Technical progress in GDP production and CO_2 emissions in Brazil: 1970–2012

Márcio Santetti, Adalmir Antônio Marquetti
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Abstract

In this study, technical progress is analysed in terms of its influence on the mix of inputs of labour, capital and energy that go into the production of gross domestic product (GDP) and carbon dioxide (CO_2) emissions. The results of this analysis show that the Brazilian economy exhibited a Marx-biased pattern of technical progress during the period under study. Within the framework of this overall pattern, however, three different phases of technical progress in Brazil can be identified. Between 1970 and 1980, a Marx-biased pattern was observed, followed by the stagnation of technical progress between 1980 and 2003. In the years from 2003 to 2012, the pattern of technical change was Harrod-neutral.

Keywords

Economic growth, technological change, industrial production, greenhouse gases, input-output analysis, economic indicators, Brazil

JEL classification

E01, E23, O33

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I. Introduction

The exponential growth of production in capitalist societies has been made possible by the use of natural resources and human labour, the expansion of education and a greater utilization of machines and equipment that incorporate technical innovations.[1] Technical progress is a fundamental driver of economic growth. Classical Marxism identifies incentives for the adoption of labour-saving, capital-using technical change as workers and capitalists struggle over value added. Firms adopt technical change to reduce their production costs at prevailing prices so that they can obtain higher profits than their competitors. Technical progress takes the form of mechanization and is reflected in rising labour productivity and declining capital productivity. The accumulation of capital leads to increasing use of machines and equipment in the production process, which translates into an increase in the capital-labour ratio; Foley and Michl (1999) call this form of technical change "Marx-biased".

Mechanization-based economic growth inevitably generates adverse environmental impacts, since mechanization requires the inevitably environmentally harmful use of energy to mobilize productive physical capital. According to Kümmel (1989), the idea that the use of mechanization to drive industrial development has irreversible effects on society and nature is fairly recent. For centuries, the waste generation flow was the result of the propagation of solar energy in the atmosphere, which was manifested in heat radiation and was not harmful to the planet. With the advent of the industrial revolution, however, new sources of energy came into use (most importantly, fossil fuels such as petroleum) that heightened the adverse effects which economic activity has on the natural environment.[2] The intensive use of these energy inputs –in the place of the more inefficient sources, such as wood, that had been available up until that time– underpinned economic growth during the industrial revolution and have continued to do so ever since (Harvey, 2006). The carbon dioxide emissions[3] resulting from the use of those fuels are one of the causes of global warming (Stern, 2006; Foley, 2009).[4,5]

Thus, the pattern of technical change supports certain hypotheses about the use of energy in the production process and the generation of bad outputs. The Marxist-biased pattern relates to the use of energy and the generation of bad outputs, the productivity of energy (the ratio between good outputs and energy use), the energy-to-labour ratio and the energy-to-capital stocks ratio.

Along classical Marxist lines (Duménil and Levy, 1995; Foley and Michl, 1999; Marquetti and Pichardo, 2013), the model to be used here combines inputs of labour, capital and energy in the production of a good output (gross domestic product (GDP)) and an undesired output (CO_2 emissions).[6] This approach is used to take an in-depth look at the production of both types of outputs and technical

[1] The capitalist system is grounded in a search for ever-increasing profits and the unbounded amassment of wealth. Over time, the capitalist dynamic engendered a deepening rift between the countryside and the cities (Burkett, 2003), and farming areas ceased to receive the effluents from the cities to fertilize them. In other words, the specialization of production and rural/urban bipolarization and interrupted the circular flow of organic material. This breakdown in the nutrient cycle triggered mounting pollution in the cities (Foster, Clark and York, 2010). The ever-greater scale of production and the application of business models to what had been traditional farms accelerated the degradation of the environment.

[2] Petroleum is composed of fossilized organic matter (zooplankton and algae) from the Jurassic period (169–144 million years ago). Because it is so energy-dense and easy to transport and store, petroleum has become the world's main energy input, and the global system has come to be heavily reliant on that natural resource (Li, 2014). The use of natural resources to fuel exponential economic growth inevitably increases emissions of harmful gases, such as carbon dioxide (CO_2) and methane (CH_4), into the environment.

[3] The terms "carbon dioxide", "carbonic gas" and "CO_2" are used interchangeably throughout this article.

[4] On how the concept of global warming has evolved over time, see Arrhenius (1896), Callendar (1938) and Maslin (2004).

[5] The production of carbon dioxide is one of the main forms of waste generation in capitalist systems. It makes up 77% of global greenhouse gas emissions, and 57 percentage points of that figure correspond to the burning of fossil fuels (IPCC, 2007). Pollution is an inherent characteristic of capitalist production and is one of the manifestations of an increasing accumulation of capital.

[6] Baran and Sweezy (1966) have shown that, in addition to expanding emissions of CO_2, capitalist economic activity produces various types of waste, including unnecessary expenditures on fancy packaging and the mounting cost of the escalating advertising needed to boost demand for the system's products. While these factors are major reasons for the inefficiencies of capitalism and for its environmental impacts, their implications fall outside the scope of this article.

progress in the Brazilian economy in the period 1970–2012. The contribution being made by this study is based on its characterization of energy use as an input and carbon dioxide emissions as an undesired output of the production process.

This approach makes it possible to undertake a more detailed analysis of the pattern of technical progress. One of the main hypotheses of this study is that, in the period under analysis, the Brazilian economy exhibited a Marx-biased pattern of technical progress, particularly during the years of higher economic growth. The results show a larger increase in GDP output than in CO_2 emissions, and a pattern of technical progress marked by rising labour productivity, declining capital productivity and a fall in the profit rate in Brazil between 1970 and 2012.

The article is divided into four sections, one of which is this introduction. The second section describes technical progress and the production of GDP and CO_2 emissions from a classical Marxian perspective. The third analyses GDP, CO_2 emissions and the pattern of technical change in the Brazilian economy between 1970 and 2012. The fourth and final section offers concluding remarks and observations.

II. An approach for studying production and technical progress from a classical Marxian perspective

Political and economic changes that began to arise in the 1960s and 1970s have had implications in terms of pollution and the use of natural resources. The reconstruction of advanced countries after the Second World War and the expansion of industry in the United States and the Soviet Union during the cold war called for greater inputs of energy and natural resources and this, in turn, led to increased pollution. The pioneering studies of Rachel Carson (1962) and Wassily Leontief (1970) and the development of ecological economics (Georgescu-Roegen, 1971; Daly, 1977) laid bare the trade-offs between economic growth and natural resource constraints.

