoxyribonucleic acid (DNA) sequencing, and robotic technologies that perform a high number of molecular operations rapidly and accurately. It should be recalled that this technological progress has led to the development of many important drugs, products and processes. However, a growing population around the globe requires increased health services and more resources such as food, animal feed, fibres for clothing and housing, and sources of energy and chemicals for manufacturing; this is of significant importance to meet the needs of the growing population. A new and more effective bio-economy that is fuelled by innovative ideas and practices that can help to address these needs in new, more powerful ways is urgently needed.

Further, Priefer *et al.* (2017) in addressing the pathway to shape bio-economy reviewed several terms to define bio-economy (the core idea of the bio-economy, also referred to as the BBE or the knowledge-based bio-economy). The study limited bio-economy in the replacement of non-renewable fossil fuel resources used in industrial production and for energy supply by renewable biogenic feedstock and ignored the wide dimensions of bio-economy that is linked to biotechnology involvement in the wide range of economic activities around the globe. Moreover, the study tried to link bio-economy sustainability by stating that the orientation towards sustainability not only is a major challenge, but also an important prerequisite for a successful transition to the bio-economy. As the analysis of the current discourse has shown, there are different understandings of the relationship between sustainability and the bio-economy. Based on the majority of experts, the paper mentioned that the bio-economy will only contribute to a more sustainable future if certain requirements are met. The development of a framework of principles and criteria for a sustainable bio-economy, involving ecological, social and economic aspects, is a key task for policy, science and society.

Moreover, Staffas *et al.* (2013) demonstrated the bio-economy strategies and policies regarding the bio-economy on the publication of the policy agenda on the bio-economy by the OECD in 2009. The study analysed selected national strategies and policies regarding the development of a bio-economy. It gifts a comparative overview of the strategies and policies for developing a bio-economy in the EU, the USA, Canada, Sweden, Finland, Germany and Australia. Meanwhile, Boterman (2011) reviewed bio-economy in China based on this paper as well McCormick and Kautto (2013) reviewed the bio-economy in Europe based on sustainability concept.

Finally, others define the bio-economy simply as an economy that is more dependent on renewable resources; this could include such sectors as non-biological sources of energy. In this paper, we refer to the production, processing, marketing, transportation and consumption of biologically derived products, and all the products generated from the involvement of biotechnology.

Bio-economy and environmental concerns

The main concern of developing a bio-economy is the environmental damage caused through any undesirable output produced by its activities. To ensure sustainable development in its dual dimensions (technological progress and environmental protection), this should be considered through addressing green productivity issues to ensure the right of forthcoming generations to enjoy a better standard of living and well-being.

In this respect, as has been mentioned in US National Bioeconomy Blueprint (2012), from clean air and water, to abundant food and raw materials for much of our building construction, to the more intangible benefits of nature and ecosystem services, we depend on the living world to support and enrich our quality of life. In addition, the well-being of the living world and its ability to provide sustainable resources depend on responsible human stewardship, which, in turn, requires fundamental knowledge. Basic and applied biological research has the potential of producing a whole generation of the new knowledge and technologies needed to understand how the living world functions, to monitor and mitigate human impact, and to develop informed approaches to use and restore environments.

It should be noted that modern biotechnology is making inroads into environmental management and restoration of resources to ensure the right of forthcoming generations to enjoy the equal benefits of these resources and grant its sustainability. Microorganisms and their constituents are being used to wash industrial waste and clean ecosystems contaminated by environmentally hostile practices. In addition, the mounting field of environmental restoration will eventually be the key to recovering healthy, functioning ecosystems in heavily degraded areas. It may also ultimately permit mitigation of some of the effects of climate change by allowing the design of ecosystems with better capacity for removing carbon from the atmosphere and sequestering it in biomass for other uses. In addition, resource-based industries such as textiles and paper have moved towards bio-based products and away from use of petrochemical products for both manufacturing and clean-up; they now use microorganisms or biologically derived industrial enzymes that are more environmentally friendly and cost effective.

