Patterns of technical change and de-industrialization

Luis Villanueva, Xiao Jiang*

Abstract:

Using a classical political economy approach we find aggregate regularities in the patterns of technical change followed by high income and developing countries (mostly from Latin America and Sub Saharan Africa) respectively. Such regularities allow us to propose an alternative definition of de-industrialization and study the issue of "premature de-industrialization" from a political economy perspective. In the (capital productivity, labor productivity) plane, a characteristic trajectory of high-income countries typically fluctuates in the quadrant where labor productivity growth rates are positive while capital productivity growth rates are negative (the industrialization quadrant). De-industrializing countries, on the other hand, have transitioned from the quadrant with positive labor productivity growth rates and negative capital productivity growth rates to the opposite quadrant (with negative labor productivity and positive capital productivity growth) and remained in this quadrant during the 1980s and 1990s. Both groups of countries, high income and de-industrializing seem to follow a cyclical pattern, revealing that the rate of industrialization is constantly fluctuating with varying labor and capital productivity growth rates.

* Denison University, Granville, Ohio, USA, email: villanueval@denison.edu; jiangx@denison.edu

From the perspective of classical political economy, capitalist economies are complex and dynamical in nature; countries are constantly going through various patterns of technical change resulting in different growth and distributional outcomes. For Marx, for example, the competition among capitalists to reap the highest profits creates a powerful incentive for the adoption of production techniques that use more capital and less labor, a technical change that is labor-saving and capital-using. Foley and Michl (1999) call this pattern "Marx-biased technical change" (MBTC). Before Marx, Smith and Ricardo had also emphasized the role of technical change as a central factor in a country's economic growth and the long-run evolution of productivity. Smith's insights focused on how the division of labor leads to increasing returns and eventually higher economic growth. Ricardo incorporates social classes (rentiers,

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workers, and capitalists) in his economic analysis and, in his chapter "On Machinery", studies the impact of machinery on the well-being of the different classes of society.

Unfortunately, the dynamical nature of capitalist economies is not captured by the conventional characterizations of the world based on income-levels, which merely indicate a country's material position at a point of time, but is silent about all other aspects of this economy. Using a classical political economy approach of studying patterns of technical change, we motivate an alternative way of characterizing the world based on patterns of technical change rather than income levels (although the latter can be related to the former). Such effort is made possible with the Extended Penn World Tables (EPWT) – an international database that contains data on labor and capital productivity (two important pieces of information to measure technical change) for over 120 countries over 5 decades (from 1963 to 2008). By looking at the evolution of each country's labor and capital productivity growth rates over time, we are able to characterize countries based on their four possible patterns of technical change, namely, Marx-biased, Hicks neutral, Anti-Marx-biased, and Anti-Hicks neutral.

This way of studying patterns of technical change gives rise to an alternative meaning for the terms 'industrialization' and 'de-industrialization'. De-industrialization is conventionally defined as the decline in the industrial sector's employment and output as a share of total employment and output respectively (see e.g., Saeger, 1997; Tregenna, 2014; Rodrick, 2016). This paper proposes a different definition: de-industrialization is defined here as the change in the production technique that involves a decrease in labor productivity and an increase in capital productivity. In other words, a technical change that is labor using and capital saving (the opposite of the so-called Marx biased technical change). In this paper, we call this pattern of technical change "Anti MBTC".

The key difference between these definitions is that the conventional definition focuses on the outcome of production, while our alternative definition is based on the process of production. We believe that our definition of de-industrialization captures the complex and dynamical nature of capitalist economies better to some extent. For example, Anti MBTC patterns are theoretically associated with more inequality and less economic growth (see Foley and Michl, 1999).[2]

There exists extensive literature on the phenomenon of industrialization because it is often viewed as a natural process in capitalist economic development, and the economic growth driven by it is often called labor-augmenting growth. However, the phenomenon of de-industrialization is under-studied because it is often viewed as an unlikely case in advanced capitalist economies. Kaldor (1966) pioneered the study of de-industrialization in the British context and later Saeger (1997) focused on OECD countries. It is until relatively recent that studies such as Dasgupta and Singh (2006), Chang (2008), Rodrik (2011) and Tregenna (2014) have suggested and warned of the possibility of developing countries taking this path in the contemporary world. Rodrik (2016) calls this phenomenon "premature deindustrialization". Our paper's contribution to the literature on premature deindustrialization is twofold: 1) it provides an alternative definition of deindustrialization grounded in the classical political economy tradition; and 2) it proposes a framework to explain why and how does

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[2] This framework provides a theoretical relationship between patterns of technical change and functional income distribution (wages and profits). There is no distinction between rents/rentiers and human capital, it is assumed that rents will be assimilated to profits, and it uses variables such as output, capital stock and labor at an aggregate level. A sectorial analysis would require a series of input-output tables from 1963 to 2008 for developed and developing countries, not available at this point.

deindustrialization happen, bringing to the analysis the capital-labor struggle where variables such as unemployment and the bargaining power of workers play a key role in determining the pattern of technical change resulting in deindustrialization.

1. Technical change and its measurement

Authors working in the classical political economy tradition have used the growth distribution schedule (GDS) to find patterns of technical change in a given economy over time. The GDS put forth by Foley and Michl (1999) can identify different techniques of production (a particular method of combining labor and capital to produce output), which can be described in terms of labor productivity, capital productivity and the rate of depreciation. Other authors who have used this framework are Foley and Marquetti (1997; 1999), Marquetti (2002), Marquetti and Soares (2014) and Ferretti (2008).

The theoretical derivation and empirical implementation of the GDS requires the following variables for a given year (available in the Extended Penn World Tables, EPWT); real GDP (X), number of workers employed (N), capital stock net of depreciation (net stock of non-residential fixed assets, K), aggregate consumption (includes all incomes other than gross investment, C), gross investment (I), depreciation (D), total worker compensation (W), gross profit ($Z = X - W$), net profit ($R = Z - D$) and net output ($Y = X - D$).

For convenience, we express absolute measures in per worker terms. Hence, $x = \frac{X}{N}$ is real GDP per worker (or labor productivity), $k = \frac{K}{N}$ is capital per worker (or capital intensity), $w = \frac{W}{N}$ is the average real wage, $c = \frac{C}{N}$ is social consumption per worker, and $i = \frac{I}{N}$ is investment per worker. It is also useful to express other variables in terms of capital stock: $\rho = \frac{X}{K}$ is output per unit of capital (or capital productivity), $v = \frac{Z}{K}$ is the gross rate of profit, $d = D/K$ is the depreciation rate, $r = v - d$ is the net rate of profit, and $g_k + d = I/K$ is the rate of capital accumulation (the ratio between gross investment and the capital stock). The growth rate of labor productivity and capital productivity are respectively $g_x = \frac{x_{t+1} - x_t}{x_t}$ and $g_\rho = \frac{\rho_{t+1} - \rho_t}{\rho_t}$. The profit share of national income is $\pi = z/x$, and the wage share is $1 - \pi = w/x$.

Figure 1 — *The GDS including the expenditure and income sides of the national accounts*
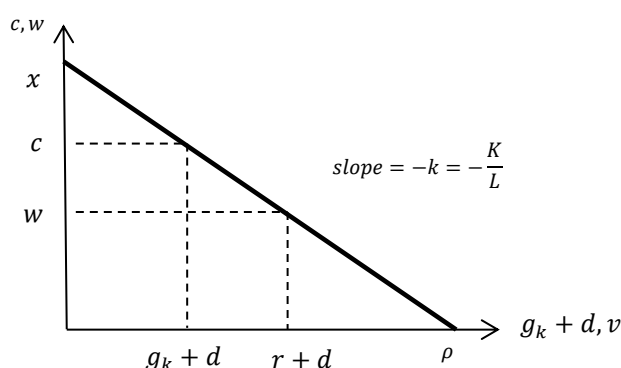
Notes: x is labor productivity, ρ is capital productivity, $g_k + d$ is the growth rate of capital stock plus depreciation, c is the social consumption per worker, $v = r + d$ is the gross rate of profit (net rate of profit plus depreciation), w is the average real wage.
Source: Foley and Michl (1999).

