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A North-South Model of Economic Growth, Technological Gap, Structural Change and Real Exchange Rate

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ABSTRACT

The aim of this work is to present a model of economic growth, technological gap, structural change and real exchange rate in a formal and theoretical manner, explicitly incorporating the effects of North–South technology gap and the real exchange rate (RER) at a level compatible with its "industrial equilibrium" taking in account the external constraint. In the short term, an increase in the South growth rate of the demand implies that its natural growth rate must also rise, i.e., the level of industry participation and economic productivity should also increase. In the long run the effect of RER on economic growth is conditional on the size of the technological gap and the level of industry participation in South gross domestic product. This condition generates two different dynamics such as a saddle path and multiple equilibriums. To a large extent these results are achieved from the model complex dynamics.

1. Introduction

Structural change and technological development in open economies are linked directly to the pattern of productive specialization. The productive structures of the countries are formed from their different competitive capabilities both domestically and in foreign markets.

According to the ECLAC's structuralism and structuralist macroeconomics contributions, different patterns of specialization among countries are central to the explanation of economic backwardness. More developed productive structures can produce and exports more sophisticated goods, and help to catch up by reducing the technological gap and the development of new technological capabilities in their national innovation systems.

A growing literature has been showing that a competitive level of the real exchange rate (RER) can help the economies to offset their technological and productive asymmetries by means of redefining their patterns of specialization. In general, there is a support in the empirical literature that stable and depreciated RERs favors exports diversification toward higher technological goods. Still, an overvalued real exchange rate discourage firms to invest in more sophisticated tradable goods, reducing the intensity of learning and negatively affecting the income elasticity of exports[1]. Indeed, according to Gala (2006, 2008) and Cimoli

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[1] Following Bhaduri and Marglin (1990), Gala (2006, 2008) shows that depreciated real exchange rates contributes to increase investment and capital accumulation through the rise of capacity utilization and exports. If the response of investment and exports are sufficiently elastic, the

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et al. (2013) cases of success in catching up process and convergence in the years after the World War II had depreciated levels of the real exchange rates as well as industrial and technological governmental active policies.

The aim of this paper is to present a formal model of economic growth, technological gap, structural change and real exchange rate that encompasses the effects of the North–South technology gap and the level of real exchange rate (RER) at a level compatible with its "industrial equilibrium" on economic growth in external constraint conditions[2].

The model intends to integrate technological gap and the real exchange rate level in a Kaldor–Verdoorn cumulative causation framework, showing their effects on the productive structure of developing countries (South) and developed countries (North). In this sense, integrates Evolutionary and Post-Keynesian approaches, as well as analyses how government policies can influence the path of the catching up process.

The basic theoretical hypothesis is that the effect of the level of the real exchange rate over the long-term growth depends on the extent of the technological gap and the level of share of industry in GDP for each country.

The economic growth of the South and the potential for catching up are related to its history of economic development (path dependency) and the degree of sophistication of its national innovation system (IS). Countries with greater capacity for learning and spillovers absorption have a higher possibility of carrying out the process of catching up. Otherwise, they may remain in a low-growth trap ("falling behind"). In this model new channels to economic growth and the potential for catching up are formally explored from the share of industry in gross domestic product and the use of real exchange rate (among others factors).

In a first long-term set up, the technological gap between the North and South is constant and the model presents a saddle path so that the stability thereof is conditional to the initial parameters. In another long-term set up it is considered the dynamic change of the technological gap over time. In this case the system displays multiple equilibriums: one stable and other unstable.

To a large extent, these results are achieved from the model complex dynamics. Due to its endogenous features, the model does not converge "automatically" to a certain point. Much of the development of complex dynamic economy has been presented by post-Keynesian models (Rosser, 2006)[3].

To fulfill the proposed objective this paper is divided into seven other sections, besides this introduction. Section 2 presents the structuralist macroeconomics arguments about the productive asymmetry and economic growth. Section 3 displays the basic structure of the model which relates economic growth with external constraint and the potential output growth rate. Section 4 shows the part of the model related to structural change and the real exchange rate. Section 5 presents the relationship of the real exchange rate, mark up, wage and price levels. Section 6 makes the analysis of the long-term stability of the model considering a constant technological gap. Section 7 shows the technological gap dynamics and the Verdoorn learning growth rate in the long run. In this case, the technological gap will be changing over time. Finally, in Section 8, the final remarks are presented.

2. Structuralist macroeconomics and productive asymmetries

According to Dutt and Ros (2003, p.6), since the beginning of the 1980s there has been a resurgence of the research on economic development by at least four branches/developments.

In the first branch/development it was observed a blooming new neoclassical approach applying the tools of industrial organization, game theory and economics of information to agrarian issues, causes of poverty and income inequality. This tradition enlarges the applications of microeconomic theory on those issues[4]. In the second development the emphasis was put on major macroeconomic features of neoclassical growth theory and the renewed interest by the new growth theories[5]. The third development presents a less formalized literature that reexamines the experience of developing countries, especially for the East Asian NICs (Newly Industrialized Countries). This approach is interdisciplinary, incorporating ideas and theories of sociology, political science and economics[6].

A fourth development, object of this section, shares the post Keynesian and the Kaleckian theory of economic growth. It analyses the determinants of growth, income distribution, inflation and fiscal complications as well as balance of payments issues, especially in developing countries (Dutt and Ros, 2003).

The structuralist macroeconomics presents a variety of macroeconomic models, in which the simplest version of these models consists of "two sectors", as long as

economy will go into a pattern of investment-led growth. Regarding the process of technological change, if the real exchange rate is excessively appreciated this will affect the profitability of investments in the industrial sector, where increasing returns to scale are present. The reallocation of resources to non-industrial sectors, such as activities involving the production of commodities and services, where we observe decreasing returns to scale, the real appreciation of the exchange rate reduces the overall productivity of the economy. In the work of Hausmann et al. (2005) were identified 83 episodes of growth acceleration where the rate of growth of per capita income was raised by 2 percentage points or more in a sustainable manner for at least eight years. Before each episode occurred sharp depreciation of the real exchange rate (RER). In Sections 4–6 the arguments concerning the real exchange rate will be further developed in accordance with the purposes of the present work.

[2] In this work RER is defined as the price of foreign currency in terms of domestic currency adjusted by the price levels set by the North (developed economy) and South (developing economies).

[3] For a deeper discussion about this topic see Setterfield (2006b) – "Complexity, Endogenous Money and Macroeconomic Theory" – Chapter 6 – J. Barkley Rosser, Jr.

[4] Examples for this approach are in Ray (1998), Bardhan and Udry (1999) and Basu (1998).