The production process involves the use of energy to transform inputs into final goods and entails exchanges of matter and energy with the environment. This transformative process produces waste, since part of the energy that goes into that process leaks out, and that waste has a negative impact on the natural environment and its ecosystems.

Carbon dioxide is one of the main pollutants generated by economic activity and represents 77% of global greenhouse gas emissions; 57 percentage points of that figure corresponds to the burning of fossil fuels, while 17 points are attributable to deforestation and the decomposition of biomass and the remaining 3 percentage points to other sources (IPCC, 2007). The build-up of carbon dioxide in the atmosphere is an unintended consequence of human activity in a capitalist economic system.[7]

In the 1960s, some scholars turned back to classical and Marxian lines of analysis (Garegnani and Petri, 1989), one of which focuses on the falling rate of profit as a basis for exploring long-term trends in the global economy (Okishio, 1961; Morishima, 1973; Christiansen, 1976; Roemer, 1977).

The classical Marxian approach to the analysis of capitalism and its development focuses on the conflict between capitalists and workers over the appropriation of the economic surplus and the incentives that competition provides for the adoption of cost-cutting technologies (Foley, 1998). Competition spurs

[7] There is evidence of alternating cycles of high and low concentrations of carbon dioxide in the atmosphere that dates back to prehistoric times (Vicente, 2014). In the absence of human interference, natural flows of carbonic gas follow a cyclical pattern. However, that pattern began to break down around 1750, and the atmospheric concentration of CO_2 began to climb quite steeply. This was the period during which the industrialization process was gaining momentum as fossil fuels came into increasing use as sources of energy. The felling of forests in order to clear the land for farming also boosted the level of emissions (Vitousek and others, 1997).

companies on to adopt technical changes that will lower their production costs so that they can attain an above-average profit rate. Marx described this process as the engine of technical change in capitalist systems of production. The expectation of realizing above-average profits is what drives businesses to incorporate labour-saving, capital-intensive technical changes into their production processes.

The increasing mechanization of the economy is evident in the expanded use of machines and equipment, natural resources and energy. The use of labour rises when the rate of capital accumulation is outpacing the rate of growth in labour productivity. This leads to an expansion of GDP production, which boosts capitalists' profits, and of undesired outputs, which take the form of pollution and waste. If wages rise in step with labour productivity, however, mechanization may reduce the profit rate.

The classical Marxian theory of the tendency of the rate of profit to fall (TRPF) posits the following long-term trends for a capitalist economic system:

(i) An upward trend in the production of GDP and CO_2 emissions;

(ii) An increase in the capital-labour ratio;

(iii) An increase in labour productivity and a decline in capital productivity; and

(iv) A reduction in the rate of profit provided that income distribution remains constant.

Foley and Michl (1999) and Duménil and Levy (2003) have developed economic models to explain the trends that arise in capitalist economies. Focusing on accounting entities and the classical Marxian tradition, these authors find that many societies are undergoing Marx-biased technical changes over the long term (Pichardo, 2007). If the energy used in the production process comes from fossil fuels, then carbonic gas emissions will rise.

For the purposes of this analysis of trends in economic growth and technical change, it will be posited that an economy produces a desired output, X, and an undesired output, B. The desired output is represented by GDP, measured in reais at 1995 prices based on data from IBGE (1990) and IBGE (2003) for 1970–1985 and on IBGE (2010) for 1995–2008. For 2008–2012, IPEA (2016) data were used. B represents CO_2 emissions. The data on CO_2 emissions, in kilograms (kg), for 1970–2008 were taken from Boden, Marland and Andres (2016).

At the end of each period, a portion of the capital stock is depreciated. $K\text{-}D$ stands for the amount of capital that remains at the end of the production period. The rate of depreciation is the ratio between depreciation and capital stock ($\delta = D/K$).[8] Table 1 provides an overview of the use of capital, labour and energy inputs to produce GDP and CO_2 emissions.

Table 1

Input-output ratio for the production of GDP and CO_2 emissions

Inputs			Outputs		
Capital	Labour	Energy	GDP	CO_2	Capital
K	*N*	*E*	*X*	*B*	*K-D*

Source: Prepared by the authors.

A production process can be represented by a production function which indicates how inputs are combined to create a final good. Equations (1) and (2) illustrate the Leontief production functions for X and B, respectively.

$$X = min\,(\rho K,\ xN,\ eE) \tag{1}$$

$$B = min\,(aK,\ bN,\ cE) \tag{2}$$

8 The symbols used for the different variables and selected parameters are based on a solid body of literature on economic growth led by Foley and Michl (1999). Marquetti and Porsse (2014) also use these same variables in their study on Latin America.

K represents the net capital stock of fixed assets. It was estimated using the perpetual inventory method and is measured in reais at 1995 prices (Marquetti and Porsse, 2014). The data on gross fixed capital formation were obtained from IBGE (2003) for 1970–1985, IBGE (2010) for 1995–2008 and IPEA (2016) for 2009–2012. N stands for the number of workers. The sources of these data are IBGE (2003) for 1990–1995 and IBGE (2010 and 2015) for 1995–2012. The data for the other years in the study period were taken from the national censuses of 1970, 1975, 1980 and 1985 and from the Heston, Summers and Aten database (2006). E stands for the supply of energy. The data for the domestic energy supply for 1970–2012, expressed in tons of oil equivalent (TOE), were obtained from the full historical series published in the *Brazilian Energy Balance* compiled by the Energy Research Office (EPE) of the Ministry of Mines and Energy (MME, 2014). $x=X/N$ represents the productivity of labour, measured in 1995 reais per worker; $\rho=X/K$ stands for the productivity of capital, which is a pure number such as an interest rate, measured as an annual percentage; and $e=X/E$ is the productivity of energy, expressed as the ratio between GDP and the energy supply, measured in 1995 reais per TOE. $a=B/K$ represents CO_2 emissions per unit of capital, measured in tons/reais at 1995 prices; $b=B/N$ stands for CO_2 emissions per unit of labour, measured in tons per worker; and $c=B/E$ represents CO_2 emissions per unit of energy, measured in tons per TOE. Finally, $o=X/B$ is the ratio between GDP and CO_2 emissions, measures in 1995 reais per ton.