The GDS illustrates a particular method of combining labor and capital to produce output, and output can be interpreted from its different national account components. Hence, from the expenditure side of national accounts, the point $(g_k + \delta, c)$ on the GDS tells us how the total output per worker produced is spent between gross investment in future output and social consumption, $x = c + i = c + g_k k + dk = c + (g_k + d)k$. When all the output per worker is invested ($c = 0$), the rate of capital accumulation reaches its highest value and equals capital productivity (if $c = 0, x = c + (g_k + d)k \Rightarrow \frac{x}{k} = \frac{X}{K} = g_k + d$). When all the output per worker is consumed ($i = 0$), social consumption per worker equals labor productivity.

Table 1 – *Common patterns of technical change in the literature*

$\rho = \dfrac{X}{K}$	$x = \dfrac{X}{N}$	Characterization
Constant	↑	Harrod neutral or pure labor saving technical change. It increases labor productivity while capital productivity remains constant. Shown by a clockwise rotation of the GDS around its horizontal axis. *See figure 2, shift from technique B to C.*
Constant	↓	Labor using technical change. It decreases labor productivity while capital productivity remains constant. Shown by a counterclockwise rotation of the GDS around its horizontal axis.
↑	Constant	Solow neutral or pure capital saving technical change. It increases capital productivity while labor productivity remains constant. Counterclockwise rotation of the GDS around its vertical axis. *See figure 2, shift from technique A to B.*
↓	Constant	Capital using technical change. It decreases capital productivity while labor productivity remains constant. Shown by a clockwise rotation of the GDS around its vertical axis.
↑	↑	Hicks-neutral technical change. Both labor and capital productivity increase at the same pace. Shown by a parallel (outward) shift of the GDS. *See figure 2, shift from technique A to C.*
↓	↑	Marx-biased technical change (MBTC). It increases labor productivity and decreases capital productivity. GDS pivots around the switching point, located in the positive orthant. *See figure 2, shift from technique B to D.*

*Notes*: in figure 2, A, B and C are the solid lines. D is the dotted line.
Source: based on Foley and Michl (1999).

The income side of national accounts, $(r + d, w)$, tells us how the value of total output per worker is distributed between wages and profits ($x = w + z = w + rk + dk = w + (r + d)k$). When all the output per worker is distributed towards profits ($w = 0$), the maximum rate of profit is reached and is equal to capital productivity (if $w = 0, x = w + (r + d)k \Rightarrow \frac{x}{k} = \frac{X}{K} = r + d$). When all the output per worker is distributed toward wages, the maximum average real wage per worker is reached, and it equals labor productivity. Figure 1 shows a theoretical growth distribution schedule including the expenditure and income side of national accounts.

Different types of technical change can be represented by the GDS.[3] Table 1 summarizes the common patterns in the literature.

Figure 2 illustrates the example of Harrod neutral, Hicks neutral, Solow neutral and Marx biased technical change (described in table 1 for each case). Harrod's observation that, if the wage rate increases by the same proportion as labor productivity then the profit rate will remain unchanged with labor saving technical change, gives name to this pattern. Hicks neutral technical change comes from Hicks' observation that, under constant returns to scale in both factors of production, proportional changes in both factors of production does not change the labor-capital ratio. Solow neutral technical change implies that, if capital productivity increases by the same proportion as the profit rate, then the wage rate will remain unchanged. Marx biased technical change (MBTC) captures Marx's observation that the competition among capitalists as well as the struggle between capitalists and workers over the value added create a powerful incentive to use more machines and fewer workers. Hence, in advanced capitalist economies, mechanization that raises labor productivity and decreases capital productivity is an important feature (labor saving and capital using pattern). If functional income distribution is constant, MBTC implies that the rate of profit falls.

Figure 2 — *Shifts in the GDS*
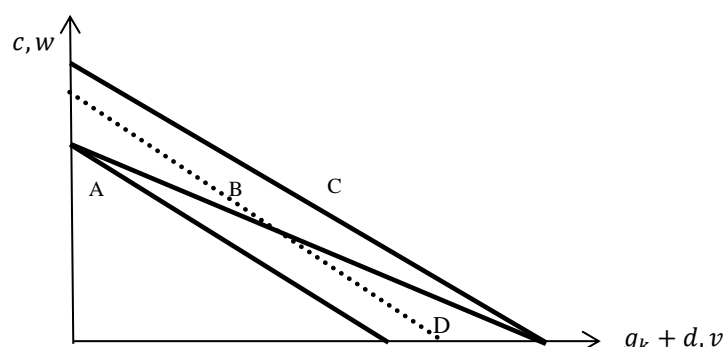
Notes: c is the social consumption per worker, w is the average real wage. $g_k + d$ is the growth rate of capital stock plus depreciation and $v = r + d$ is the gross rate of profit (net rate of profit plus depreciation).
Source: based on Foley and Michl (1999).

2. Patterns of technical change in the world economy

From table 1 we know that the growth rate of capital productivity and labor productivity, g_ρ and g_x, can be used to identify the patterns of technical change. While GDS is a powerful tool

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[3] The GDS traces its origins to Sraffa (1960) and his wage-profit rate relation. The GDS as a straight line (with capital productivity in the x-axis and labor productivity in the y-axis) is an approximation to the wage–profit relation. The one-sector production model of this framework assumes that the price of capital goods in terms of consumption goods is fixed at unity; therefore, changes in relative prices do not matter, which avoids capital controversy issues. On the empirical side, however, there are further issues to be considered that are beyond the scope of this paper. Empirical evidence that the wage–profit relation in real economies can be approximated by linear functions is provided by Ochoa (1989) and Schefold (2008). A detailed study on the origins of the wage-profit curve and its relationship with the Cambridge capital controversy can be found in Cohen and Harcourt (2003).

to study individual country's patterns of technical change, at global level GDS becomes visually untractable. Thus, we construct a four-quadrant plot to capture various countries' patterns of technical change (to be explained later). Moreover, we use data on labor and capital productivity corrected for the business cycle[4] to identify patterns of technical change that are insulated from cyclical demand shocks.

To capture the pattern of changes of labor and capital productivity over time, we calculate the change of capital productivity (g_ρ) and labor productivity (g_x) using 5-year continuous time intervals. Since the adoption of technical change at country level takes time, we consider 5 years as an appropriate time length that captures such change from a short-run perspective. Furthermore, by collecting all the observations using a continuous time window, we are able observe the long-run pattern of technical change for a (set of) countries. The observations are plotted in a four-quadrant Cartesian coordinate, where the g_ρ is on the horizontal axis and g_x is on the vertical axes. Observations that fall in the (–, +) quadrant in figure 3 are the countries that have gone through the MBTC during a period of time. Countries identified with MBTC are viewed as industrializing countries as they have substituted labor with capital during the given period.

The opposite of the MBTC pattern occurs in the (+, –) quadrant, where countries experienced increasing capital productivity (g_ρ) and decreasing labor productivity (g_x) over time. We define this quadrant the de-industrialization quadrant because increasing g_ρ and decreasing g_x are associated with the substitution of capital with labor (labor deepening) – an important sign for de-industrialization. The remaining quadrants of the Cartesian plane correspond to the rest of the patterns of technical change described in table 1.

Figure 3 — *Patterns of Technical Change 1963-2008, World Economy*

Source: based on data from EPWT.

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[4] In the Extended Penn World Tables, business cycles are corrected using the HP filter, thus the filtered data on capital and labor productivity should represent more accurately outcomes of technical change.