[5] To a review and evaluation of this literature see Ros (2000).

[6] According to Dutt e Ros (2003, p.7): "(. . .) there appears to be a move away from extreme views on matters such as state intervention and free market policies with the recognition, that the state and markets both have a role to play in development". For further extension of this development see Amsden (1991) and Wade (1990).

multi-sector models work on more complex structures (Dutt and Ros, 2003). This modeling approach is built upon stylized facts of the peripheral economies. There is a consensus that the structuralist macroeconomics was formalized and initially pioneered from Lance Taylor[7].

The North–South models of Dutt (2003), Cimoli (1988) and Blecker (1996), as well as Skott and Larudee (1998), Ros and Skott (1997), Ros (2000) and Botta (2009, 2012) are examples of the tradition on structuralist macroeconomic models. The common feature of these models is the role of productive and trade asymmetries between developed and developing countries as well as the balance of payments disequilibrium in the tradition of demand-led economic growth models.

According to Gibson (2003, p. 57) although these kind of models are demand led supply-side factors are also taken into account, since "(. . .) net investment accumulates in the form of capital stocks which in turn determine the level of the next period's capacity, technological change, productivity, and other supply-side issues are obviously involved."

Following the ECLAC structuralist tradition, the economic backwardness depends on the role played by developing economies in the international economic system. In this context, international economic relations affect the pattern of trade in backward economies, their participation in the international division of labor and its growth potential.

Productive asymmetries between countries hamper the development of the South. Furthermore, these productive asymmetries are reflected in differences in the income elasticity of exports between North and South and in keeping the technological and income gap between these two regions.

Cimoli and Porcile (2013) present a model that captures key ideas of Latin American Structuralism School, such as the above mentioned technological asymmetries and structural heterogeneity[8]. Targetti and Foti (1997), Castellacci (2002) and León-Ledesma (2002), between others, developed export-led post-Keynesian models in which the Kaldor–Verdoorn laws are extended to some indicator of technological progress. In these works depending on the cumulative causation mechanisms in relation to technological knowledge it can occurs converging or diverging dynamics. However, they do not explicitly incorporate, such as in Botta (2009, 2012) the role of structural change and industry participation level in the knowledge accumulation process.

In the present work we present two main contributions in the context of above mentioned literature. The first is related to the dynamics of the real exchange rate, which depends on its industrial equilibrium level. The second contribution is the connection of current growth rate and the potential rate following Palley (1996, 2002). The former feature is further discussed in Section 4, and the latter in Section 3.

3. A Kaldorian growth model with external constraint

In the tradition of Balance-of-Payment-Constrained (BPCG) growth models, asymmetric productive structures can give rise to uneven growth by affecting the external constraint on growth in developing countries, as in Thirlwall (2011) and McCombie and Thirlwall (1994), among others[9]. Besides, the production specialization in economic sectors already mature or of stagnant technologies can lower the competitiveness of the production in these countries, reinforcing the first external constraint and reducing the level of the demand and the economic potential for growth. Therefore, different production structures generate singular growth trajectories.

In the long run, growth is not only restricted by the balance of payments, but also there is the need for the output growth rate equals the potential output growth rate (i.e., Harrod natural growth of rate). According to Setterfield:

> (. . .) demand-led theories (. . .) explicitly model the rates of growth of demand and hence actual output, and then implicitly rely on what Cornwall (1972, pp. 67–9) dubs 'Say's Law in reverse' to ensure that the potential rate of growth (i.e., the rate of growth of supply) converges towards the (explicitly modeled) rate of growth of demand. *The problem with all this is that the reconciliation of the rates of growth of demand and supply is too important to be treated only by means of implicit theorizing.* Hence absent the equality of the rates of growth of potential and actual output, the economy will experience either ever-increasing or ever-decreasing rates of capacity utilization. (Setterfield, 2006a, p.490)—Emphasis added.

Following Palley (1996, 2002) a possible way to resolve this inconsistency is through the inclusion of excess capacity level in a growth model with external constraints. Originally, Palley (1996, 2002) makes the elasticity of demand for imports a negative function of overcapacity, *E*. The reason is that imports are influenced by bottlenecks. When excess capacity and unemployment decrease, these bottlenecks become more prominent and the share of additional increments of income on imports increase[10].

[7] The structuralist approach to macroeconomics is fully developed in Taylor (1983). The starting point of this work is a model in which output is determined by demand in the tradition of Keynes–Kalecki which analyzes the relationship between growth and income distribution. First is shown a unisectorial model with fixed prices with a markup rule and the excess capacity is the way used to explicitly introduce the effective demand for a less developed economy. Afterwards, the analysis is extended to a developing economy with two sectors with flexible prices and sticky prices in the agriculture industry markets. The same approach is used to analyze North–South interactions in Taylor (1981). This was one of the first contributions in the tradition of North–South models, which has since grown exponentially. In Taylor (1991) is possible to observe the structuralist macroeconomics also applied to developed countries.

[8] These authors' link post Keynesian macroeconomics based on BOP constraint with evolutionary microeconomics. With the authors' model it can be analyzed how shocks and policies decisions affect the supply side and demand-side parameters of the model.

[9] The main precursor of the Thirlwall (2011) original model was Harrod (1939) with the multiplier of international trade, which was redesigned by Kaldor (1966), Kaldor (1975) and Thirlwall (2011).

[10] The empirical evidence for this hypothesis can be found in Thirlwall and White (1974) and Thirlwall and Hughes (1979). In these two papers,

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When the steady-state excess capacity (E) is constant, demand and supply grow at the same rate. In this model it will be used the variable "u" to represent the level of capacity utilization[11]. By introducing u in the model we include Palley (2002)'s suggestion as a way to reconcile the current rate of growth and the potential rate of growth in an external constraint model in which income elasticity of import demand is endogenous to the rate of capacity utilization. An increasing level of u is linked to the existence of bottlenecks in the domestic economy, allowing the increase of the growth rate of imports.

From the above implications, we assume the following structure for the South economy[12], in real terms over time:

$$\hat{x}_s = a_0 g_n \quad (1)$$

$$\hat{m}_s = (b_0 u_s) g_s \quad \text{com} \quad 0 < u_s < 1 \quad \text{and} \quad b_0 > 0 \quad (2)$$

$$\hat{x}_s = \hat{m}_s \quad (3)$$

$$\hat{\lambda}_s = c_0 + c_1 h_s g_s \quad (4)$$

$$g_s = \hat{\lambda}_s + n_s \quad (5)$$

where $\hat{x}_s$ is the South export rate of growth, a_0 is the export income elasticity, g_n is the North income rate of growth; $\hat{m}_s$ is the South import rate of growth, b_0 is the import income elasticity, u_s is the South utilization level of installed capacity and g_s is the South income growth rate; $\hat{\lambda}_s$ is the growth rate of labor productivity in the South, h_s is the share of the industry in South GDP (in terms of added value); c_0 is the autonomous part of labor productivity growth, c_1 is the Verdoorn coefficient, and n_s is the South labor force growth rate.