Technology is defined as the full array of production techniques available in an economy at a given point in time. A production technique can be described in terms of technical variables and emissions-intensity variables. The former are represented by the parameters (x, ρ, e), linked to GDP production, while the latter are represented by the parameters (a, b, c), which refer to CO_2 emissions. According to Foley and Michl (1999), a production technique has three characteristics with regard to the production process: (i) the amounts of capital and energy needed to supply one unit of labour, i.e. the capital-labour ratio ($k=K/N$) and the energy-labour ratio ($\varepsilon=E/N$); (ii) the quantity of GDP and CO_2 emissions that have been generated by the end of the period in question per worker; and (iii) the capital stock that is depreciated during a given period of production. Table 2 gives the input-output coefficients.

Table 2

Input-output coefficients for the production of GDP and CO_2 emissions

Inputs			Outputs		
Capital	Energy	Labour	GDP	CO_2	Capital
k	e	1	x	b	$(1 - \delta)k$

Source: Prepared by the authors.

Technical change consists of variations in at least one of the parameters (x, ρ, e) and (a, b, c) over time and can be represented by growth rates. For example, the growth rate of labour productivity is calculated as $g_x = \Delta x/x$, where Δ represents the variation in the parameter between two periods. Then, $g_\rho = \Delta\rho/\rho$ is the growth rate of capital productivity; $g_e = \Delta e/e$ is the growth rate of energy productivity; $g_a = \Delta a/a$ is the growth rate of emissions per unit of capital; $g_b = \Delta b/b$ is the growth rate of emissions per unit of labour; $g_c = \Delta c/c$ is the growth rate of emissions per unit of energy; and $g_o = \Delta o/o$ is the rate of increase in the ratio between GDP and CO_2 emissions. Technical change is considered to be neutral when its adoption does not change income distribution (Jones, 1979). For example, Harrod-neutral technical progress raises the growth rate for labour productivity ($g_x > 0$) without altering the growth rate for capital productivity ($g_\rho = 0$). Solow-neutral technical progress raises the growth rate of capital productivity ($g_\rho > 0$) without altering the growth rate of labour productivity ($g_x = 0$). Hicks-neutral technical progress creates savings equally in all inputs, implying equivalent increases in their respective productivity growth rates ($g_x = g_\rho = g_e$).

According to Marquetti (2003), labour-saving and capital-using technical changes predominated during the twentieth century. In other words, the growth rate of labour productivity rose ($g_x > 0$) and the growth rate of capital productivity fell ($g_\rho < 0$). The observed technical changes are consistent with Marx's analysis (1991) of technical progress in a capitalist system of production. The increasing mechanization of an economy reduces the demand for labour and expands the demand for capital per unit of output, so labour productivity rises and capital productivity declines. This pattern of technical progress is what is known as Marx-biased technical progress (Foley and Michl, 1999; Marquetti, 2003; Pichardo, 2007).

III. Growth, technical progress and emission intensity in Brazil: 1970–2012

This section will look at economic growth in Brazil, its pattern of technical progress and indicators of emissions intensity for the period under study. Between 1970 and 2012, the Brazilian economy grew at an annual rate of 4.13%, while the annual rate of increase in carbon dioxide emissions was 3.87%. As shown in figure 1, however, this timespan can actually be divided into three different growth phases in Brazil. Between 1970 and 1980, GDP grew by 8.27% —with that growth being driven by the "economic miracle" and the Second National Development Plan— and carbonic gas emissions climbed by 6.91%. Between 1980 and 2003, Brazil's GDP and carbon dioxide emissions rose at similar rates (2.37% and 2.40% per year, respectively). During what is known as the "lost decade", low growth rates were coupled with high inflation, and the Brazilian economy's pace of growth then remained sluggish with the advent of neoliberalism in the 1990s. Between 2003 and 2012, the move towards a policy that combined some elements of neoliberalism with developmentalism spurred economic growth. During these years, the GDP growth rate and the rate of increase in CO_2 emissions were similar to the averages for the period as a whole.

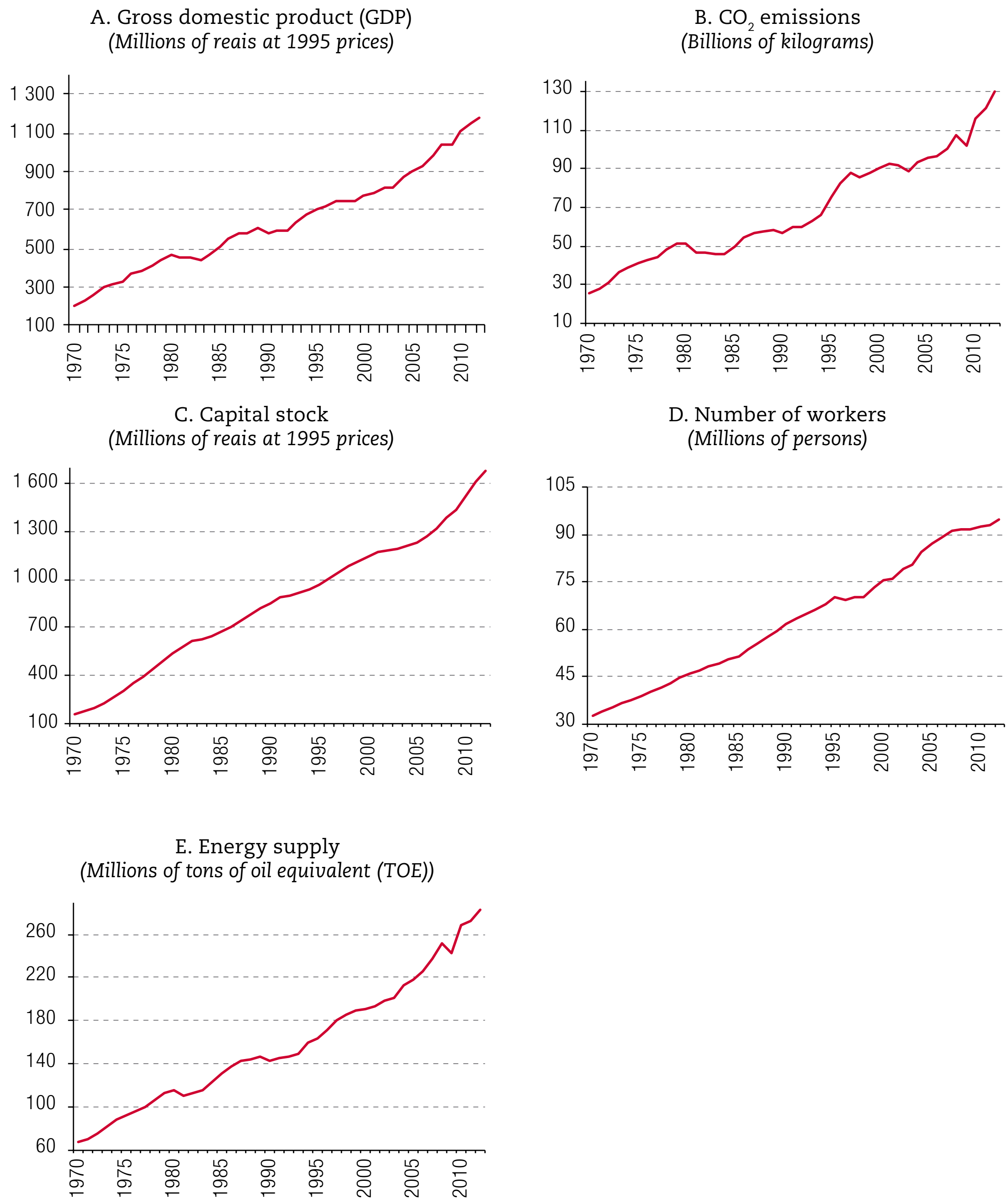
Between 1970 and 2012, the use of capital, labour and energy inputs rose at average rates of 5.66%, 2.53% and 3.43% per year, respectively. As may be seen from figure 1, changes in the rates of increase in the use of inputs are consistent with the three growth phases that marked the Brazilian economy's development during the study period. In fact, the capital stock growth rate fell from 12.39% in the 1970s to 3.45% in 1980–2003.