Figure 3 pools all the countries and years on the same plot. It is clear that from 1960 to 2008 many data points have fallen into the (–, +) quadrant, namely, MBTC industrialization. This result, to a large extent, is consistent with Marx's description. However, there also exists a group of countries that went against the trend and fell into the de-industrialization (+, –) quadrant. This group is of particular interest for us for several reasons. First, it is against the global trend of MBTC. Second, workers in countries that fall into the de-industrialization quadrant tend to be in a vulnerable position because the decline in g_x and the increase in g_ρ might imply a reduction of workers' wage bargaining power and re-distribution from workers to capitalists. Third, the increase of capital productivity associated with a country's de-industrialization might be the result of capital flight, which can be either the cause or effect of political instability. Last but not the least, de-industrialization might also be the sign of policy failures in the global economy when countries decide to engage in international trade by specializing in low value added labor-intensive goods. In other words, it might be associated with phenomena such as the middle-income trap and the poverty trap.

Figure 4 shows the evolution of the pattern of technical change at the world level over the past five decades. The first plot clearly illustrates that during the 1960s and 1970s, most countries were clustered in the (–, +) quadrant. Hence, de-industrialization seems to be a phenomenon that started in 1980s, and the trend continued in the 1990s. However, in the 2000s the de-industrialization trend seems to have decreased.

To get a better understanding of those de-industrializing countries, we organize the countries that fall in the (+, –) quadrant in accordance with the World Bank (WB) classification: 1) high income OECD, 2) high income non-OECD, 3) upper middle income, 4) lower middle income, and 5) low income. The addition of categories 3, 4 and 5 is commonly known as developing countries, and the sum of categories 1 and 2 is known as developed countries. Figure 5 shows that de-industrialization mostly takes place in categories 3-5 (developing countries) and with much less frequency in developed countries.[5] We can conclude that de-industrialization is mostly a developing country phenomenon that emerged in the 1980s.
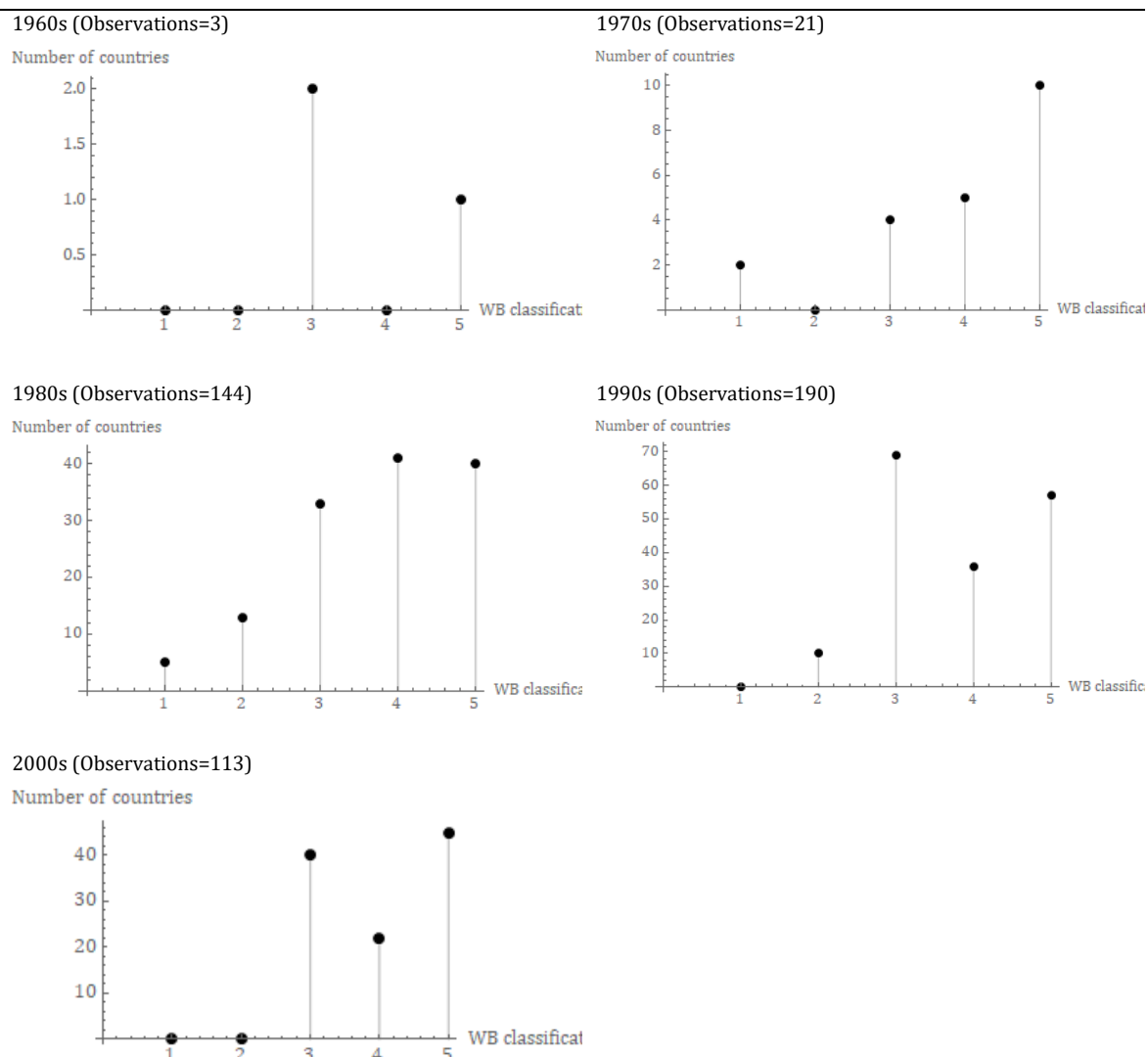
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[5] We must acknowledge that classifying countries according to their level of development is a controversial task and is not the purpose of our paper. We chose the WB classification for practical and analytical purposes. It does not mean that we consider this classification the only one or that we advocate this approach to categorize countries. The shortcomings of using income to measure the level of development are well known, for example Sen (1999) argues for a holistic view of development, where opportunity and freedom of choice play a key role. A closer look at the literature on classifying countries according to their levels of development reveals that several international organizations (e.g. WB, IMF, UN, OECD, WTO), have their own criteria to categorize countries for their own analytical or practical mandates. Each criterion has a threshold that changes through time leading to comparability problems. For a detailed overview of the diverse development taxonomies currently in use and proposed alternative taxonomies, see e.g. Nielsen (2013), Tezanos Vázquez and Sumner (2013), Alonso et al. (2014), and Fialho and Bergeijk (2017).