Moreover, biotechnology helps to move from traditional plant breeding to synthetic biology, a range of products from bio-fuels to medical treatments and petroleum replacements. It should be mentioned here that future benefits of bio-economy will be of help to bio-manufacturing; this will be significantly simplified by the capability to design and use biological systems and organisms rapidly. However, the modification of biological organisms, and the construction and use of organisms that are not found in nature, carry potential safety and security risks if misused. These need a range of considerations for responsible conduct, including ethics, responsible use, and environmental awareness. Finally, these advances increase vital ethical and security issues that are also top priorities for the US administration, and other countries who are interested in implementing a bio-economy.

Bio-economy and research and development (R&D)

It should be recalled that the bio-economy is centred on R&D collaborations across different sectors, and the public and private sector, in order to break through with new products. This will be done through invention and innovation activities that are required for developing new products or processes that are based on technological progress; this would make the difference in generating and copying bio-economy products. In this regard, as stated in the US National Bioeconomy Blueprint, non-traditional research collaborations that feature the sharing of information, resources and capabilities is transforming the bio-economy towards new discoveries. New collaborations and smart partnerships between the public and private sectors are considered to be precompetitive collaborations, where "competitors" partner and pool resources, are growing as partners seek new ways to leverage constrained resources and surmount shared problems. Meanwhile, smart partnerships for innovation are increasingly observed as a response to changing economic and technological conditions around the globe.

For example, in the agriculture sector, as the public and private sectors pursue increased information for the bio-economy on potential crop characteristics, there is increased sharing of that information. This sharing of genetic information is happening, both domestically and internationally, in order to develop new products based on biotechnology activates that modify crops, the so-called GM crops. In this respect, the sharing of genetic information enhances US agricultural competitiveness for food, energy, chemical production in plants, and other bio-based-product crop species around the globe.

Finally, in the health sector, precompetitive collaborations and smart partnerships are having significant effects in clinical-trial design and biomarker discovery and other areas in the health field. It should be mentioned that combined industrial R&D has contributed to this transformative progress, despite major challenges such as increased management costs due to inter-collaborations and smart partnerships, and the requirement to develop effective communication networks across companies locally and around the globe.

Bio-economy regulatory framework

It is very important to state that for the bio-economy to be comprehended and placed in practice, it should have a well-developed regulatory framework as a platform in order to be run and work smoothly. This is to overcome all the problems associated with bio-economy activates development as new phenomena. In this respect, the American National Bioeconomy Blueprint (2012) stated that developing regulations is extremely important for protecting human health and the environment. The regulations would also reduce the safety and security risks associated with potential misapplications of any technology that required new laws to resolve the issues brought by biotechnology discoveries. When new laws are not carefully created or become obsolete, however, they can become barriers to innovation and market expansion. If new laws are not developed to overcome the problems brought by new bio-economy activities, this could discourage the investment that is very important to the bio-economy.

It should be noted that Pellegrini (2013) explained that the regulatory frameworks on GM crops present several differences depending on the specific procedures they follow to deal with what they consider to be risks. These risks are based on the concept of bio-economy and are considered the same as cybercrimes brought about by the digital or knowledge economies. The USA and Europe have studied some of these differences; however, other countries that have developed their economies based on bio-economy have other scenarios and subjects that may also be involved in the new frameworks. In this respect, Argentina has one of the first regulatory agencies in the region to regulate bio-economy activities; in addition, major land areas have been devoted to transgenic agriculture in Argentina. Nevertheless, Argentina's regulatory policies towards genetically modified organisms (GMOs) have several differences from some international regulatory policies. These include a precautionary approach, the Cartagena Protocol on Biosafety and the labelling of food derived from GM crops. When compared with Europe, and showing how commercial interests in agriculture may explain each regulatory approach, the GMO regulatory framework in Argentina should be analysed in order to understand this position.

Furthermore, Chandler and Rosenthal (2007) stated that intellectual property (IP) may be involved in plant biotechnology development, including patents, breeders' rights and regulatory systems specifically designed for GMOs. These should be viewed in different ways in order to produce a common IP to be used by all the countries; this would be similar to that agreed by the World Trade Organisation on trade issues. The regulatory framework should define what can be done with GMOs by openly specifying procedures that connect their utilisation, evaluation and assumption.