Eq. (1) shows the South exports growth rate (in terms of quantum) as a function of the income elasticity of exports (a_0) and the North growth rate. Assuming implicitly constant terms of trade, the growth rate of exports is not affected by changes in relative prices.

Eq. (2), stands for the South imports growth rate (in terms of quantum) as a function of income elasticity of imports ($b_0 u_s$) and the South growth rate. It should be noted that the income elasticity of imports is not constant, but a positive function of the degree of capacity utilization, due to the effects that production bottlenecks have on the propensity to import from the South economy.

Eq. (3) shows the condition for the intertemporal equilibrium of the balance of payments under a zero mobility capital account. In this case, the balance of payments is in equilibrium "if" and "when" the export growth rate is equal to the imports growth rate.

Eq. (4) shows the South growth rate of labor productivity as a function of the GDP growth rate[13]. It must be noted that the growth of the labor productivity induction depends on the industry GDP ratio. In this case, productivity growth is induced, for a given share of the industry in GDP, by the industrial production growth rate. This labor productivity growth equation specification follows Botta (2009, 2012), which is a very accurate representation of the so-called "Kaldor–Verdoorn Law".

Eq. (5) expresses the condition for the presence of a balanced growth path, which suppose a constant unemployment rate over time. This condition is that the growth rate of the South economy is equal to the sum of the labor productivity growth rate and the labor force growth rate.

Solving for u_s and g_s and substituting Eqs. (1) and (2) in (3) we have:

$$u_s = \frac{a_0}{b_0}\frac{g_n}{g_s} \quad (6)$$

The level of capacity utilization (u_s) depends on the ratio of income elasticity of export–import and the North–South ratio growth rates, so that the balance of payments is balanced. The higher the North growth rate and the South exports income elasticity, the lower the income elasticity of imports, the higher will tend to be the level of capacity utilization. As will be shown, the g_s growth without reducing u_s, or without generating pressures on the balance of payments (this happens through $\hat{m}$), is the only possibility to get a structural change in the South economy, so that the ratio of elasticities is changed in favor of the least developed region.

We will now turn our attention to the supply side of the model. Substituting Eq. (4) into Eq. (5) and taking into account (6) we have:

$$g_s = \frac{c_0 + n_s}{1 - c_1 h_s} = g_{ns} \quad (7)$$

Eq. (7) shows the South growth rate along its balanced growth path – the so-called natural growth rate (g_{ns}) – as a function of the labor force growth rate, the autonomous portion of labor productivity growth and the share of industry in the South GDP. We are, therefore, joining Nicholas Kaldor contributions, where the industry is seen as the central element of long-term economic growth. In this sector, there is a strong correlation between industrial product growth rate and the growth rate of non-industrial product[14].

Substituting (7) into (6) we get the following expression:

$$u_s = \frac{a_0}{b_0}\frac{(1 - c_1 h_s)}{(c_0 + n_s)} g_n \quad (8)$$

The capacity utilization level is an increasing function of the income elasticity of exports and of the North growth

it is shown that the elasticity of demand for imports increase under conditions of excess demand.

[11] The utilization of u (capacity utilization level) will change just the expected signal of b_0, which in the work of Palley (2002) is negative and in the present work is positive, in other words, according to Eq. (2), higher u levels, greater will be the import growth rates. Formally, if $u = 1$ (full capacity utilization), the equivalent is $E = 0$ (excess capacity nonexistent). In this way, the excess capacity rate of change is given by $dE/E = g_d - g_s$, so that if $dE/E = 0$, $g_d = g_s$, i.e., the domestic income growth rate is equal to the potential output growth rate.

[12] The model does not consider the free movement of capital. According to Bresser Pereira and Nakano (2003), Botta (2009), among others, the free movement of capital did not relax the external constraint on growth in developing countries and many of the times generated economic instability.

[13] Importantly, the variables λ with circumflex accounts for productivity growth over time and not the rate of acceleration in productivity growth.

[14] In Section 4 we further explore this relationship.

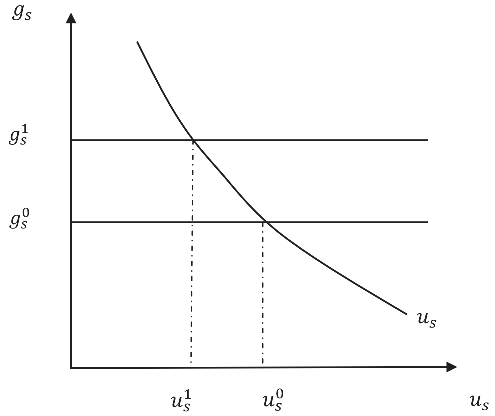

Fig. 1. Level of the capacity utilization and south growth rate. *Source:* Author's own elaboration.

rate and a decreasing function of the share of industry in the South GDP[15], autonomous component of labor productivity growth and of the South workforce growth rate of the.

Fig. 1 displays the equilibrium growth rate and the South capacity utilization level for two different levels:

4. Structural change, technological gap and the real exchange rate (RER)

In the previous section we highlighted that the share of the industry in the South GDP is a key element of its economic growth, thus industrialization is the engine of long-term growth.

The emphasis on industrialization as the crucial cause in the North–South convergence follows the Kaldorian[16] and structuralist[17] literature, which emphasize the fundamental role of industry as an increasing returns activity and the source of dynamic economies. The latter refers to increasing returns posed by technological progress induced by learning by doing and economies of scale.

There are robust empirical evidences that suggest that the industry plays a special role, mainly in developing countries. Rodrik (2009)'s findings points that the rapid growth in developing economies since 1960 is associated with the transfer of resources to more modern industrial sectors. In this sense, the structural change toward industrial activities worked as an engine of growth.

Szirmai (2012) presents the main empirical and theoretical arguments of the industry as the engine of growth in economic development. Basically, the productivity is higher in the manufacturing sector than in the agricultural sector because the transfer of resources from the latter to the former provides a "structural change bonus". This structural bonus arises as a result of the transfer of labor from low productivity activities to high productivity activities. This will automatically increase the productivity level of the economy. However, the pattern of structural change drives resources toward services, and given that productivity growth in this sector is usually slower than in industry, countries experience a "structural burden". In this case the process of structural change has a negative impact on productivity growth.