Figure 4 — *Patterns of Technical Change per decade, the world economy*
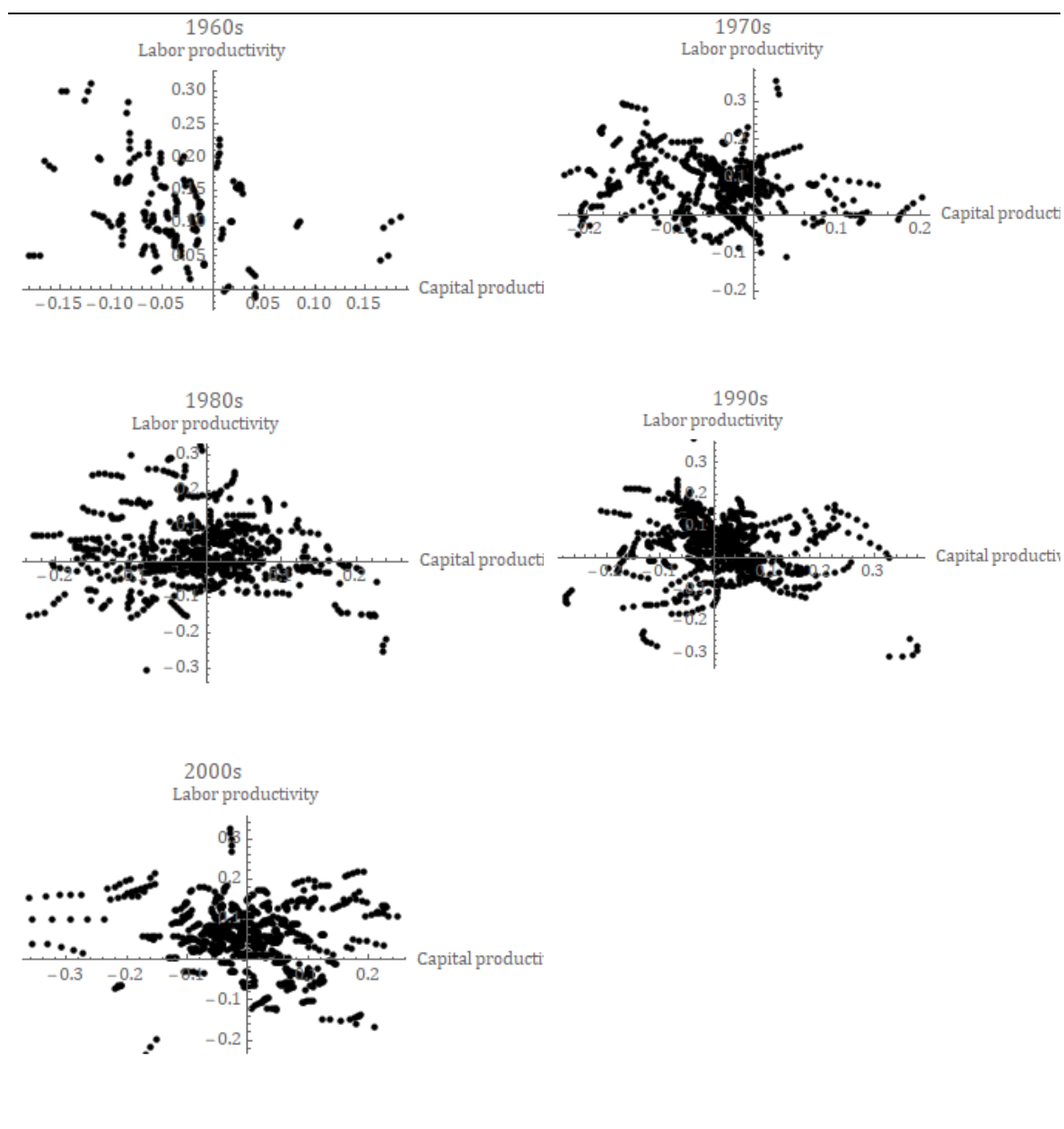
Source: based on data from EPWT.

Figure 5 — *Types of countries that fall in the (+,-) quadrant according to the WB classification*

1960s (Observations=3)

1970s (Observations=21)

1980s (Observations=144)

1990s (Observations=190)

2000s (Observations=113)

Source: based on data from EPWT.

A more detailed study of the developing countries that fall in the de-industrialization quadrant requires extracting a list of countries in each decade. Since some countries could have reached the de-industrializing quadrant by accident (due to a natural disaster or political turbulence, for example), we only focus on the countries that fall into the de-industrialization quadrant with more frequency. The logic behind this selection is that the countries that hit the (−, +) quadrant on a regular basis are likely to be countries whose economies de-industrialized due to some long-term structural changes rather than short-term shocks. Table 2 shows that the countries that have de-industrialized with more frequency[6] come from two regions of the world that suffer from underdevelopment and extreme income inequality: Sub-Saharan Africa

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[6] The threshold is set to six times. See footnote 7 for a detail explanation of this choice.

and Latin America.[7] Could these two common phenomena, de-industrialization and inequality, be related? We leave the answer to this question for the discussion section. For now the main results of this section are: 1) de-industrialization seems to be a phenomenon that hit the world economy in the 1980s; 2) de-industrialization has been taking place mostly in developing countries; and 3) the two regions of the world that have de-industrialized with more frequency are Sub Saharan Africa and Latin America.

Table 2 — *Countries that fall in the* (+ , —) *quadrant with more frequency*

Decade and frequency	Countries and region of the world	Total
1980's (At least 6 times)	Bolivia, Peru and Venezuela -> Latin America (3) Ghana, Madagascar, Mauritania, Namibia, Sierra Leone, South Africa, Zambia, Zimbabwe -> Africa (8)	11
1990's (At least 6 times)	Brazil, Barbados, Cuba, Ecuador, Venezuela -> Latin America & Caribbean (5) Algeria, Cameroon, Comoros, Cote d'Ivoire, Gabon, Kenya, Liberia, Malawi, Mauritania, Niger, Sierra Leone, South Africa, Togo -> Africa (13) Jordan, Mongolia, Solomon Islands -> Other (3)	21
2000's (At least 5 times)	Algeria, Burundi, Cameroon, Central African Republic, Comoros, Djibouti, Gabon, Liberia, Lybia, Malawi, Somalia, Swaziland, Togo -> Africa (13) Haiti, Paraguay -> Latin America & Caribean (2) Iraq, Jordan, Lebanon -> Middle East (3) Solomon Islands -> Other (1)	19

Source: based on data from EPWT.

3. Trajectories of individual countries

Once we have identified the de-industrializing countries, we can study the trajectories that these countries' labor and capital productivities have followed over time: in other words, we are now interested in investigating the historical path these countries have taken on to de-industrialization. We select the countries from Africa and Latin America that have fallen in the de-industrialization quadrant with greater frequency (the threshold is set to six times), and trace each country's path in the (g_ρ, g_x) plane.[8]

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[7] Such rise in inequality and reduction in economic growth has been documented (see e.g., Gasparini et al., 2011, and Cornia, 2012), especially in the 1980s and 1990s in Latin American countries and Sub Saharan African countries.
[8] We admit that this threshold is arbitrary: however, since every data point represents the change of labor productivity over a five-year period, this means that the countries that have hit the Anti MBTC quadrant at least six times consecutively have been de-industrializing for at least a decade. Hence, setting the threshold to six is practical and helps visualizing trends per decade. For example, a quick look at the case of Bolivia (in figure 6) reveals that the 1980s is a decade of de-industrialization since all six points fall in the Anti MBTC quadrant, and the reader can see that the 1970s is a decade of transition from the MBTC to the Anti MBTC quadrant. Countries do have to hit the Anti MBTC consecutively to be considered a de-industrializing country. The logic behind this criterion is that the countries that hit the Anti MBTC quadrant on a regular basis are likely to be countries whose economies de-industrialize due to long-term structural changes rather than short term shocks (such as natural disasters or political turbulence).

Figures 6 and 7 show the trajectories followed by the selected countries in the (g_ρ, g_x) plane over time. A couple of observations are important to make: first, almost all the trajectories follow a counter clock-wise dynamics, except for Peru; second, the trajectories followed by countries are diverse, in some cases countries pass through the (+, +) or the (–, –) quadrants before reaching the de-industrialization region. Bolivia and Ecuador are examples of the first case, whereas Venezuela, Brazil, Algeria, Cameroon and Gabon are examples of the second. Other countries seem to have jumped directly from industrialization to de-industrialization (for example, Comoros, South Africa, Sierra Leone and Mauritania). We believe that these diverse trajectories reflect the diversity of policies, institutions, social relations and economic structure that countries have gone through time. A country-by-country analysis would be required to reveal the underlying changes behind individual trajectories.

Our main focus is on aggregate regularities that de-industrializing countries might share. For example, the counter clockwise dynamics of individual trajectories suggests that the 1970s seems to be the period when most countries started to move towards the de-industrialization region. The 1980s and the 1990s is when most countries remained in the de-industrialization quadrant. By the 2000s, some countries were able to escape from this quadrant (for example, Bolivia, Peru, Cuba, Mauritania, and South Africa), others have remained (see Togo, Algeria, Cameroon, and Comoros), and some others are in the process of escaping (e.g., Venezuela, Brazil, Ecuador, and Gabon).