However, usually at a more understood level, each regulatory framework also reflects a position over complex issues that are considered as a risk in these technologies and how to mitigate them. The question that should be asked here is: do we need to introduce new IP rights to fit with bio-economy? As this economy is based on R&D activities that should be protected with new rules that should be developed based on bio-economy reality.

These regulatory frameworks may diverge between countries, but the study of this diversity of regulatory styles is concentrated mainly in the regulatory frameworks of the USA and Europe (Dunlop, 2000; Vogel, 2001; Vogel and Lynch, 2001; Prakash and Kollman, 2003; James, 2011). Both great powers have struggled in international fora to impose their position. Meanwhile, the rivalry between them has been analysed by Daniel Drezner, who shows the GMO friendly regulations sustained by the USA, and the promotion of the precautionary principle and the resistance to GMOs by the European Union. On occasion, the lobbying that they have displayed to recruit other countries has been notable, as the case when Zambia was confronting a drought and a subsequent food crisis, but rejected food aid with GM corn fearing that its own agricultural exports would be blocked from the European Union if it showed itself to be permissive of GM products (Drezner, 2007; Paarlberg, 2008; Cleaver *et al.*, 2006).

The main purpose of this paper is to show that biotech regulatory policies cannot be understood as a matter of preference between standards, but that diverse interests are involved. The regulatory framework should be developed based on combined regulatory frameworks from all the countries that are developing bio-economy activities. This should be seen as a common ground to be used around the globe and accepted by all countries as a legal framework to overcome all the issues associated with bio-economy products. Nevertheless, not all regulatory policies on GMOs may be explained as a mere follower of one or the other bloc. It should mentioned that Argentina's regulatory policies, which aforementioned authors have analysed, have been associated for some issues with those of the USA; however, they also differ on many issues.

Methods and estimations procedures

This paper reviews the studies undertaken on bio-economy issues around the globe; several methods have been used to measure bio-economy issues. These include descriptive analysis, non-parametric analysis, such as data envelope analysis, input output analysis, and dynamic computable general equilibrium.

To fill the gap in measuring bio-economy, this paper 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 will be used in this study such as (extensive growth, and intensive growth (labour productivity and capital productivity), as explained by Ahmed (2017).

In this paper, 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 direct presentations of extensive growth theory for model 1, the output (gross domestic product (GDP)) is the dependent variable, and capital, labour and biotechnology are the explanatory variables based on their quantity. Moreover, the framework presents the total factor productivity (TFP) that is expressed the combined contribution of the quality of the inputs (explanatory variable).

The production function for an economy can be represented as follows:

$$\mathrm{GDP}_{t,i} = F\left(K_{t,i},\ L_{t,i},\ \mathrm{BIO}_{t,i},\ T_{t,i}\right) \tag{1}$$

where country $i = 1, 2, \ldots$ in years t, output real GDP is a function of real fixed physical capital input K, labour input L, BIO, that proxies for biotechnology, and time T, that proxies for TFP as a technological progress of the economies.