The rapid accumulation of capital in the 1970s reflected the intensification of the process of import substitution under the Second National Development Plan. A large portion of these investments were financed by international loans and, according to Marquetti and Porsse (2014), waning profits and rising international interest rates were the factors that drove down the capital formation rate in the 1980s. This downward trend was also evident in the years between 1989 and 2003. The late 1980s were the period when the deindustrialization of the Brazilian economy became evident, as industry's shares of GDP and exports began to shrink.[9] A slight uptick was seen in the rate of capital accumulation between 2003 and 2012, when the stock of capital climbed by an average of 3.83% per year.

The total number of employed workers also rose more rapidly in the 1970s, and the downturn in this growth rate in 1980–2003 was not as steep as it was in the case of the other inputs. Employment increased more sharply in services than in the industrial sector, as is illustrated by the data provided in the table on resources and uses published by IBGE. In 1996, the services sector employed 40.6% of the working population. In 2009, its share had swelled to 45.6%. Meanwhile, employment in industry climbed more slowly, edging up from 18.9% in 1996 to 19.6% by 2009 (Jacinto and Ribeiro, 2015). Between 2003 and 2012, the number of workers rose at lower rates than in the previous phases, which points to the possibility that the 2008 crisis may have had a stronger impact on labour than it did on other inputs.

9 On the deindustrialization of the Brazilian economy, see Furtado and Carvalho (2005) and Feijó and Lamonica (2012).

Figure 1
Brazil: production of GDP and CO_2 emissions and use of inputs of labour, capital and energy, 1970–2012



Source: Prepared by the authors.

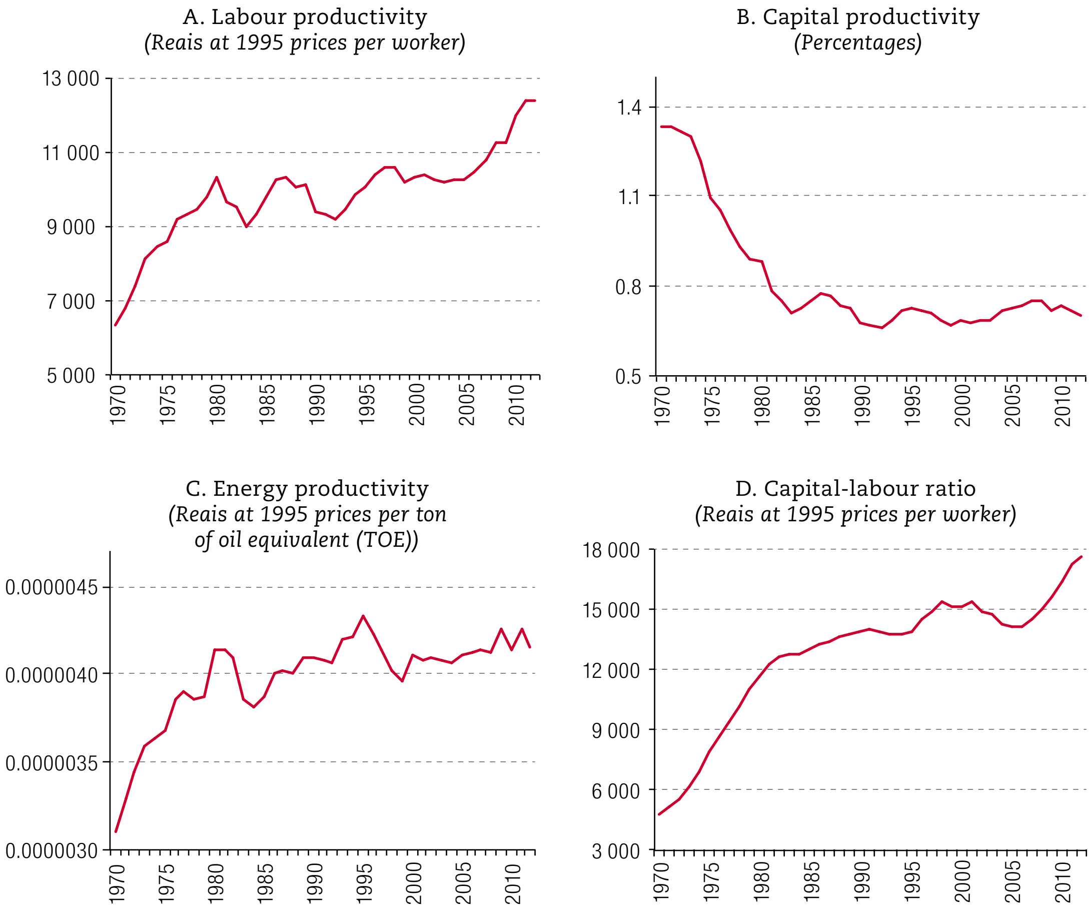
In the 1970s, energy generation soared by an average annual rate of 5.38%, but it then slipped to an average of 2.44% per year between 1980 and 2003 before strengthening again in 2003–2012. These variations point to the existence of a link between the Brazilian economy's growth phases and the expansion of its energy supply.