To contrast our findings, we compare figures 6 and 7 with the trajectories of a sample of high income OECD countries. Figure 8 shows the trajectories of eight OECD countries (data for Germany start in the 1980s). A couple of observations are in place: first, the trajectories of these countries tend to constantly remain in the (–, +) quadrant, the USA, Taiwan, South Korea and Canada have remained in this quadrant for the entire period of analysis (five decades), the UK and Australia temporarily left this quadrant, and Japan and Germany have migrated to the (+, +) quadrant. This implies that these countries in general have been experiencing increasing labor productivity and decreasing capital productivity throughout the history from the 1960s, and the cyclical patterns are driven by the changes of the rate of growth of the g_ρ and g_x. Second, the trajectories followed by these countries are diverse too, and include counter-clockwise dynamics (e.g., USA, Germany, Japan, UK, and Australia) as well as clockwise dynamics (e.g., South Korea, and Taiwan).

Figure 6 — *Trajectories of selected de-industrialized countries from Latin America*
(*1960s-2000s*)
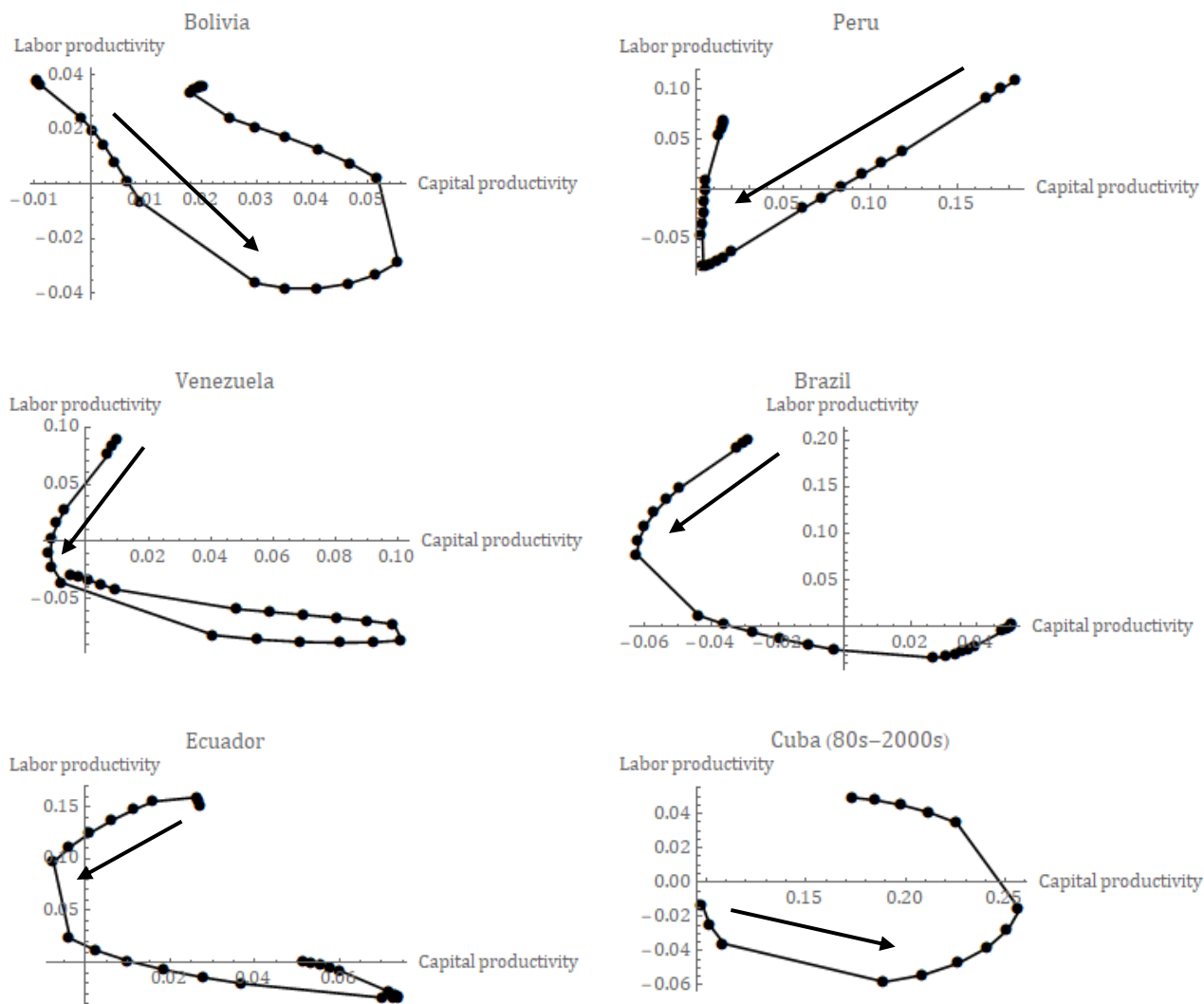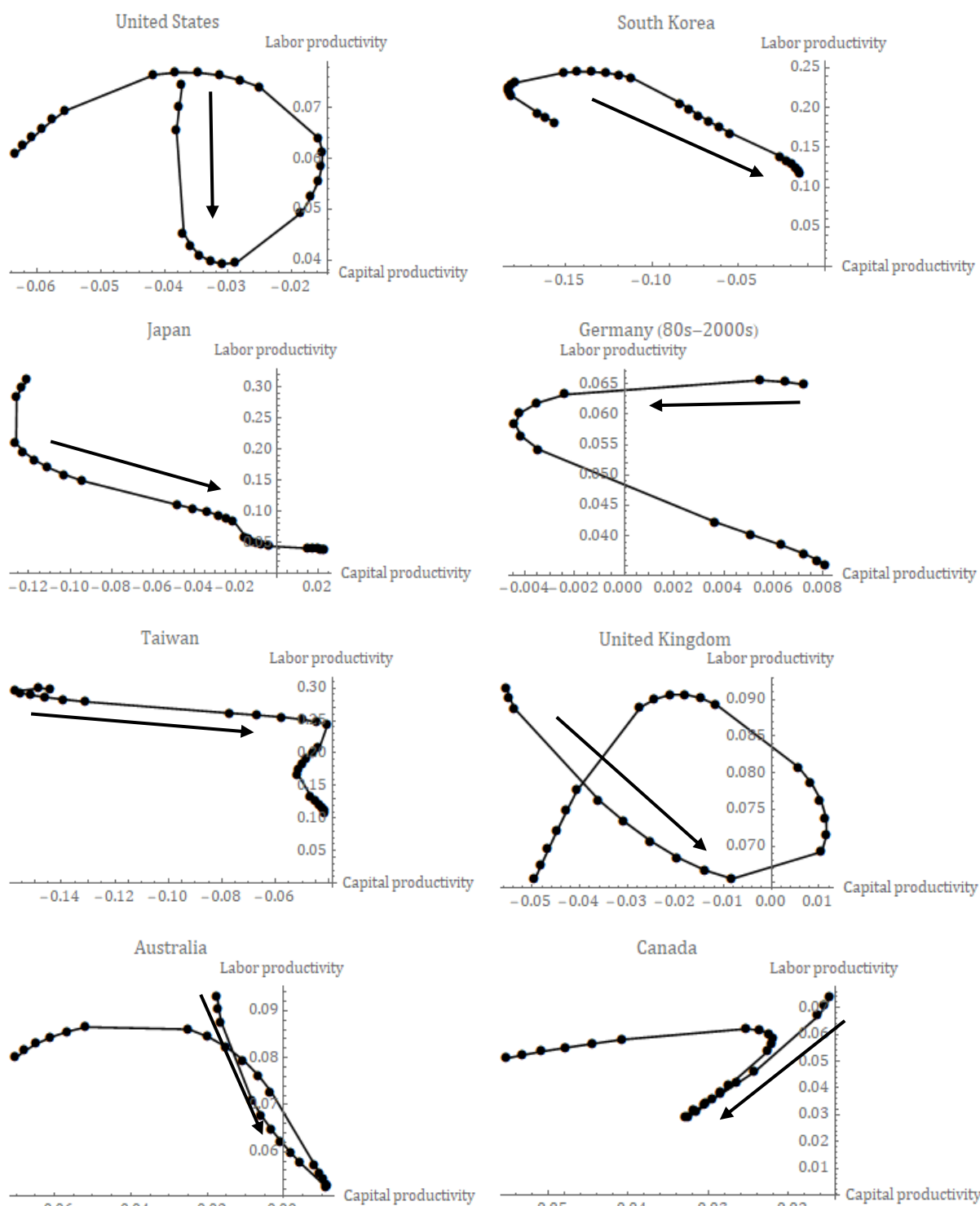

Source: based on data from EPWT.