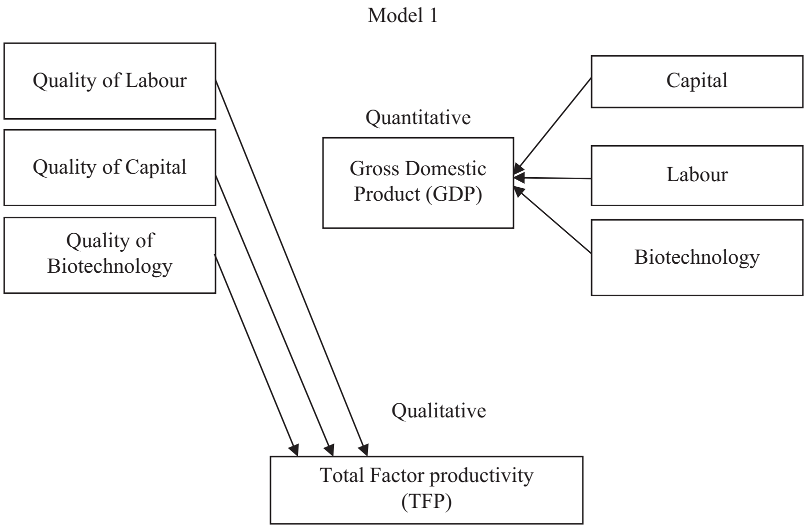

Figure 1.
Bio-economy productivity framework, extensive growth theory

Extensive growth theory

This subsection presents the extensive growth theory based on GDP that is decomposed into physical capital, employment and bio. 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:

$$\Delta \ln \mathrm{GDP}_{t,i} = a + \alpha.\ \Delta \ln K_{t,i} + \beta.\ \Delta \ln L_{t,i} + \lambda.\ \Delta \ln \mathrm{BIO}_{t,i} + \varepsilon_{t,i}$$
$$t = \text{Number of years} \quad (2)$$

where α is the output elasticity with respect to capital; β is the output elasticity with respect to labour; λ is the output elasticity with respect to Biotechnology; a is the intercept or constant of the model[1]; ε is the residual term[2]; ln is the logarithm to transform the variables; and 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:

$$\Delta \ln \mathrm{TFP}_{t,i} = \Delta \ln \mathrm{GDP}_{t,i} - \left[\alpha.\Delta \ln K_{t,i} + \beta.\Delta \ln L_{t,i} + \lambda.\Delta \ln \mathrm{BIO}_{t,i}\right] \quad (3)$$

where the weights are given by the average value shares as follows: $\Delta \ln \mathrm{GDP}_{t,i}$ is the growth rate of output; $\alpha.\Delta \ln K_{t,i}$ is the contribution of the aggregate fiscal capital; $\beta.\Delta \ln L_{t,i}$ is the contribution of the aggregate labour; $\lambda.\Delta \ln \mathrm{BIO}_{t,i}$ is the contribution of the Biotechnology; and $\Delta \ln \mathrm{TFP}_{t,i}$ is the TFP growth.

The framework decomposes the growth rate of GDP into the contributions of the rates of growth of the aggregate physical capital, labour and biotechnology, plus a residual term typically referred to as the growth rate of TFP.

Intensive growth theory (labour productivity)

The second framework (Figure 2) is direct presentations of intensive growth theory (labour productivity) for model 2, the labour productivity or output per labour (GDP)/labour is the dependent variable, and capital per labour and biotechnology per labour are the

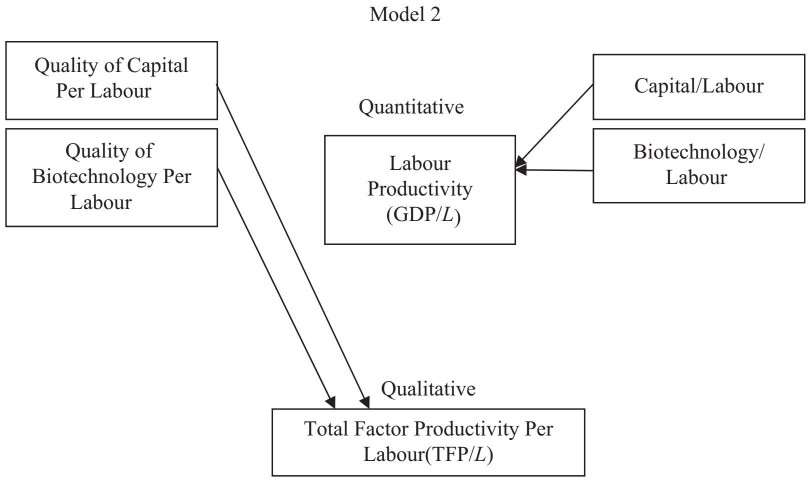

Figure 2. Bio-economy productivity framework, intensive growth theory (labour productivity)