The manufacturing sector, in special, offers special opportunities for economies of scale, which are less available in agriculture or services, according to Szirmai (2012). Besides, the manufacturing sector offers special opportunities for both embodied and disembodied technological progress and diffuses it to other sectors. Part of this process occurs because of linkages and spillovers effects, which are stronger in this sector.

Felipe et al. (2009) use Kaldor's framework to analyze Asia's growth performance from the point of view of its structural change. According to them increases in the output growth rate are strongly associated with industry share growth (Kaldor's first law).

More specifically, in Felipe et al. (2009)'s findings the sector with the largest engine of growth elasticity, after controlling for common shocks, is industry, followed by services and manufacturing. The larger elasticity of industry relative to manufacturing is because industry activities such as electricity and other utilities have important forward and backward linkages. Besides, this characteristic of industry is based on the fact that capital accumulation and technical progress are strongest in this sector, having important spillover effects on the rest of the economy.

The Kaldor–Verdoorn law (or Kaldor–Verdoorn's second law) states that there is a strong positive relationship between the growth of manufacturing production and the growth of manufacturing productivity. In other terms, as manufacture is subject to economies of scale it presents lower employment elasticity with respect to output when compared with other sector, as productivity grows as a by-product of output expansion. Felipe et al. (2009)'s works presents that the sector with the lowest employment elasticity is in manufacturing.

Finally, Kaldor's asserts that when manufacturing grows, the rest of the sectors will transfer labor to manufacturing, raising the overall productivity of the economy (Kaldor's third law). Felipe et al. (2009)'s findings present that although to a lesser extent than industry, services appear to have significant productivity growth inducing effects. Besides, the latter appears to be driving productivity gains through factor reallocation effects depending of country samples analyzed, but still the authors highlight the industry importance in overall productivity growth, even when the services are considered as relevant as the industrial sector. In this work we explore formally the role of industry in economic dynamics from the stylized facts verified mainly in development economies, as we presented above.

In our model, the South industrialization dynamics are influenced by the price competitiveness as well as no price competitiveness. With regard to the price competitiveness, an overvalued exchange rate which is below the level that makes the industries operate in the state of art world technology in the international market, leads to a progressive reduction of the share of industry in GDP, since such a

[15] The higher the level of participation of industry in the GDP, the lower the required magnitude of "u" for the same amount of goods produced by the sector.

[16] Kaldor (1957, 1966, 1970).

[17] See Section 2.

situation induces an increased transfer of productive activities to other countries. We will call this level of the real exchange rate of "industrial equilibrium level"[18]. Thus, an overvalued RER is associated with a negative structural change on the economy, which we may call early deindustrialization (Palma, 2005). An undervalued exchange rate above its industrial equilibrium level would have the opposite effect, to induce a transfer of productive activities to the South, thereby increasing the share of the industry in the GDP.

A fundamental premise of the North–South models is that the South economy is far from the technological frontier and therefore their companies cannot operate with the technology world state of the art. This technological gap negatively affects the nonprice competitiveness of South industries, which produce manufactured goods that are of inferior quality and/or lower technological intensity than the manufactured goods produced in the North (Verspagen, 1993). It follows that the existence of the technological gap is an aspect that acts to reduce the competitiveness of South industries, thus contributing to a reduction in its share of the manufactured product of this region[19].

From above discussion, it is assumed that the dynamics of the share of industry in South GDP is given by the following differential equation:

$$\hat{h}_s = \sigma(\theta - \theta^i) - \beta(G - 1) \quad \text{with} \quad 0 \le \sigma < 1 \qquad (9)$$

where $\hat{h}_s$ is the growth rate of the share of industry in the South GDP; θ is the level of the real exchange rate; θ^i is the real exchange rate at the "industrial equilibrium level"; G is the technological gap[20]; σ is a parameter that represents the discretionary policies that directly address the industrial development; β is a coefficient that captures the sensitivity of the productive structure to the technological gap.

From Eq. (9) it can be seen that if South is at the technological frontier, the level of the real exchange rate to which the share of industry in South GDP is constant over time is equal to the real exchange rate at the "industrial equilibrium level"[21]. However, if the South economy is far from the technological frontier, then the share of industry in the GDP can only increase over time if the level of the real exchange rate is higher than its industrial equilibrium level, that is, if the actual exchange rate is undervalued (depreciated).

5. Real exchange rate dynamics

The real exchange rate is defined as the ratio between the prices of goods produced in the North denominated in South currency and the prices of goods produced in the South, as noted in the following equation:

$$\theta = \frac{EP_n}{P_s} \qquad (10)$$

where E is the nominal exchange rate, in other words, the price of the North currency in terms of the South monetary unit; P_n is the North price level and P_s is the South price level. The exchange rate dynamic over time is expressed as follows:

$$\hat{\theta} = \hat{E} + \widehat{P_n} - \widehat{P_s} \qquad (11)$$

where $\hat{\theta}$ is the growth rate of the real exchange rate, $\hat{E}$ is the growth rate of the nominal exchange rate; $\widehat{P_n}$ is the inflation rate of the North $\widehat{P_s}$ is the inflation rate of the South.

Following Kalecki (1954) we assume that the prices of goods produced in the North and South are set from a mark-up rule on unit production costs. We will assume that labor is the only input variable used in the production process in the North and South. In this context, the price rates of change of goods produced in the North and South will be given by:

$$\widehat{P_n} = \hat{z}_n + \hat{w}_n - \hat{\lambda}_n \qquad (12)$$

$$\widehat{P_s} = \hat{z}_s + \hat{w}_s - \hat{\lambda}_s \qquad (13)$$

where $\hat{z}_n$ is the change rate of the mark up of the Northern firms; $\hat{z}_s$ is the change rate of the mark-up of the Southern firms; $\hat{w}_n$ is the North nominal wage rate variations; $\hat{w}_s$ is the South nominal wage rate variations. Finally, $\hat{\lambda}$ stands for the growth rate of labor productivity, as already showed in Eq. (5).

Substituting (12) and (13) in (11) we get the following expression:

$$\hat{\theta} = \hat{E} + \left(\hat{z}_n - \hat{z}_s\right) + \left(\hat{w}_n - \hat{w}_s\right) + \left(\hat{\lambda}_s - \hat{\lambda}_n\right) \qquad (14)$$

Following Kaldor (*apud* Setterfield, 1997, p.55) we suppose that the structure of relative wages in the North and South remains constant over time. So:

$$\hat{E} + \hat{w}_n = \hat{w}_s \qquad (15)$$

Concerning the rate of mark-ups variation over time in the North and South we will assume that Northern companies keep a constant rate of mark-up so that the change in the mark-up rate in the North is equal to zero. The South companies will adjust their mark-up rates depending on the dynamics of its price competitiveness in international markets. If the real exchange rate is undervalued, i.e., above the industrial equilibrium level, then the South firms will increase the mark-up in an attempt to increase their profitability. However, if the exchange rate is overvalued, the South firms will reduce their mark-up in an attempt to

[18] See Bresser-Pereira (2010) and Bresser-Pereira, Oreiro and Marconi (2014) about the exchange rate at the industrial equilibrium level.