Brazil's energy profile is a distinctive one. In 1970, 58.4% of the country's domestic energy supply came from renewable resources, and the Brazilian economy has diversified its energy matrix further since then. For example, firewood and coal –highly polluting energy sources– accounted for 48% of the energy mix in 1970 but had dropped to 12% by 2008, while the share of new energy sources, such as sugar cane bagasse and hydraulic energy, expanded. The country's dependence on petroleum has changed very little, however, slipping only slightly from 38% in 1970 to 36.6% in 2008, and, in that latter year, 46.1% of its total energy supply came from non-renewable sources such as petroleum and petroleum products, natural gas, coal and uranium (MME, 2014). By way of comparison, renewable sources accounted for 12.7% of the rest of the world's energy matrix (MME, 2007).

Technical progress can be analysed from the standpoint of GDP production and CO_2 emissions by looking at the trends in technical variables (x, ρ, e, k, ε) and in variables relating to the intensity of CO_2 emissions (a, b, c, o). Clearly, patterns in technical progress were influenced by the growth of the Brazilian economy between 1970 and 2012.

Figure 2 depicts trends in the relevant technical variables and in the rate of profit between 1970 and 2012, along with the ratio between profits and capital stock.[10] During this period, labour productivity gained ground (see figure 2A), capital productivity declined (see figure 2B), the productivity of energy rose somewhat (see figure 2C), the capital-labour ratio increased (see figure 2D), as did the energy-labour ratio (see figure 2E), and the rate of profit fell (see figure 2F). This pattern of technical change can be likened to a Marx-biased pattern.

Figure 2
Brazil: patterns of technical change and the profit rate, 1970–2012

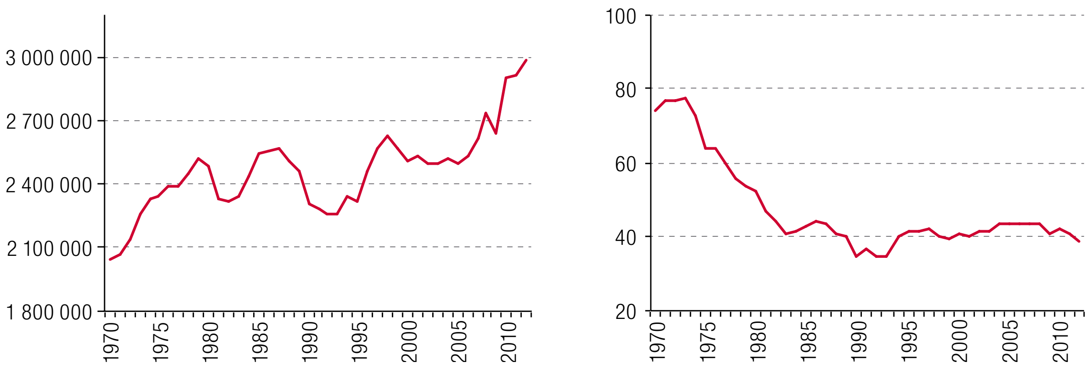


[10] See the analysis of the profit rate in Brazil and the exploration of how it tied in with the above-mentioned technical variables during the period studied by Marquetti and Porsse (2014). The unit of measurement for the rate of profit is percentages per year.

Figure 2 (concluded)

E. Energy-labour ratio
(Tons of oil equivalent (TOE) per worker)

F. Profit rate
(Percentages)



Source: Prepared by the authors.

Trends in the variables of technical change and the pattern of technical progress reflect three different phases which are aligned with the Brazilian economy's growth. During the first phase, between 1970 and 1980, there was a rapid mechanization process and labour productivity climbed by 4.88% per year while capital productivity sagged by 4.1% per year and energy productivity rose by 2.89% per year (see table 3). During this phase, the annual growth rates for the three technical variables mentioned earlier were statistically different from zero at a 5% level of significance, and the pattern of technical progress was Marx-biased.

Table 3
Brazil: annual growth rates of gross domestic product (GDP), carbon dioxide (CO_2) emissions, inputs, technical variables and CO_2 emissions intensity, 1970–2012
(Percentages)

Period	gX	gB	gK	gN	gE	gx	gρ	ge	gk	gε	ga	gb	gc	go
1970-2012	4.13	3.87	5.66	2.53	3.43	1.60	-1.53	0.70	3.13	0.90	-1.79	1.34	0.44	0.26
1970-1980	8.27	6.91	12.39	3.40	5.38	4.88	-4.11	2.89	8.99	1.99	-5.48	3.51	1.53	1.37
1980-2003	2.37	2.40	3.45	2.43	2.44	-0.06	-0.58	-0.07	0.94	0.01	-1.05	-0.03	-0.04	-0.03
1980-1989	2.62	1.49	4.72	2.88	2.75	-0.25	-2.10	-0.12	1.85	-0.13	-3.23	-1.38	-1.25	1.13
1989-2003	2.21	2.98	2.63	2.14	2.24	0.07	-0.42	-0,03	0,48	0.10	0.35	0,83	0.74	-0.77
2003-2012	4.02	4.27	3.83	2.03	3.82	1.99	0.19	0.20	1.80	1.79	0.44	2.24	0.45	-0.25

Source: Prepared by the authors.

During the second phase, which stretched from the early 1980s to 2003, very little technical progress was made in the Brazilian economy, and technical variables and emissions-intensity variables displayed cyclical variations. As shown in table 3, the annual growth rates for technical variables and for CO_2 emissions intensity were very close to zero, and the annual growth rates for labour, capital and energy productivity were not statistically different from zero during that period. This phase can thus be described as one of technical stagnation.

During the third phase, between 2003 and 2012, labour productivity climbed by 1.99% per year, on average, while capital productivity increased by 0.19% and energy productivity by 0.20% per year. Statistical tests show that the annual growth rates for labour productivity were statistically different from zero, while this was not the case for capital or energy productivity. In other words, the Brazilian economy displayed a Harrod-neutral pattern of technical progress during this period (Foley and Michl, 1999).

After 2003, the government stepped up its efforts to spur economic growth. The favourable external conditions created by the upswing in commodity prices gave the government more headroom for implementing developmentalist macroeconomic policies and, despite the negative impacts of the subprime crisis, it managed to promote a rapid recovery through countercyclical policies.