Figure 7 — *Trajectories of selected de-industrialized countries from Africa* (*1960s-2000s*)
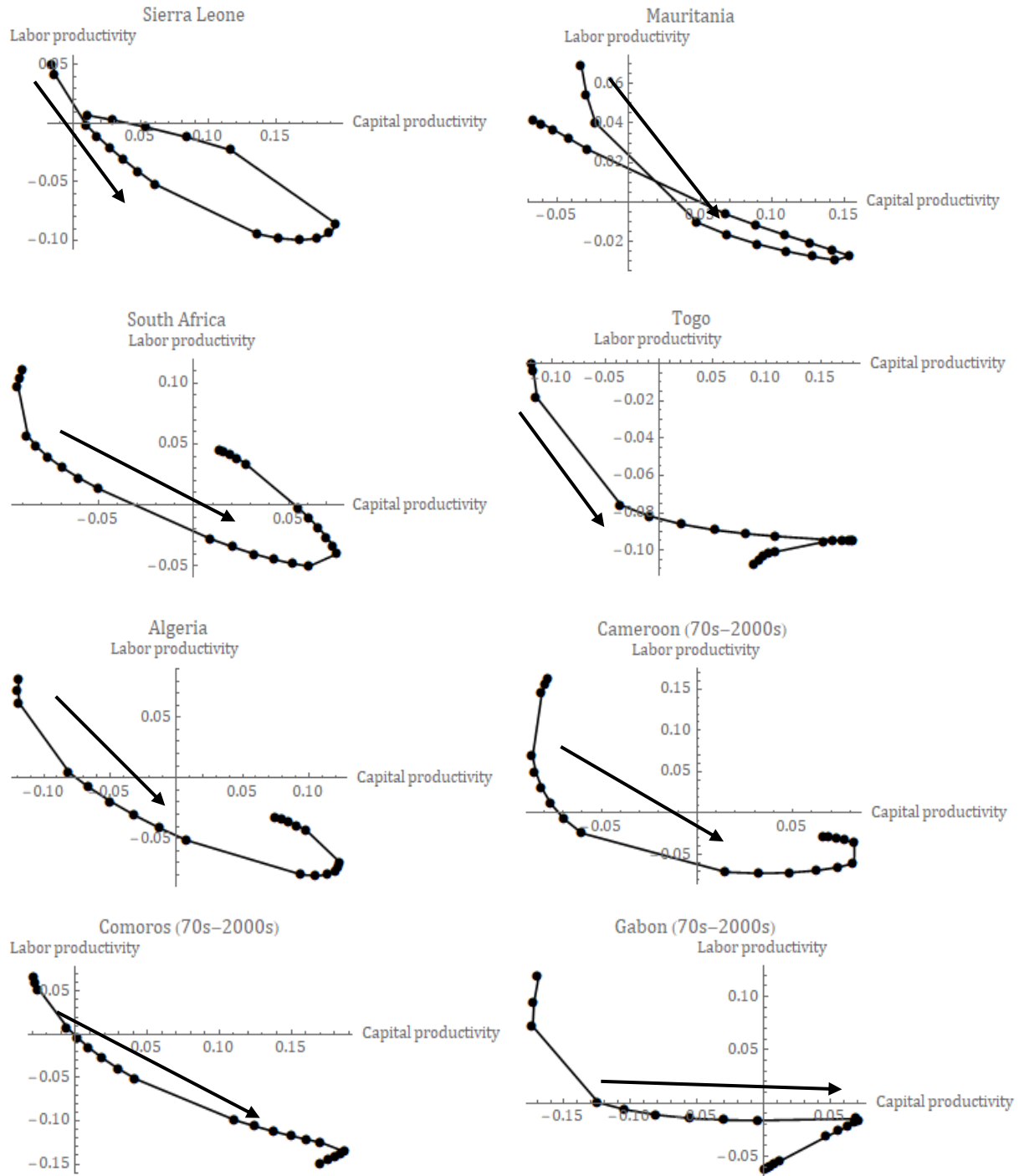
Source: based on data from EPWT.

Figure 8 — *Trajectories of a sample of OECD countries (1960s-2000s)*

Our comparison between figures 6, 7 and 8 reveals that a characteristic feature of de-industrializing countries is that, during the 1970s, they transitioned to the (+, –) quadrant and most of them remained in this quadrant during the 1980s and 1990s. In contrast, high-income countries have remained most of the time on the (–, +) quadrant.

4. The extended Goodwin model

The stylized facts show that each country's pattern of technical change tends to exhibit a counter-clock cyclical path in the plane of g_ρ and g_x. In this section, we attempt to construct a simple growth model that can explain such pattern. The model is rooted in Goodwin is 1967 model but incorporates endogenous technical change; hence, we call it an extended Goodwin model.

Let us begin with the conventional production function $y = f[k, l]$ for an abstract economy. The technology is assumed to be Leontief with fixed proportions of labor and capital inputs. Let y_t be output, k_t capital input, l_t labor input (or employment), σ_t capital-output ratio (k_t/y_t), which is also the inverse of capital productivity (y_t/k_t), and a_t labor productivity (y_t/l_t). The subscript t indicates time. At any point in time, output is determined by:

$$y_t = \frac{k_t}{\sigma_t} = a_t l_t \tag{1}$$

Equation (1) states that output is determined by the amount of capital inputs multiplied by output-capital ratio ($1/\sigma$), which also equals the amount of labor input multiplied by the output-labor ratio (or labor productivity) at time t (a_t). From equation (1), we obtain the equation for labor demand, that is:

$$l_t = \frac{k_t}{\sigma_t a_t} \tag{2}$$

Equation (2) states: labor demand equals total output (that is k_t/σ_t from equation (1)) divided by labor productivity.

We further assume that capital owners save and reinvest all of their profit from the previous period; hence, k_t grows at a rate equal to the rate of profit of the previous period. Let π_t be profit earned at t, hence the profit rate r_t must equal π_t/k_t, which can be decomposed into (π_t/y_t) · (y_t/k_t). The first term is the share of total output that goes to profits, the profit share. Since output is distributed between wages and profits only in this model, the profit share is also one minus the wage share, u_t. The second term is the output-capital ratio, which is equal to $1/\sigma$. Hence, the process of capital accumulation can be described by equation (3) below:

$$k_t = (1 + r_t)k_{t-1} = \left(1 + \frac{1 - u_{t-1}}{\sigma_t}\right)k_{t-1} \tag{3}$$