explanatory variables based on their quantity. Moreover, the framework presents the TFP per labour (TFP) that is expressed 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 biotechnology per unit of labour. Moreover, following Dollar and Sokoloff (1990), Wong (1993), Felipe (2000) and Ahmed (2006a), when constant returns $\beta = (1 - \alpha - \lambda)$ to scale are imposed, Equation (2) becomes:

$$\ln \mathrm{GDP}_{t,i} = a + \alpha .\ \ln K_{t,i} + \lambda .\ \ln \mathrm{BIO}_{t,i} + (1 - \alpha - \lambda).\ \ln L_{t,i} + \varepsilon_{t,i}$$
$$t = \text{Number of years} \tag{4}$$

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:

$$\ln (\mathrm{GDP}/L)_T = a + \alpha \ln (K/L)_T + \lambda \ln (\mathrm{BIO}/L)_T$$

This will not be used in this study:

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

$$\ln (\mathrm{GDP}/L)_T = a + \alpha_1 \ln (K/L)_T + \alpha_2 [\ln (K/L)_T]^2 + \lambda_1 \ln (\mathrm{BIO}/L)_T + \lambda_2 [\ln (\mathrm{BIO}/L)_T]^2$$

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

$$\Delta \ln (\mathrm{GDP}/L)_{t,i} = a + \alpha 1.\Delta \ln (K/L)_{t,i} + \alpha_2 \left[\Delta \ln (K/L)_{t,i}\right]^2$$
$$+ \lambda_1.\Delta \ln (\mathrm{BIO}/L)_{t,i} + \lambda_2 \left[\Delta \ln (\mathrm{BIO}/L)_{t,i}\right]^2 + \varepsilon_{t,i}$$
$$t = \text{Number of years} \tag{5}$$

Then, it follows that: $\Delta \ln (\mathrm{GDP}/L)_{t,i}$ 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 deepening; $\overline{\lambda}..\Delta \ln \overline{(\mathrm{BIO}/L)} = \lambda_1.\Delta \ln (\mathrm{BIO}/L)_{t,i} + \lambda_2[\Delta \ln (\mathrm{BIO}/L)_{t,i}]^2$ is the contribution of the biotechonolgy intensity; $\varepsilon_{t,i}$ is the residual term that proxies for TFP intensity growth ($\Delta \ln (\mathrm{TFP}/L)_{t,i}$); and Δ is the difference operator denoting proportionate change rate.

The intercept (a) has no position in the calculation of the productivity growth rate indicators, therefore it becomes:

$$\Delta \ln (\mathrm{GDP}/L)_{t,i} = \overline{\alpha}.\Delta \ln \overline{(K/L)}_{t,i} + \overline{\lambda}.\Delta \ln \overline{(\mathrm{BIO}/L)}_{t,i} + \Delta \ln (\mathrm{TFP}/L)_{t,i} \tag{6}$$

where $\overline{\alpha}$ and $\overline{\lambda}$ denote the shares of capital deepening and biotechnology intensity, and TFP/L is the translog index of TFP intensity growth.

To calculate the average annual growth rate of the TFP intensity, as well as of other productivity indicators contribution in the model, Equation (6) becomes:

$$\Delta \ln (\mathrm{TFP}/L)_{t,i} = \Delta \ln (\mathrm{GDP}/L)_{t,i} - \left[\overline{\alpha}.\Delta \ln \overline{(K/L)}_{t,i} + \overline{\lambda}.\Delta \ln \overline{(\mathrm{BIO}/L)}_{t,i}\right] \tag{7}$$

Thus, Equation (7) expresses the decomposition of labour productivity growth into the contributions of capital deepening, increasing usage of biotechnology intensity, and the combined contribution of the quality of input terms. This is expressed as TFP per unit of labour (intensity) contribution.

Intensive growth theory (capital productivity)

The third framework (Figure 3) is direct presentations of intensive growth theory (capital productivity) for model 3, the capital productivity or output per capital (GDP)/capital is the dependent variable, and labour per capital and biotechnology per capital are the explanatory variables based on their quantity. Moreover, the framework presents the TFP per capital (TFP/K) that is expressed the combined contribution of the quality of the inputs (explanatory variable).