When labour productivity and the pace of economic activity are picking up, an increase in the productivity of energy is essential in order to mitigate the upward pressure on emissions exerted by economic growth (Von Arnim and Rada, 2011). In such cases, the energy supply will pave the way for a higher level of GDP production or for the maintenance of the existing rate of growth while using a lower level of energy inputs.

Labour productivity gains can be broken down ex post into two different components: energy intensity and energy productivity (Von Arnim and Rada, 2011).[11] [12] In Brazil, both of these components increased during the 1970s. During the first phase (1970–1980), energy productivity accounted for 59% of the increase in labour productivity. During the second (1980–2003), the relevant variables exhibited rates close to zero, and the period was thus one of economic stagnation. During the third phase (2003–2012), growth was primarily linked to energy intensity, which accounted for 90% of the upswing in labour productivity. This pattern is similar to the one seen in countries that are having difficulty in curbing CO_2 emissions (Von Arnim and Rada, 2011).

Historically, economic growth in developing countries has been associated with an environmentally harmful increase in energy intensity (Taylor, 2008). In the period of interest here (1970–2012), energy intensity accounted for 57% of the increase in labour productivity, with the remainder being accounted for by the other variable of interest.

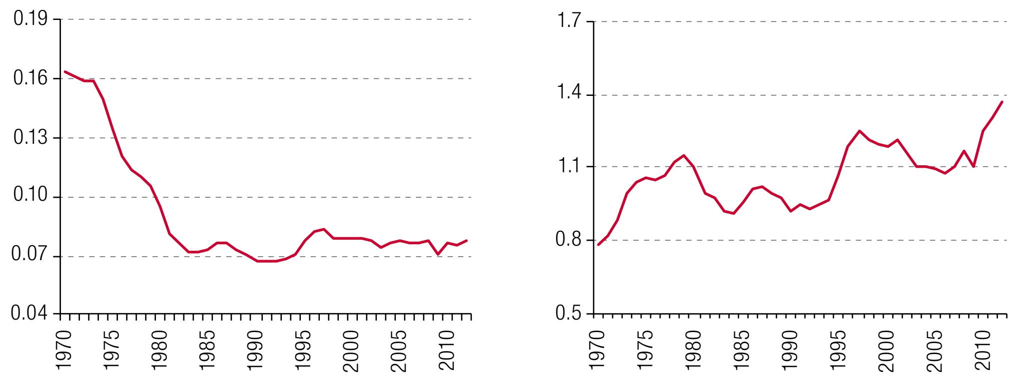
Figure 3 portrays the intensity of CO_2 emissions in 1970–2012. On average, there was a 1.79% reduction per year in emissions per unit of capital (see figure 3A), increases of 1.34% per year in emissions per worker (see figure 3B) and of 0.44% per year in emissions per unit of energy (see figure 3C) and a slight rise of 0.26% per year in the ratio between GDP and CO_2 emissions (see figure 3D). The different phases of growth and technical change are not so clearly delineated as they are in the case of the growth of outputs and technical variables.

Figure 3

Brazil: patterns of changes in carbon dioxide emissions, 1970–2012

A. Emissions per unit of capital
(Tons per real at 1995 prices)

B. CO_2 emissions per worker
(Tons)



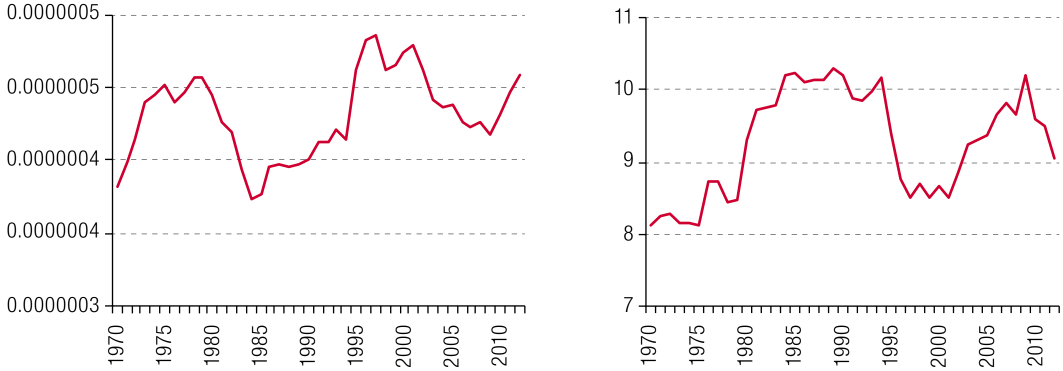
[11] Labour productivity can be represented as: $x = e\,\varepsilon$, o X/N=(X/E)(E/N). Logarithmic differentiation yields $gx=ge+g\varepsilon$. Divisia (1926), Ocampo, Rada and Taylor (2009) and Von Arnim and Rada (2011), among others, have all disaggregated economic growth in this manner.

[12] Another way to disaggregate labour productivity gains is to use the following equation: X/N=(X/K)(K/N)= $(\rho)(k)$. The logarithmic differentiation of this mathematical expression shows that $gx=g\rho+gk$. If we equate this result with the disaggregation noted in footnote 11, then $gx=ge+g\varepsilon= g\rho+gk$. Thus, if E/K is constant, we find that $g\varepsilon=gk$.

Figure 3 (concluded)

C. CO_2 emissions per unit of energy
(Tons of CO_2 per ton of oil equivalent (TOE))

D. GDP-CO_2 ratio
(Reais at 1995 prices per ton)



Source: Prepared by the authors.

On average, emissions per unit of capital declined by 5.48% per year between 1970 and 1980. The moderate fluctuations in this variable seen between the early 1980s and 2012 can be explained by the slowing growth of CO_2 emissions made possible by the moderation of the use of petroleum products in production processes and a lower rate of capital formation. In 2012, the level of emissions per unit of capital was more or less on a par with what it was at the start of the 1980s. Statistical tests show that the growth rate for emissions per unit of capital was negative and different from zero at the 5% level of significance for 1970–1980. The statistical tests also show, however, that the rate of increase in this variable was not significantly different from zero in the phases 1980–2003 and 2003–2012.

CO_2 emissions per worker increased by an average of 3.51% per year between 1970 and 1980 —the highest rate recorded in the entire study period— and behaved cyclically, rising during times of more rapid growth and waning when the pace of growth slowed. Emissions thus declined between 1980 and 1984, whereupon they held steady until 1994 and then climbed until 1997, when they again entered into a downward phase that lasted until 2003. Between 2003 and 2012, CO_2 emissions per worker expanded by an average of 2.24% per year, with the bulk of this increase being concentrated towards the end of that period. Statistical tests show that the rate of increase in CO_2 emissions per worker were different from zero at the 5% level of significance during the first phase (1970–1980), but this was not the case during the following two phases.