[19] The export income elasticity captures the influence of these non-price features such as technological contents, differentiation of exports relative to the international market, added value of these products, quality, distribution efficiency network, warranties, and so on... Even if some country has some products or an export basket alike, but uses different technological level, production technics, or any other factor that produces some sort of product differentiation, the income elasticities of the exported products will not be equal because despite of the production of the same good, the consume markets will not be the same, as well as the economic dynamics for each product. In the specific case of industrial firms it can be highlighted that most of them are characterized by an oligopolistic market structure in which the rule of competition is through non-price features (McCombie e Thirlwall, 1994, p.262–300).

[20] In Eq. (27), Section 7, the technological gap is formally introduced. For now, it enough to know that if $G = 1$ means complete catching up while $G = 0$ means complete lagging behind.

[21] If we make $\hat{h}_s = 0$ in Eq. (9), we will obtain the following expression: $\theta = \theta^i + \left(\beta/\sigma\right)(G - 1)$; with $G = 1$ (supposing that the technological frontier is constant) we have $\theta = \theta^i$, which makes the share of industry in the domestic product constant.

regain price competitiveness that was eroded by the appreciation of the exchange rate[22].

Thus, we have the following behavioral equations for changings in mark-up rate in the North and the South:

$$\hat{z}_n = 0 \quad (16)$$

$$\hat{z}_s = \alpha\left(\theta - \theta^i\right) \quad (17)$$

where α is a parameter that captures the sensitivity of the South mark-up in relation to the behavior of the real exchange rate in relation to its industrial equilibrium level.

Finally, growth rates of labor productivity in the North and South are given by:

$$\hat{\lambda}_n = c_0 + c_1 h_n g_n \quad (18)$$

$$\hat{\lambda}_s = c_0 + c_1 h_s g_s \quad (19)$$

Substituting Eqs. (15)–(19) into (14), we obtain the following expression:

$$\hat{\theta} = -\alpha\left(\theta - \theta^i\right) - c_1\left[h_n g_n - h_s g_s\right] \quad (20)$$

In Eq. (20) changes of the real exchange rate over time is a function of the exchange rate misalignment and the difference between North and South growth rates, both weighted by the respective industry's share in their respectively GDP.

Substituting (7) into (20) we get the following differential equation:

$$\hat{\theta} = -\alpha\left(\theta - \theta^i\right) - c_1 h_n g_n + \left(\frac{c_1 h_s}{1 - c_1 h_s}\right)(c_0 + n_s) \quad (21)$$

Eq. (21) shows the dynamics of changes in the real exchange rate as a function of exchange rate misalignment, the North natural rate growth, the industry share in the North, the industry share in the South, the autonomous part of labor productivity growth rate in the South and the growth rate of the labor force in the South.

The higher the exchange rate misalignment, the greater (undervalued) should be the real exchange rate of South economy. Thus, the industry will have incentives for greater investment in the production of tradable goods, using the latest technology in a sustainable way[23].

With the depreciated real exchange rate there is an increase in profit margins ($\hat{z}_s$), which increases the revenue of the industrial tradable sector generating incentives for the growth of the sector's investments. This process can produce a structural change in the South economy, increasing the exports income elasticity and reducing or eliminating its external constraint on growth.

6. Long run stability analysis with a constant technological gap

Less developed countries with immature national innovation systems (NIS) faces more difficulties in the absorptive and learning capacity as well as in the growth of the R&D investment by companies. Therefore, we first assume that the technological gap is constant and exogenous, i.e., $G = \bar{G}$ and relax this assumption in the next section, so we can take a look at the dynamic implications arising from changes in the technological gap.

Eqs. (9) and (21) show the system dynamics over time:

$$\hat{h}_s = \sigma(\theta - \theta^i) - \beta(G - 1) \quad (9)$$

$$\hat{\theta} = -\alpha(\theta - \theta^i) - c_1 h_n g_n + \left(\frac{c_1 h_s}{1 - c_1 h_s}\right)(c_0 + n_s) \quad (21)$$

It is a system of nonlinear differential equations, in which we have two state variables ($\hat{\theta}$ and h_s). In long-run equilibrium we have: $\hat{h}_s = \hat{\theta} = 0$. Making $\hat{h}_s = 0$ in (9) we obtain the following expression:

$$\theta^* = \theta^i + \frac{\beta}{\sigma}(G - 1) \quad (22)$$

where θ^* is the level of the real exchange rate in the long-run equilibrium of the system.

Eq (22) states that the long-term equilibrium level real exchange rate is an increasing function of the technological gap, that is, as further away the South industries are from the technological frontier, more depreciated/undervalued (with respect to the value of the industrial equilibrium exchange rate) will have to be the real exchange rate level for a constant participation of South industries over time.

Making $\hat{\theta} = 0$ in (21) we have:

$$\left(\frac{c_1 h_s}{1 - c_1 h_s}\right)(c_0 + n_s) = \alpha\left(\theta - \theta^i\right) + c_1 h_n g_n \quad (23)$$

Eq. (23) defines the locus of the combinations between the share of industry in South GDP and the real exchange rate to which the change in the real exchange rate ($\hat{\theta}$) is constant.

Making $f(h_s) = h_s/(1 - c_1 h_s)$ and differentiating Eq. (23) with respect to h_s and θ we have[24]:

$$\left[\frac{\partial\theta}{\partial h_s}\right]_{\hat{\theta}=0} = \frac{f' c_1 (c_0 + n_s)}{\alpha} > 0 \quad (23a)$$

Substituting (22) in (23) we obtain the long-run equilibrium value for the share of industry in the South:

$$f(h_s^*) = \frac{\alpha\beta\sigma^{-1}(G - 1) + c_1 h_n g_n}{c_1 (c_0 + n_s)} \quad (24)$$

To analyze the local stability of the system of Eqs. (9) and (21) we linearize it around its long-run equilibrium position through the first term of the Taylor expansion, and write the resulting system in a matrix form. We then have that:

$$\begin{bmatrix} \hat{h}_s \\ \hat{\theta} \end{bmatrix} = \begin{bmatrix} 0 & \sigma \\ f' & -\alpha \end{bmatrix} \begin{bmatrix} h_s - h_s^* \\ \theta - \theta^* \end{bmatrix} \quad (25)$$

A system with two differential equations has the following characteristic equation:

$$\lambda^2 - p\lambda + q = 0 \quad (26)$$

[22] See Missio (2012) for empirical support of this process.
[23] See Gala (2006, 2008) and Missio (2012) for more details about how these incentives work. In the first footnote we summarize the main arguments about this process.
[24] It must be observed that: $\partial f/\partial h_s = f' = 1/(1 - c_1 h_s)^2 > 0$.