According to equation (3), capital accumulation depends on the wage share u of the previous period. Let w_t be the real wage at time t, the wage share at time t becomes $w_t l_t/y_t$. Since l_t/y_t is also the inverse of labor productivity $1/a_t$, the wage share is simply determined by:

$$u_t = \frac{w_t}{a_t} \tag{4}$$

This model does not assume full employment, so there is always a fraction of total population that is unemployed in the economy. The ratio between employed workers and total

population is called the employment ratio, v_t. This ratio determines the growth rate of wages in our model. When the employment ratio is high, a large portion of the population is hired, workers have higher bargaining power, and so the wage rate will increase. Vice versa when the employment ratio is small. Assuming the relationship between wages and the employment ratio was linear, with γ being the intercept and ρ the slope, equation (5) below is the law of motion that governs the changes in wages:

$$w_t = [1 + (-\gamma + \rho v_t)]w_{t-1} \tag{5}$$

Let L_t be the population of the economy at period t, the employment ratio v therefore is:

$$v_t = \frac{l_t}{L_t} \tag{6}$$

In this model, total population L grows exogenously at a steady rate α, that is:

$$L_t = L_0 e^{\alpha t} \tag{7}$$

At this stage, all we have left to determine are the growth rate of labor productivity a_t and the output-capita ratio σ_t at time t. In the conventional Goodwin's model, a_t grows at an exogenous rate and σ_t is held constant over time. However, in our extended model these variables are endogenously determined within the system. For labor productivity, we have:

$$g_{x,t} = \frac{-\lambda(a_t-1)+\kappa[u_t-(1-\sigma_t\beta)]}{a_t} \tag{8}$$

In equation (8) above, $1 - \sigma_t\beta$ is the (unstable) equilibrium level of the wage share in the conventional Goodwin model, and $u_t - (1 - \sigma_t\beta)$ therefore expresses how much the actual wage share is above or below the equilibrium level. Essentially, the story behind this equation is the following: as an economy moves above its equilibrium wage share level, firms tend to adopt labor-saving technical change, henceforth the acceleration of the growth rate of labor productivity. The opposite is true when the wage share is below the equilibrium level: firms are likely to adopt capital-saving technical change, which results in the slowing down or even decline of the growth rate of labor productivity.

Finally, the capital-output ratio σ_t in this model depends on the rate of technical change, which is the growth rate of labor productivity as determined in equation (8):

$$\sigma_t = (1 + \mu g_{x,t})\sigma_{t-1} \tag{9}$$

Noticing that in equation (9) $d\sigma_t/dg_{x,t} > 0$, we can deduct that the acceleration of labor productivity is associated with the increase in the use of capital inputs, that is to accelerate the growth of labor productivity, each worker needs to work with more capital. Henceforth, the positive relationship between the growth rate of labor productivity $g_{x,t}$ and capita-output ratio σ_t. The growth rate of capital productivity $g_{\rho,t}$ at any point in time necessarily becomes:

$$g_{\rho,t} = \frac{\sigma_{t-1}}{\sigma_t} - 1 \tag{10}$$

These 10 equations fully specify the model. The model is simulated for 20 rounds using *Mathematica* with the parameters and initial values provided in table 3.
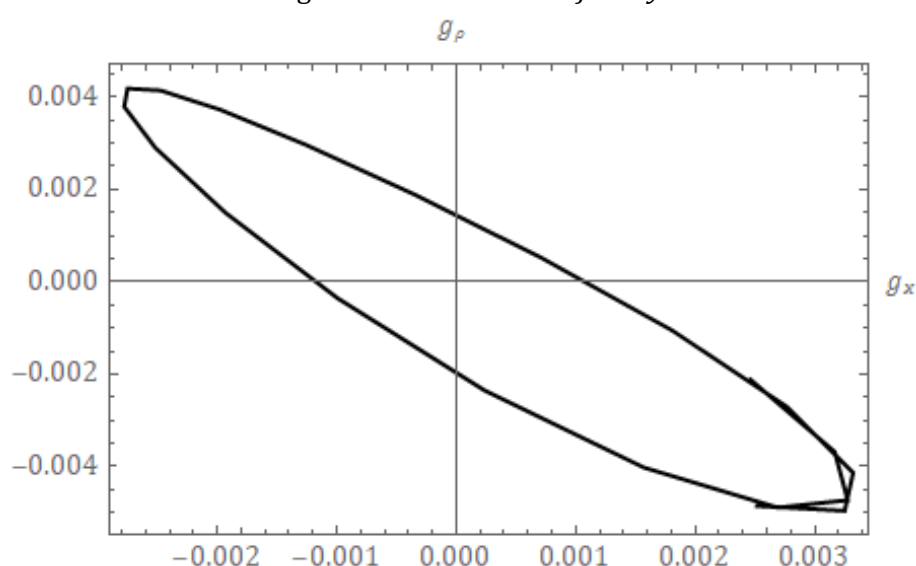
The simulation results for the growth rate of labor and capital productivity g_x and g_ρ are plotted on the vertical and horizontal axes, respectively in figure 9.

Table 3 – *Model simulation parameters*

Parameters	β	ν	ρ	λ	κ
	0.05	1.9	2.27	0.1	0.015
Initial values	σ	k	u	a	u
	10	0.5	0.835	1	0.5

Figure 9 — *Simulated trajectory*

Source: elaboration using *Mathematica*.

Figure 9 mimics the dynamics of changes in labor and capital productivity as observed in the previous section. For the purpose of illustration, the parameters of the model are chosen so that it forms a limit-cycle. The dynamics can be easily turned into a spiral sink or spiral source with different parameter values.

To understand the cycle, let us start at the point on the cycle where the growth rate of labor productivity is just recovering from decline to growth (near the left side of the cycle). The initial acceleration of labor productivity growth induces more capital to be put in production via equation (9), hence the decline in the growth rate of capital productivity. However, the growth rate of capital productivity will not fall forever. As labor productivity accelerates, it will initially help wage share via equation (4) thus capital accumulation slows down, based on equation (3), and therefore the recovery of the growth rate of capital productivity. The acceleration of labor productivity hits its limit when high labor productivity exerts downward pressure on employment and the employment ratio via equations (1) and (6), which consequently pushes down real wages and the wage share via equations (4) and (5). As the wage share goes far below the equilibrium level defined according to equation (8), capital

saving technical change will be encouraged, henceforth the decline of the growth rate of labor productivity. As the growth rate of labor productivity slows down, the growth rate of capital productivity hits its limit as the falling wage share due to labor productivity growth deceleration results in a higher profit rate, via equation (3), henceforth the slowdown of the growth rate of the output-capital ratio (capital productivity). Thus, in the spirit of Goodwin (1967), our model sees the pattern of technical change as the result of the interaction between the capital-labor struggle and the choice of production technique.

5. Discussion and conclusions

Using data from the EPWT (covering the period 1963-2008), we identified patterns of technical change to study the trajectories that various countries have taken over time. The identification of such patterns of technical change allows us to propose an alternative definition of de-industrialization based on political economy perspective. Our paper has highlighted that: 1) de-industrialization seems to be a phenomenon that emerged in the world economy in the 1980s and continued in the 2000s, 2) de-industrialization has been taking place mostly in lower income and developing countries,[9] and 3) in the developing world, two regions have seen their countries de-industrialize with more frequency: Sub Saharan Africa and Latin America.

These three results coincide with the findings of Shafaeddin (2005), Dasgupta and Singh (2006) and Rodrik (2016), who have documented, using the traditional definition of de-industrialization, how developing countries (with the exception of Asian countries), have experienced de-industrialization since the 1980s. However, our study also reveals some aggregate regularities shared by de-industrializing countries. For example, for de-industrializing countries, the 1970s seems to be the period when they started to move towards the de-industrialization region, and the 1980s and the 1990s is when they remained in the de-industrialization quadrant (mostly following a counter clockwise trajectory). In contrast, high income countries have remained most of the time on the (–, +) quadrant with varying trajectories (see figures 6, 7, and 8). These aggregate regularities led us to propose a framework to understand the forces behind the de-industrialization.

What could be the factors behind the de-industrialization that mainly affected Sub Saharan Africa and Latin America? Recent studies (e.g., Lora et al., 2002; McMillan and Rodrik, 2011; McMillan et al., 2014; Rodrik, 2016) point us to the global phenomenon of structural reforms and globalization. Figure 10 shows the intensity of the main structural reforms enforced by Latin American countries. From 1970 to 1985, the main structural reform is privatization, and from 1985 to 2000 the dominant structural reform is trade and financial liberalization. For Sub Saharan Africa, privatizations started in the mid-1980s, intensified in the 1990s, and continued in the 2000s. Trade expansion is the dominant structural reform from the mid-1980s to the 2000s (see Berthélemy et al., 2004, and Shafaeddin, 2005).