In this subsection, the capital productivity decomposition into labour and biotechnology per unit of capital is presented in Ahmed (2017). When constant returns $\alpha(1-\beta-\lambda)$ to scale are imposed, Equation (2) becomes:

$$\ln \mathrm{GDP}_{t,i} = a + (1-\beta-\lambda).\ \ln K_{t,i} + \beta \ln L_{t,i} + \lambda.\ \ln \mathrm{BIO}_{t,i} + \varepsilon_{t,i}$$
$$t = \text{Number of years} \tag{8}$$

For the purposes of this study, Equation (8) was transformed by dividing each term by K (capital input) and then the output elasticity was calculated with respect to labour deepening, biotechnology per capital (intensity), i.e. $\beta=\beta_1+\beta_2$, $\lambda=\lambda_1+\lambda_2$, respectively. According to Ahmed (2017), the production function can be in the form:

$$\Delta \ln \left(\mathrm{GDP}/K\right)_{t,i} = a + \beta_1 \Delta \ln \left(L/K\right)_{t,i} + \beta_2 \left[\Delta \ln \left(L/K\right)_{t,i}\right]^2 + \lambda_1 \Delta \ln \left(\mathrm{BIO}/K\right)_{t,i} + \lambda_2 \left[\Delta \ln \left(\mathrm{BIO}/K\right)_{t,i}\right]^2 + \varepsilon_{t,i}$$
$$t = \text{Number of years} \tag{9}$$

Then, it follows that: $\Delta \ln\ (\mathrm{GDP}/K)_{t,i}$ is the 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 deepening (labour per unit of capital); $\overline{\lambda}\Delta \ln \overline{(\mathrm{BIO}/K)} =$

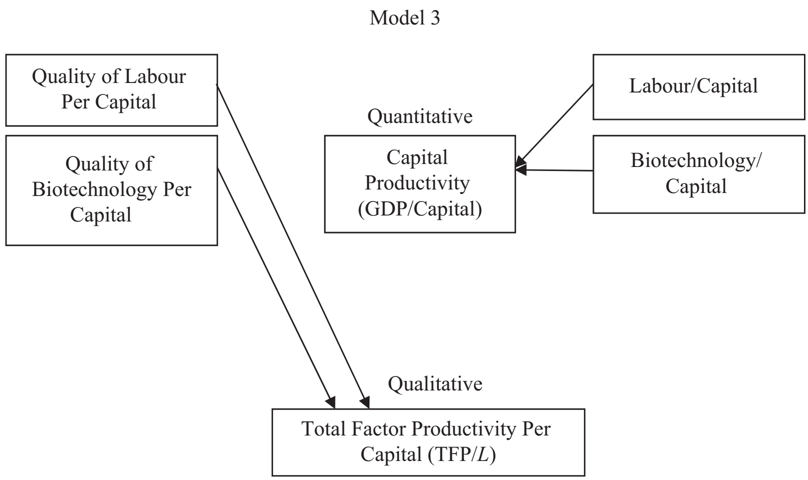

Figure 3. Bio-economy productivity framework, intensive growth theory (capital productivity)

$\lambda_1 \Delta \ln (\text{BIO}/K)_{t,i} + \lambda_2 [\Delta \ln (\text{BIO}/K)_{t,i}]^2$ is the contribution of the biotechnology intensity (BIO per unit of capital); $\varepsilon_{t,i}$ is the residual term that proxies for TFP intensity (TFP per unit of capital) growth ($\Delta\ln(\text{TFP}/K)_{t,i}$); and Δ is the difference operator denoting proportionate change rate.

The intercept (a) has no position in the calculation of the productivity growth rate indicators, therefore it becomes:

$$\Delta \ln \left(\text{GDP}/K\right)_{t,i} = \overline{\beta}.\Delta \ln \overline{\left(L/K\right)}_{t,i} + \overline{\lambda}.\Delta \ln \overline{\left(\text{BIO}/K\right)}_{t,i} + \Delta \ln \left(\text{TFP}/K\right)_{t,i} \tag{10}$$

where $\overline{\beta}$ and $\overline{\lambda}$ denote the shares of labour per unit of capital and biotechnology per unit of capital, and (TFP/K) is the translog index of TFP per unit of capital growth.