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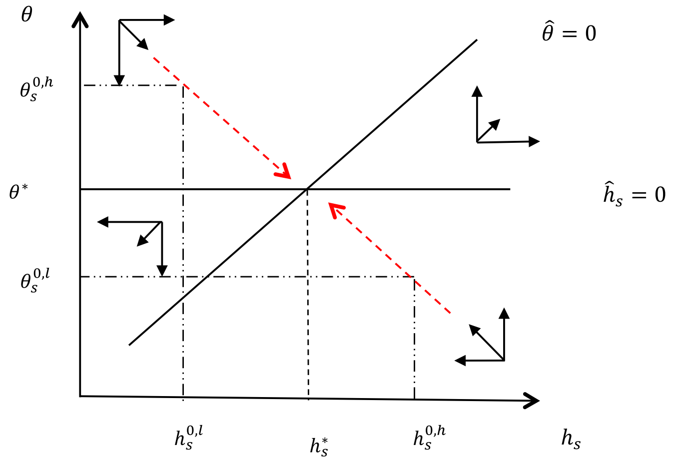

Fig. 2. Phase diagram considering the $\hat{h}_s$ and $\hat{\theta}$ system. *Source:* Author's own elaboration. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

where p is the trace of the Jacobian matrix and q is its determinant (Takayama, 1993). In this case, the trace of the Jacobian Matrix is negative (and equal to $-\alpha$). The determinant of the Jacobian Matrix $\begin{bmatrix} 0 & \sigma \\ f' & -\alpha \end{bmatrix}$ is negative (and equal to $-f\sigma$). It follows that the long-term equilibrium of the system is a saddle path trajectory so that the stability thereof is conditional to its initial parameters (Gandolfo, 1997, p.358).

The unstable and stable directions of the saddle path are determined from the intersecting on an equilibrium point defined in Fig. 2, given the long-term equilibrium values in (22) and (24). It may be noted that the trajectories approach the origin by the stable direction (red dashed line), and departs from the same by the unstable direction. In other words, stable and unstable directions are asymptotes for all trajectories passing through points out of them. This means that "(. . .) the presence of endogenous complex dynamics means that the economy is not necessarily self-stabilizing or optimal" (Rosser, 2006, p. 75).

For the dynamic analysis of the model we assume that the share of industry in the South GDP is a state variable so that it cannot give "jumps", i.e., it cannot provide an infinite rate of change. The real exchange rate is considered a control variable, which can be manipulated by the monetary authority and can "jump" instantaneously from one value to another. Finally, we suppose that the monetary authority chooses the initial value of the real exchange rate in order to place the economy exactly on its saddle trajectory[25].

In Fig. 2, we consider that the initial value of the share of industry in the product is equal to $h_s^{0,l}$. In this case, the monetary authority will adjust the real exchange rate to the level necessary to place the economy on top of its saddle path (the red dashed curve in Fig. 2). We can see that the level of the real exchange rate required for the dynamic adjustment of the economy is greater than its industrial equilibrium value, so that throughout all long-run adjustment path the exchange rate is undervalued (depreciated).

We must also note that along the adjustment path of the economy to its equilibrium position, the share of the South industry in the GDP will increase. This structural change process will be accompanied by an increase of South growth rate [Eq. (7)], higher level of markup [Eq. (17)] in the industrial sector and the increase of the income elasticity of exports of tradable goods due to the fact that the real exchange rate level is above its industrial equilibrium level [Eq. (9)], which, in turn, increases the incentives for bolster the investment in this sector with the latest technology in a sustainable way [Eq. (21)].

The described mechanism of changing the income elasticity of exports occurs if the exchange rate is at a competitive level (industrial equilibrium), which enables the country to increase its exports of manufactured goods modifying a country productive structure toward more sophisticated products (manufacturing), such as presented by Marconi et al. (2015) and Bresser-Pereira et al. (2014). In an empirical study with 64 countries and 18 years period, Marconi et al. (2015, p.17) confirms that maintaining the real exchange rate at the industrial equilibrium level enables the countries to expand its manufactures exports, modifying its productive structure and the composition of the exports, consequently, relaxing the external constraints on growth because the income elasticity of exports tends to rise in relation to the income elastic of imports.

Consider now the case where the initial value of the share of industry in the GDP is equal to $h_s^{0,h}$. In this case, the level of the real exchange rate required to set the economy along the saddle path is lower than its industrial equilibrium level ($\theta_s^{0,l}$) so that throughout all the adjustment path of the South economy the exchange rate is overvalued (appreciated). Along the way the share of industry in South GDP is decreasing, so that the economy of the South is going through a process of deindustrialization associated with the overvaluation of the real exchange rate.

Eqs. (22) and (24) state that the long-run equilibrium level of the real exchange rate and the share of South industry in its GDP are conditional to the technological gap,

[25] Actually, the policy instrument is the nominal exchange rate. Then, the monetary authority must consider the inflation rates in North and South, which are influenced by productivity, markup and nominal wages.

which is considered as constant and exogenous in this section. The gradual reduction of the technological gap with respect to countries that are at the technological frontier is part of the development of the South, so we must consider the impact on the long-term dynamic lowering the technological gap.

7. Technological gap dynamics and the verdoorn learning rate in the long run

So far, we have assumed stability of the technology gap ($G = \bar{G}$). Thereafter we suppose time varying stock of knowledge in South and North. By endogenizing the technological gap we postulate that the South can catch up either in technological and productive areas.

With respect to the formal treatment of the evolutionary approach there is a growing attention to international technological change as the main source of economic growth as seen in Nelson and Winter (1982), Dosi et al. (1990), Verspagen (1993), Fagerberg and Godinho (2005), among others. The technological specializations decisively influence the international trade of countries in that: "(...) the pattern of trade is considered a process of technological divergence and convergence, for which the innovative process induces divergence while imitation and diffusion induce convergence between countries" (Cimoli, 1998, p.2).

This literature highlights the importance of technological gap in the international production specialization. Demand-side asymmetries in the patterns of domestic consumption in relation to prices and income elasticities play a crucial role between productive specialization and the level of economic growth. These factors influence the terms of trade balance, which in turn determines the differences at the rate of growth in open economies.