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[9] This characterization according to the World Bank's classification of countries using GNI/per capita.

Figure 10 – *Index of structural reforms, 17 Latin American countries*
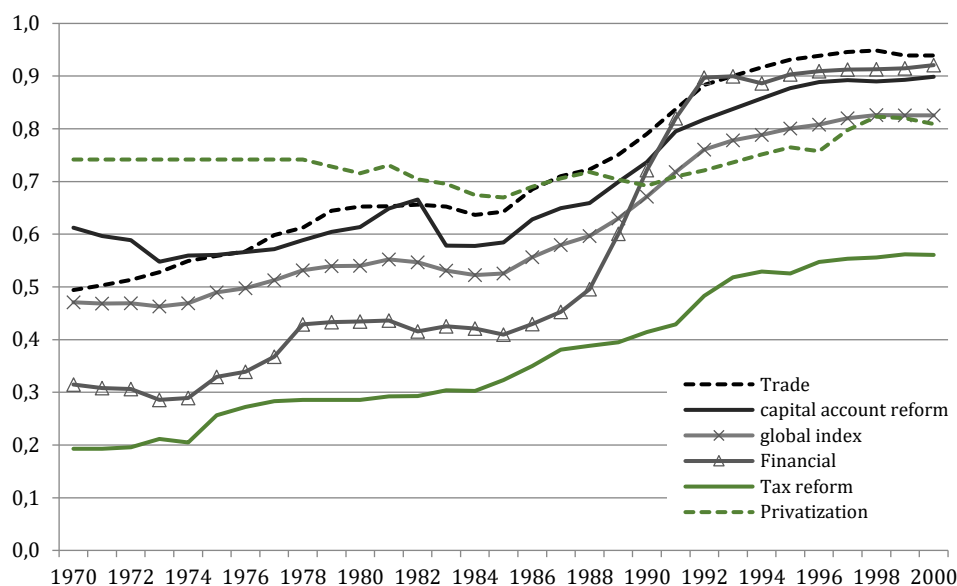
Source: based on data from ECLAC.

We believe privatization and trade expansion are compatible with our framework. The literature on the economic history of Latin American (e.g., Cárdenas et al., 2000; Portes and Hoffman, 2003; Ocampo and Bertola, 2012) suggests that the beginning of the neoliberal era (1970s) was characterized by the destruction of formal jobs (created mostly by the state during the state-led industrialization period) and the inability of the industrial sector to absorb the surplus population from rural and urban areas, hence enlarging the informal sector.[10] The 1970s marked the end of the import substitution industrialization (ISI) period of development in Latin America and Africa. According to Ocampo and Bertola (2012), the privatizations that took place in this time did not entail any new accumulation of capital stock. Since the state stopped investing in capital accumulation, it was mostly a redistribution of assets previously owned by the state towards private hands.[11]

The above well-documented and studied trends in the literature (high unemployment and low capital stock accumulation) are in fact two essential components in our framework, where a trajectory towards de-industrialization happens through a constant decline in labor productivity and a constant increase in capital productivity. Increased unemployment and informality, according to our model, lead to a decrease in the wage share (since the bargaining power of workers is weak when there is high unemployment) which in turn encourages the adoption of capital saving technical change and thus leads to a decline in the growth rate of labor productivity. On the other hand, slower capital stock accumulation leads to the

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[10] McMillan and Rodrik (2011) have also shown that during the structural reform period (early 1970 to 1990s) in Sub Saharan Africa and Latin America, labor moved away from the manufacturing sector towards lower-productivity activities (services and informality).

[11] Shaffaedin (2005) shows that for Latin America and Sub Saharan Africa, I/GDP ratios are lower as compared with the pre-structural reform period, mostly due to a deteriorating investment environment for domestic investors (public investment was cut and private investors shifted to less risky investment).

acceleration of capital productivity (X/K). Hence, the privatization and trade expansion story fits in compatibly with our framework.

Another strand of the literature (see Corden, 1984; Sachs and Warner, 1999; Berry, 2008; Lartey, 2011) highlights the risks associated with the reliance on comparative advantage in primary products, which makes countries vulnerable to the Dutch disease problem and to experience de-industrialization as they open up to trade.[12] The basic idea is that the scarce and immature manufacturing industry created in primary goods-producing countries (such as Latin America and Sub Saharan Africa) during the import substitution industrialization period is not able to compete with mature manufacturing sectors of advanced economies, hence making countries to return to the production of primary goods (re-primarization of the economy), specialize in low value-added export activities and become importers of manufacturing, reversing a long process of import-substitution.[13] To the extent that Dutch disease implies high unemployment, employment informality, and low accumulation of capital stock, this theory also fits in our framework. However, more work is needed to specify other potential mechanisms that connects the Dutch disease explanation with our framework.

To close our discussion, we summarize some insights that our paper might be able to provide. The cyclical pattern we observed in the (g_ρ, g_x) plane for many countries might be a manifestation of the capital-labor struggle. For example, although most developed countries stayed within the (–, +) industrialization quadrant, the cyclical pattern implies that the growth rate of labor and capital productivity is by no means stable. In other words, even for these countries, the rate of industrialization fluctuates constantly, with varying labor and capital productivity growth rates. For de-industrialized countries, the cyclical pattern indicates that in the 1970s workers started experiencing a loss in their bargaining power while less accumulation of capital stock took place, hence the simultaneous decline of labor productivity and increase of capital productivity growth rates. The force of falling labor productivity growth rate is so strong that these countries end up having negative labor productivity growth with increasing capital productivity, henceforth the phenomenon of de-industrialization. After labor productivity falls, capital productivity growth slows down and labor productivity starts to recover. Based on our extended Goodwin model, the cycles are explained by the complex interaction between capital-labor struggle and choice of production technique.[14] Where do labor and capital productivity growth rates go after? It is possible that the force of labor productivity growth recovery is so strong that the country cycles back to the industrialization (–, +) quadrant, like Mauritania, and it is also likely to happen for South Africa and Algeria (see figure 7). However, it is also possible that some countries will have an unstable equilibrium

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[12] Under the influence of the Dutch disease, the discovery of a profitable natural resource (e.g., gas, oil, mineral) induces a sharp inflow of currency towards the country with the newly discovered natural resource, diverting the economic resources needed for the development of other crucial sectors of the economy (e.g. manufacturing) and appreciating the currency. The appreciation of the currency makes the manufacturing products less competitive in the export market re-enforcing the dependency on primary goods (Berry, 2008).

[13] Rodrik (2016, p. 4) suggests that developing countries could also "import" deindustrialization from the advanced countries. As developing countries become exposed to the relative price trends originating from advanced economies, "the decline in the relative price of manufacturing in the advanced countries puts a squeeze on manufacturing everywhere, including the countries that may not have experienced much technological progress. This account is consistent with the strong reduction in both employment and output shares in developing countries (especially those that do not specialize in manufactures). It also helps account for the fact that Asian countries, with a comparative advantage in manufactures, have been spared the same trends."

[14] For example: 1) profit-maximizing firms starting to substitute capital with labor due to high r/w ratio; 2) the result of distributional change due to the deepening of labor-capital conflict, for example, during the commodity boom period employment and the bargaining power of workers might have recovered.

within the de-industrialization quadrant (+, –), so that the rate of labor productivity decline will speed up again before it becomes positive (returning back to the de-industrialization quadrant). A typical example would be Sierra Leone (see figure 7). A comparison between Sierra Leone and the USA might reveal the powerful insight that industrializing and de-industrializing countries might have two different equilibrium in the (g_ρ, g_x) plane. The equilibrium within the (–, +) de-industrialization quadrant might very well be an important sign of a "middle-income trap" or "poverty trap". However, why would a country's trajectory have its (likely unstable) equilibrium at a particular location in the (g_ρ, g_x) plane in the first place, can only be explained by the country's own history, policies and the socioeconomic structure.

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