As shown in figure 3C, CO_2 emissions per unit of energy increased by an average of 0.44% per year during the reference period. This variable was influenced by the phases of the economic cycle and oil prices, as its level climbed steeply during economic booms and appears to have fallen when fossil fuel prices were on the rise. In 2008, emissions per unit of energy equalled 425 kg per TOE, reflecting an increase in the share of non-renewable sources in the energy matrix. In 1970, the value of that variable had been 381 kg per TOE and, after dipping in 2008 and 2009, the growth rate in that variable steepened again. Statistical tests show that the annual rates of increase in CO_2 emissions per unit of energy were not substantially different from zero at the 5% level of significance during any of the three phases in question.

Finally, the ratio between the GDP and CO_2 emissions (see figure 3D) rose by 0.26% per year between 1970 and 2012. Here again, the variable moved cyclically, although no clear-cut correlation with the economic cycle is apparent.

The sluggish pace of technical progress after 1980 was the result of factors both within the Brazilian economy and outside of it. The main domestic factor was the reduction in capital formation triggered by a weakening profit rate. Two of the chief external factors at work in this regard were rising international interest rates and the level of external debt payments, which eroded the economy's investment capacity and thus rendering it incapable of sustaining high economic growth rates.

Furthermore, the innovations associated with what is known as the fifth technological revolution (the information and telecommunications era) had few economic repercussions in the country in the 1980s and 1990s and did not bring about any significant structural changes. Pérez (2002) contends that the economic impacts of these innovations were not as great as those engendered by earlier technological revolutions.

Table 3 gives the annual growth rates for the two outputs of interest here, as well as for labour, capital and energy inputs, technical variables and CO_2 emissions intensity for 1970-2012 as a whole and for the different growth phases of the Brazilian economy. The highest growth rates were registered between 1970 and 1980, when technical progress displayed a Marx-biased pattern. During the crisis of the import substitution industrialization model in the 1980s and the time of neoliberalism, between the late 1980s and 2003, technical progress stagnated in Brazil.

Growth picked up somewhat after 2003, with increases in GDP, CO_2 emissions and the employment of the inputs referred to earlier, while the relevant technical variables and emissions intensity all exhibited a Harrod-neutral pattern. In the period of 1970–2012 as a whole, technical progress followed a Marx-biased and energy-saving pattern.

IV. Concluding observations

This study has surveyed technical progress and the production of GDP and carbon dioxide emissions in the Brazilian economy over the period from 1970 to 2012. It has used a classical Marxian approach in analysing the behaviour of technical parameters and emissions intensities.

Economies are an open system in which flows of energy and matter are exchanged with the planet. All processes whereby organic material is converted into final goods require the use of energy. With the mechanization of production, fossil fuels have taken on a pivotal role in capitalist systems, which is why energy has been included in the model as an input along with labour and capital. This makes it possible to analyse growth and technical progress from a more realistic perspective. Joint production was assumed as the general case. Moreover, the Brazilian economy has been viewed within the context of the larger issue of pollution and the way in which human activity influences the production process in a society that relies on fossil fuels.

The classical Marxian literature identifies a number of different long-term trends that are characteristic of capitalist systems. Based on the case of Brazil, a number of observations can be made: (i) production of both GDP and CO_2 emissions increased in line with the country's economic growth over the period 1970–2012; (ii) both GDP and CO_2 emissions increased in step with the more intensive use of labour, capital and energy; (iii) labour productivity and the capital-labour ratio rose, capital productivity declined and energy productivity remained fairly stable between the first and last years of the study period, all of which is consistent with the classical Marxian literature; (iv) the predominant pattern of technical progress was Marx-biased and had an energy-saving profile marked by rising growth rates for labour productivity ($g_x > 0$) and energy productivity ($g_e > 0$) and falling growth rates for capital productivity ($g_\rho < 0$); and (v) for the period as a whole, productivity gains were dependent upon increases in energy intensity and in the capital-labour ratio. This pattern is similar to what has been observed in other developing countries. Within the framework of this pattern, however, three different phases of technical progress in Brazil can be identified during the reference period. Between 1970 and 1980, a Marx-biased pattern was observed, followed by the stagnation of technical progress between 1980 and 2003. In the final years of the period under study, from 2003 to 2012, the pattern of technical progress was Harrod-neutral.

GDP is distributed among the population of a country, but carbon dioxide emissions do not stay within a nation's borders. CO_2 emissions diffuse into the atmosphere and have an unequal impact on the planet's inhabitants, which complicates the political and economic coordination of efforts to curb its production (Marquetti and Pichardo, 2013). The continuation of this increasingly mechanized pattern of production based on the intensive use of fossil fuels will accelerate climate change and harm future generations. The ever-increasing accumulation of capital must be coupled with increased energy productivity in order to mitigate this system's adverse effects on the environment.

Bibliography

Arrhenius, S. (1896), "On the influence of carbonic acid in the air upon temperature of the ground", *Philosophical Magazine and Journal of Science*, vol. 41, London.

Baran, P. and P. Sweezy (1966), *Monopoly Capital: An Essay on the American Economic and Social Order*, New York, Monthly Review Press.

Boden, T., G. Marland and B. Andres (2010), *Global, Fossil-fuel CO_2 Emissions*, Oak Ridge, United States, Carbon Dioxide Information Analysis Center [online] http://cdiac.ornl.gov/trends/emis/tre_glob.html.

Burkett, P. (2003), "Capitalism, nature and the class struggle", *Anti-capitalism: A Marxist Introduction*, A. Saad-Filho (ed.), London, Pluto Press.

Callendar, G. S. (1938), "The artificial production of carbon dioxide and its influence on temperature", *Quarterly Journal of the Royal Meteorological Society*, vol. 64, No. 275, Royal Meteorological Society.

Carson, R. (1962), *Silent Spring*, Boston, Houghton Mifflin.

Christiansen, J. (1976), "Marx and the falling rate of profit", *American Economic Review*, vol. 66, No. 2, Nashville, Tennessee, American Economic Association.

Daly, H. (1977), *Steady-state Economics*, San Francisco, Freeman.

Divisia, F. (1926), "L'indice monétaire et la théorie de la monnaie", *Revue d'économie politique*, vol. 40, No. 1, Paris, Editions Dalloz.