These arguments are also clearly related to the demand-driven growth in the structuralist and post-Keynesian macroeconomics models, where the productive and trade asymmetries are fundamental to explain the divergence of North–South economic growth.

As the diffusion of innovation is not immediate, the most technologically advanced countries enjoy an initial advantage that allows them to expand their global market share through new products. With the process of technological catching up, backward countries can compete in some extent with the advanced countries, from that point the production costs and skilled labor earning become more important until the technological frontier move forward again in most developed countries.

In the long run, it is the ability to reduce the technological gap that allows continued economic growth, given that new technologies are generated continuously in the most dynamic sectors of advanced economies with effects on production and trade of new goods (Cimoli et al., 2005).

Following Verspagen (1993), the technological gap between the North and the South is as follows:

$$G = \ln\left(\frac{T_n}{T_s}\right) \tag{27}$$

Eq. (27) states that when the level of the stock of knowledge is equal between North and South, the technological gap is zero. Otherwise, G is an increasing function of the gap between T_n and T_s, i.e., as farther is the South from the technological frontier (represented by the North), the greater will be the technological gap. The variable G measures the North potential spillovers to the South, but such an economy can only capture these spillovers if there is sufficient learning capacity.

The growth of the stock of knowledge (T) results from the effects of an exogenous part of research related to companies and public and private institutions (NIS), which positively influences knowledge accumulation activities, as well as an endogenous part related to dynamic effects of learning process given by the accumulation of technologies.

The spillovers modeled are called net spillovers. It is assumed that these spillovers flow toward South while there is technology gap. If the gap is zero ($G=0$), the spillover effect will not take place. Thus, the value of G itself is a measure of potential spillovers. Since the current spillovers are not larger than potential spillovers, the learning ability must be between 0 and 1. For a large technological gap that capacity is 0. If this gap is small, the ability of learning will be the highest possible value (Verspagen, 1993). However, not all the spillovers can be captured, since learning capacity is required for the South to absorb them.

The decreasing ability to assimilate technological spillovers to the relative size of the technological gap is given by the rate $1/\delta$. The parameter δ represents the intrinsic capability to assimilate spillovers (or, absorptive capacity). This ability is a function of government policies on education, infrastructure investments, among others, i.e., the rate of decline in the ability to assimilate spillovers can be reduced by the action of the State.

Following Verspagen (1993), at a given level of technological gap the learning capability is determined by a set of social factors such as education of the workforce, the quality of infrastructure, the level of capitalization of the economy, the composition of sectorial output between the economy of the North (the technological frontier) and the South (backward economy), among other factors[26].

In order to get higher current spillover levels, the learning capacity must be increased, so that it is possible that the former rises until the threshold potential spillover (given by G, i.e., the technological gap itself).

Having G as the technological gap, the term $e^{-G/\delta}$ is the capability to assimilate knowledge spillovers. The equations representing the rate of growth of knowledge stock (T), incorporating in its structure the above discussion, are as follows:

$$\hat{T}_n = \beta_n + \omega_n g_{nn} \tag{28}$$

$$\hat{T}_s = \beta_s + \omega_s g_{ns} + aGe^{-G/\delta} \tag{29}$$

In Eq. (28) and (29) the rate of exogenous knowledge growth is given by β, ω is the Verdoorn learning growth rate which represents the gains from the process of learning by doing by the workers, aG is the potential spillovers. Furthermore, these equations take into account North and South growth trajectories along their balanced growth path, in

[26] For a further discussion on this subject see Verspagen (1993).

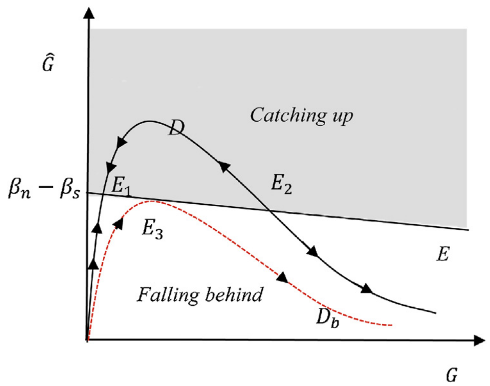

Fig. 3. Phase diagram considering the technological gap dynamics in the long run ($\hat{G} \neq \bar{G}$). *Source:* Author's own elaboration.

other words, the so called natural growth rates, $\hat{g}_{nn}$ and $\hat{g}_{ns}$, respectively.

Thus, taking into account Eq. (27) and differentiating it with respect to time, we can rewrite the growth rate of the technological gap over time ($\hat{G}$) using Eq. (28) and (29):

$$\hat{G} = \beta_n + \omega_n g_{nn} - \beta_s - \omega_s g_{ns} - aGe^{-G/\delta} \qquad (30)$$

To find the dynamics of the technology gap ($\hat{G}$) over time in relation to other variables in Eq. (30), we make $\hat{G} = 0$, so that:

$$\beta_n + \omega_n g_{nn} - \beta_s - \omega_s g_{ns} = aGe^{-G/\delta} \qquad (31)$$

Rearranging equation (31) we find the following expression:

$$\overbrace{\beta_n - \beta_s + \omega_n \overbrace{\left(\frac{c_0 + n}{1 - c_1 h}\right)}^{\text{North}} - \omega_s \overbrace{\left(\frac{c_0 + n}{1 - c_1 h}\right)}^{\text{South}}}^{E} = \overbrace{aGe^{-G/\delta}}^{D} \qquad (32)$$

Eq. (32) can be analyzed by means of a phase diagram showing the two sides of the expression—Fig. 3.

The left side of Eq. (32) – (E) – is a downward straight line for all positive values of G, since the technological gap decreases over time and so does h_s^*. Furthermore, since the North exogenous knowledge rate of growth is larger than the same variable in the South this line begins in the intercept ($\beta_n - \beta_s$), as shown in Fig. 3.

The right side part of the equation (D) begins from the origin of the graph $\hat{G} = 0$. Deriving the right of Eq. (32) side with respect to G we can find its maximum point where $G = \delta$, making it reaches aG/e at this point. With G tending to infinity $aGe^{-G/\delta}$ tends to zero.

When $G = \delta$ the State is acting through government policies in education, infrastructure investments, among others, in order to compensate and overcome the negative effects of the technology gap on the South convergence process. Furthermore, curves D below the line E imply that the technological gap will always be growing, since the learning capacity of the economy will be below the level required for the process of technological catching up and the amount of spillovers level is lower than the growth rate of the technological gap. On the contrary, curves D above the line E imply that the technological gap will become increasingly smaller.

This configuration means that there are two regions in Fig. 3, a region of "catching up" and another region of "falling behind".