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

$$\Delta \ln \left(\text{TFP}/K\right)_{t,i} = \Delta \ln \left(\text{GDP}/K\right)_{t,i} - \left[\overline{\beta}.\Delta \ln \overline{\left(L/K\right)}_{t,i} + \overline{\lambda}.\Delta \ln \overline{\left(\text{BIO}/K\right)}_{t,i}\right] \tag{11}$$

Thus, Equation (11) expresses the decomposition of capital productivity growth into the contributions of labour per unit of capital, increasing usage of biotechnology per unit of capital, and TFP per unit of capital contribution.

Following Ahmed's (2006b) assumption to measure the ICT used in the manufacturing sector, it is assumed that the usage of ICT in the Malaysian manufacturing process is increasing from year to year in the form of a geometric progression due to the revolution of ICT in the world. A geometric progression is a sequence where each term is r times larger than the previous term: r is known as the common ratio of the sequence. The nth term of a geometric progression, where a is the first term and r is the common ratio, is:

$$ar^{n-1}$$

The geometric progression of this study to measure the data of ICT used in the manufacturing sector as a dummy variable is calculated in this way; the first term is 15, in 1970, and the common ratio is 2: 15, 30, 60, …, 32, 212, 254, 720, in 2001.

This assumption can be used to generate dummy data for biotechnology as there is no clear data to measure it. Correspondingly, if it is found that biotechnology investment is a good proxy to measure biotechnology activities, this is the main driver of bio-economy.

Other variables such as GDP, physical capital and labour will be collected from World Development Indicators of the World Bank and other databases.

Conclusions and implications

The paper reviewed the bio-economy concepts and dimensions as explained in several past studies in Europe, Canada, the USA and Latin America as leading countries in bio-economy strategies and policies. It should be mentioned that bio-economy is a new stream of knowledge-based economy that exists in the new era of the ICT that provided hardware and software to facilitate economic activities around the globe. In addition to ICT being a driver of the knowledge-based economy, bio-economy emerged based on the biotechnology revolution. It should be noted that the bio-economy refers to the production of a wide range of goods and services, from plant, animal and forest-based material. It is more than just grain-based bio-fuels or bio-diesel as extensively highlighted in Latin America. It is related to biotechnology and other bio-activities, based on knowledge generated from the bio-activities and extension of the knowledge-based economy that evolved due to ICT and human capital's significant contribution to economic activities.

Unlike Latin American countries that narrowed bio-economy to biofuel activities related to agricultural activities, the USA was the first to publish its bio-economy blueprint that explained the wide range of bio-economy activities linked to knowledge-based economy activities.

The main concern in developing bio-economy is the environmental damage through the undesirable output produced by the activities of the bio-economy; there are also human health concerns. To ensure that sustainable development in its dual dimensions (technological progress and environmental protection), these concerns should be addressed through addressing green productivity issues to ensure the right of forthcoming generations to enjoy better standards of living and well-being.

Moreover, the bio-economy is centred on R&D, smart partnerships and collaborations across different sectors, and the public and private sectors, in order to break through new products through invention and innovation. In addition, for the bio-economy to be realised and put in practice, it should have a well-developed and agreeable regulatory framework as a platform for the bio-economy to be run and work smoothly to overcome all the issues associated with its products around the globe.

Finally, in terms of methodology, three bio-economy productivity frameworks were developed. Moreover, this paper has closed the gap in past studies undertaken in bio-economy research by introducing three variation models to measure bio-economy's contribution to the economies; these are combined methods of both econometric and growth account methods to calculate the parameters of the variables involved, and productivity indictors based on extensive growth theory and intensive growth such as labour productivity and capital productivity. This is considered to be the significant contribution of this study to the body of knowledge.

Notes

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.

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