Duménil, G. and D. Levy (2003), "Technology and distribution: historical trajectories à la Marx", *Journal of Economic Behavior & Organization*, vol. 52, No. 2, Amsterdam, Elsevier.

___(1995), "A stochastic model of technical change: an application to the US economy (1869-1989)", *Metroeconomica*, vol. 46, No. 3, Wiley.

Feijó, C. A. and M. T. Lamonica (2012), "The importance of the manufacturing sector for Brazilian economic development", *CEPAL Review*, No. 107 (LC/G.2536-P), Santiago, Economic Commission for Latin America and the Caribbean (ECLAC).

Foley, D. (2009), "The economic fundamentals of global warming", *Twenty-first Century Macroeconomics: Responding to the Climate Challenge*, J. Harris and N. Goodwin (eds.), Cheltenham, Edward Elgar.

___(1998), "Simulating long-run technical change", unpublished.

Foley, D. and T. R. Michl (1999), *Growth and Distribution*, Cambridge, Harvard University Press.

Foster, J. B., B. Clark and R. York (2010), *The Ecological Rift: Capitalism's War on the Earth*, New York, Monthly Review Press.

Furtado, A. and R. Carvalho (2005), "Padrões de intensidade tecnológica da indústria Brazileira: um estudo comparativo com os países centrais", *São Paulo em Perspectiva*, vol. 19, No. 1, São Paulo, SEADE Foundation.

Garegnani, P. and F. Petri (1989), "Marxismo e teoria econômica hoje", *História do Marxismo*, E. Hobsbawm (org.), vol. 12, Rio de Janeiro, Paz e Terra.

Georgescu-Roegen, N. (1971), *The Entropy Law and the Economic Process*, Cambridge, Massachusetts, Harvard University Press.

Harvey, D. (2006), *The Limits to Capital*, New York, Verso.

Heston, A., R. Summers and B. Aten (2006), "Penn world table version 6.2", Center for International Comparisons of Production, Income and Prices, University of Pennsylvania [online] http://pwt.econ.upenn.edu8.

IBGE (Brazilian Geographical and Statistical Institute) (2015), *Sistema de Contas Nacionais. Brazil 2010-2013*, Rio de Janeiro, CD-Rom.

___(2010), *Sistema de Contas Nacionais. Brazil 2004-2008*, Rio de Janeiro, CD-Rom.

___(2003), *Estatísticas do século XX*, Rio de Janeiro, CD-Rom.

___(1990), *Estatísticas históricas do Brazil: séries econômicas, demográficas e sociais de 1550 a 1988*, Rio de Janeiro.

IPCC (Intergovernmental Panel on Climate Change) (2007), *Climate Change 2007: The Physical Science Basis*, Cambridge, Cambridge University Press.

IPEA (Institute of Applied Economic Research) (2016), "Ipeadata" [online] http://www.ipeadata.gov.br.

Jacinto, P. A. and E. P. Ribeiro (2015), "Crescimento da produtividade no setor de serviços e da indústria no Brazil: dinâmica e heterogeneidade", *Economia Aplicada*, vol. 19, No. 3, São Paulo, University of São Paulo.

Jones, H. (1979), *Modernas teorias do crescimento econômico: uma introdução*, São Paulo, Atlas.

Kümmel, R. (1989), "Energy as a factor of production and entropy as a pollution indicator in macroeconomic modelling", *Ecological Economics*, vol. 1, No. 2, Amsterdam, Elsevier.

Leontieff, W. (1970), "Environmental repercussions and the economic structure: an input-output approach", *The Review of Economics and Statistics*, vol. 52, No. 3, Cambridge, Massachusetts, The MIT Press.

Li, M. (2014), *Peak Oil, Climate Change, and the Limits to China's Economic Growth*, New York, Routledge.

Marquetti, A. A. (2003), "A economia Brazileira no capitalismo neoliberal: progresso técnico, distribuição de renda e mudança institucional", *Anais do VIII Encontro Nacional de Economia Política*, Florianopolis.

Marquetti, A. A. and G. Pichardo (2013), "Patterns of growth and technical change in the production of good and bad outputs", *Investigación Económica*, vol. 72, No. 284, Mexico City, National Autonomous University of Mexico (UNAM).

Marquetti, A. A. and M. Porsse (2014), "Patterns of technical progress in the Brazilian economy, 1952-2008", *CEPAL Review*, No. 113 (LC/G.2614-P), Santiago, Economic Comission for Latin America and the Caribbean (ECLAC).

Marx, K. (1991), *Capital*, London, Penguin Books.

Maslin, M. (2004), *Global Warming: A Very Short Introduction*, Oxford, Oxford University Press.

MME (Ministry of Mines and Energy) (2014), *Balanço energético nacional, 2014*, Brazilia.

___(2007), *Balanço energético nacional, 2007*, Brazilia.

Morishima, M. (1973), *Marx's Economics: A Dual Theory of Value and Growth*, New York, Cambridge University Press.

Ocampo, J. A., C. Rada and L. Taylor (2009), *Growth and Policy in Developing Countries: A Structuralist Approach*, New York, Columbia University Press.

Okishio, N. (1961), "Technical changes and the rate of profit", *Kobe University Economic Review*, No. 7, Kobe University.

Pérez, C. (2002), *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*, Northampton, Edward Elgar.

Pichardo, G. M. (2007), "Economic growth models and growth tendencies in major Latin American countries and in the United States, 1963-2003", *Investigación Económica*, vol. 66, No. 262, Mexico City, National Autonomous University of Mexico (UNAM).

Roemer, J. (1977), "Technical change and the tendency of the rate of profit to fall", *Journal of Economic Theory*, vol. 16, No. 2, Amsterdam, Elsevier.

Stern, N. (2006), *Stern Review Report on the Economics of Climate Change*, London, HM Treasury.

Taylor, L. (2008), "Energy productivity, labor productivity, and global warming", *Twenty-first Century Macroeconomics: Responding to the Climate Challenge*, J. Harris and N. Goodwin (eds.), Northampton, Massachusetts, Edward Elgar.

Vicente, M. (2014), "Influencia de la actividad económica en el ciclo natural del CO_2 and su impacto en la temperatura terrestre", *Tendencia and ciclo en economía: teoría and evidencia empírica*, G. M. Pichardo (org.), Mexico City, Faculty of Economics, National Automous University of Mexico (UNAM).

Von Arnim, R. and C. Rada (2011), "Labour productivity and energy use in a three-sector model: an application to Egypt", *Development and Change*, vol. 42, No. 6, Wiley.