Fig. 3 shows 3 equilibrium situations. The curve D highlights two of such equilibriums. In E_1 we have a stable equilibrium where D and E [from Eq. (32)] are equal and any deviation to the right or left of the curve D will cause the system to return to its original equilibrium. As Verspagen (1993, p. 133) points out, this is the situation we can see the path dependence or hysteresis into the model. In E_2 it can be seen an unstable equilibrium, since small deviations to the right lead to infinity and if the system shifts to the left of this point it will be lead to E_1[27].

Finally, in the D_b curve (region of falling behind) the model yields a left stable and right instable equilibrium. The stable equilibrium (E_3) is where the South has only one point of tangency. This is where the learning capacity is at the level required for the process of technological catching up and the amount of spillovers is equal to the growth rate of the technological gap. It's a "razor's edge" equilibrium where small deviations to the left results in a return of the system to its initial conditions and deviations to the right result in the technological gap tending to infinity.

In stable equilibrium E_1 the potential growth rate of the South economy should be higher than the North, as well as the Verdoorn learning coefficient. This is only possible with $\theta > \theta^i$, i.e., if the contemporaneous level of the real exchange rate is higher than its industrial equilibrium level, generating greater industry share in GDP of the South. This structural change reduces the productive North–South asymmetries as well as the technological gap.

The equilibrium achieved by means of Eq. (32) in E_1 is path dependent and endogenous to South industrialization level and the level of the real exchange rate. Different "h_s" and "θ" initial conditions produce lasting effects on the industrial development of this economy and different growth trajectories. This is an important and different result from Verspagen (1993)'s model.

The South economy pattern of specialization in E_1 depends on the dynamic process by which h_s and θ are determined by its own process of economic development. Thus, changes in the internal or external economic environment which overappreciate the real exchange rate in the short term can have lasting implications on the trajectory of growth and structural change.

Hence, economic growth and the potential for catching up in South economy is related to the history of economic development and the sophistication of its national innovation system. Countries with greater capacity for learning and absorbing spillovers have a higher possibility of carrying out the process of catching up. Otherwise, they can stay in a low growth trap. Differently of Verspagen (1993), in this model there are others channels to raise economic growth and the potential for catching up from the share of industry in gross domestic product and the use of real exchange rate. So, the conditions to convergence are widened because of the role played by industrial

[27] The main difference in relation to Verspagen's original results is the greater number of possible initials conditions for catching up.

sector mainly in the developing economies, as an engine of growth.

As developed in past sections a competitive level of the real exchange rate (RER) can help the economies to offset their technological and productive asymmetries by means of redefining their patterns of specialization. Stable and undervalued RERs favor exports diversification toward higher technological goods. Therefore the industry and the real exchange rate level are important variables to reduce the technological gap and rises economic growth.

The more developed the national innovation system of the countries, the greater are the possibilities of moving toward the technological frontier of the various production sectors of the economy. In this sense, greater tends to be the degree of productive diversification base of the economy, particularly in the industrial sector. This diversification linked to higher technological content will result in a higher income elasticity of export from the South changing its structural and external constraint on growth. In other words: "(...) countries cannot rely on a combination of technology imports and investments, but have to increase their national technological activities as well" (Fagerberg, 1988, p. 451).

Another important development of the model is the role of price competitiveness in the South economy. The structural change needed to raise the share of industry in the South depends on both levels of competitive real exchange rates in relation to its industrial equilibrium level and the distance of this economy in relation to the technological frontier (North). This implies that the process of North–South convergence non-price competitiveness as well as price competitiveness play a fundamental role in the process of "forging ahead" in less developed economies.

Finally, in the stable equilibrium level the exchange rate depreciation depends on the size of the technological gap itself. Higher levels of the latter will need more depreciated real exchange rate equilibrium in relation to its industrial equilibrium level, therefore higher will be the level of potential output South (in which $E < D$). For high levels of technological gap and low levels of learning capability of this economy (in which $E > D$), the effect of the real exchange rate is not sufficient for the process of catching up and North–South convergence.

8. Final remarks

The model developed in this paper integrates different features of technological gap effects and the level of the real exchange rate (RER) under the cumulative causation *à lá* Kaldor–Verdoorn, showing their effects on the production structure of developing countries (South), which can catch up. Furthermore, it encompasses the need that output growth be equal to the natural rate of growth through the introduction of the level of capacity utilization in conditions of external constraint in both short and long term.

In the short term, an increase in the South growth rate of the demand without increasing bottlenecks that will be answered by a growing share of imports implies that its natural growth rate must also rise, i.e., the level of industry participation and economic productivity should also increase.

When the technological gap level is constant and exogenous, growth in the South economy depends on the North growth, as well as to the behavior of the real exchange rate over time (price competitiveness). The higher the exchange rate misalignment, the greater should be the level of the real exchange rate of the South. In this case, the industry will have incentives for greater investment in the production of tradable goods with higher technological content.

When a competitive level of the real exchange enables an increase in profit margins the revenues of the tradable industry grows. This process produces a structural change in the South economy, increasing the income elasticity of exports, reducing or eliminating its external constraint on growth.

Taking into account this dynamic in the long-term, the effects of the undervalued real exchange rates in relation to its industrial equilibrium level on technological and productive catching up exhibit a trajectory of saddle path or multiple equilibriums.

In the case of the saddle path, the model's stability is conditional to its initial parameters. In the stable path the monetary authority can adjust the real exchange rate to the level required to place the economy on the top of the saddle, where the share of industry in South GDP (structural change) and economic growth are rising. For the unstable trajectory this adjustment is not possible.

Under multiple equilibrium, the technological gap decreases as a function of structural changes in the South (with greater industry share in the GDP and its dynamic effects on other sectors), decreasing the technological distance from the North through the greater ability to assimilate spillovers and through government policies that qualitatively improve the national innovation system, which impact the knowledge stock growth and non-price competitiveness in the South economy.

The highest level of industry share in the South accelerates productivity gains from Kaldor–Verdoorn Law both through GDP growth as well as higher coefficients of learning.

These trajectories are path dependents. Different initial conditions of "h_s" and "θ" produce lasting effects on the industrial development of this economy and different paths in the North–South growth. Moreover, the level of depreciation of the exchange rate depends on the size of the technological gap. The higher the technological gap, more depreciated must be the real exchange rate in relation to its industrial equilibrium level.

Finally, it must be noted that maintaining an undervalued real exchange rate enables the South economy to expand its industrial share in the output, which boots productivity and growth. So, the structural change toward the industrial sector changes the income elasticity ratio between exports and imports, relaxing the constraints on South growth that arises from the need for intertemporal balance-of-payment equilibrium.

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