# A MACRODYNAMICS OF THE CREATION OF TECHNOLOGICAL INNOVATION, HUMAN CAPITAL ACCUMULATION AND INCOME DISTRIBUTION

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**Abstract:** This article develops a neo-Kaleckian theoretical model of growth and income distribution, in which a strategic interaction between the intentional creation of labor-saving technological innovation through research and development (R&D) and human capital quality of the economy is explicitly formalized. We argue that two factors are complementary. On the one hand, innovation requires skilled human capital, and on the other hand, qualitative changes in human capital may have an impact on the macroeconomic variables only when technological innovation occurs. In case innovation occurs, the rise of the average quality level of human capital through public expenditure on education may result in a rise of both the degree of capacity utilization and the growth rate in the short term. If not, public expenditure on human capital is ineffective. In the long run, when innovation occurs, the only stable equilibrium is possible under very restrictive conditions. We observe that, in the stable long-term equilibrium, firms will own most of the labor productivity gains due to a relative low bargaining power of workers. In the absence of technological innovation, equilibrium stability also requires a relative low bargaining power of workers.
**Keywords:** technological innovation; human capital; strategic complementarity; economic growth; income distribution
**Resumo:** Este artigo desenvolve um modelo teórico neokaleckiano de crescimento e distribuição de renda, no qual se formaliza explicitamente uma interação estratégica entre a criação intencional de inovação tecnológica poupadora de trabalho por meio de pesquisa e desenvolvimento (P&D) e a qualidade do capital humano da economia. Argumentamos que dois fatores são complementares. Por um lado, a inovação requer capital humano qualificado e, por outro, mudanças qualitativas no capital humano podem ter impacto nas variáveis macroeconômicas apenas quando ocorre inovação tecnológica. Caso ocorra inovação, a elevação do nível médio de qualidade do capital humano por meio do gasto público em educação pode resultar em elevação tanto do grau de utilização da capacidade quanto da taxa de crescimento no curto prazo. Caso contrário, o gasto público em capital humano é ineficaz. No longo prazo, quando a inovação ocorre, o único equilíbrio estável é possível sob condições muito restritivas. Observamos que, no equilíbrio estável de longo prazo, as empresas deterão a maior parte dos ganhos de produtividade do trabalho devido a um poder de barganha relativamente baixo dos trabalhadores. Na ausência de inovação tecnológica, a estabilidade do equilíbrio também requer um poder de barganha relativamente baixo dos trabalhadores.
**Palavras-chave:** inovação tecnológica; capital humano; complementaridade estratégica; crescimento econômico; distribuição de renda

**JEL Codes:** E12; O11; O30; O33

## Introduction

The idea of strategic complementarity between R&D activity and human capital accumulation is widely accepted in the mainstream literature related to economic growth. Education, acting as the most important determinant of human capital, would have as its main role the creation of new technologies, as well as the adaptation to these same technologies (Nelson & Phelps, 1965; Schultz, 1975). Redding (1996) argues, in an endogenous growth model, that expenditure on education on the part of workers and expenditure on R&D on the part of firms are strategically complementary, and together they both determine the growth rate of the economy. In order to prove so, he interlinks two versions of endogenous growth: on the one side, models that emphasize the importance of spending on R&D, such as those by Romer (1990) and Aghion & Howitt (1992); on the other side, models focused on the role of human capital, such as those by Lucas (1988) and Stokey (1991). Still in this tradition, other studies develop different models in which this complementarity is examined, such as those by Acemoglu (1997, 1998).

Accinelli *et al* (2009) point out the disproportion observed in the relationship between human capital stock and innovation rates in less developed nations. Mexico, for instance, is quite more developed in technological terms compared to other Latin American countries, and yet it is poor in human capital accumulation. On the other hand, Argentina and Uruguay are examples of countries with quite high levels of human capital, but at the same time with a low level of technological advance. Ros (2003) cites the Latin American nations as paradigmatic cases of the need for additional conditions capable of sustaining the growth process. Many of them, as in the case of Argentina, Uruguay and Panama, do not grow as fast as other nations beginning their trajectories with similar human capital levels. The question is: in the absence of an interaction between human capital and innovation, is either one of these factors, separately, capable of affecting the growth rate of the economy in a sustainable way over time?

In terms of empirical evidence, it is possible to find papers which show the existence of a significant relationship between expenditures on R&D and economic growth, as in the case of Lichtenberg (1992) and Coe & Helpman (1995), and also papers which corroborate the importance of human capital to growth, such as Mankiw *et al*. (1992) and Barro (1991). On the other hand, Benhabib and Spiegel (1994) find empirical evidence indicating that the impact of human capital on the growth rate occurs mainly through innovation capacity and technology diffusion.

Going in the opposite direction of the above-mentioned models, the post-Keynesian theory of economic growth places emphasis on the elements of demand, attributing great importance to income distribution as the determinant of growth. However, although on the supply side, the role of technological innovation is not ignored. By limiting the analysis to growth models à la Kalecki-Steindl (Rowthorn (1982) and Dutt (1984)), into which this paper is inserted, it is possible to observe that several studies have been developed with the purpose of including innovation as an endogenous element, affecting the distribution of income, the degree of capacity utilization, and the growth rate of the economy.

Endogenous innovation is typically treated in terms of changes in labor efficiency, i.e., through variations in its productivity. Supposedly, the rise in labor productivity is not accompanied by a rise in capital productivity, that is, innovation generates a type of technical change called Harrod neutral.

Dutt (2003) cites some of the effects of technological innovation when it is introduced endogenously into models of this nature. Firstly, a high innovation rate by impacting the desired investment of the firms positively raises the aggregate demand, and then the degree of capacity utilization. Additionally, it is possible that a reduction in the saving rate of the economy occurs because of the increase in the variety of consumer goods available (in the case of product innovations).

It is a well-known idea in this literature that innovations occur as a result of distributive conflict. An expansion in aggregate demand leads to a rapid employment growth rate, resulting in an increase in the labor-saving innovation rate (Bhaduri, 2006; Dutt, 2006; Sasaki, 2008). Among the models that analyze the innovation process are those by Rowthorn (1982), Dutt (1990, 1994), You (1994), Cassetti (2003), and Lima (2004). A series of empirical papers aimed at the relationship between innovation and growth is found in this literature, such as those by Stockhammer & Onaran (2004), Naastepad (2006), Hein & Tarassow (2010), and Vergeer & Kleinknecht (2007).

Although the neo-Kaleckian models mentioned put emphasis on technological innovation, we observe that little attention is given to the role of human capital[1] and that possible complementarities between human capital and technological innovation are totally ignored.

In this respect, this paper contributes to the neo-Kaleckian literature on growth and income distribution in two ways. We design a growth model in which the creation of technological innovation occurs as an intentional attitude of the firm, and, going further, we examine the complementarity between human capital and innovation. We assume that while the government spends on education, the firm spends on R&D. The decision on the amount spent on R&D is made based on a program to minimize costs, which takes into consideration the average quality of the human capital of researchers available (called skilled workers). The intuition is: the higher the average quality of human capital is, the better the results of the research and therefore the more inclined to spend on innovation the firm will be. When the average quality of human capital is skilled (unskilled) the firms innovate (do not innovate). In case innovation occurs, human capital may impact the wage share positively in the short term and, consequently, the degree of capacity utilization and the growth rate. In the absence of innovation, however, human capital will have no effect on the macroeconomic variables of the system, and government expenditure on education will be ineffective.

This paper is organized as follows. Section 1 describes the structure of the model. Section 2 shows its behavior in the short term. Section 3 analyzes the possible trajectories of the economy in the long term. The fourth section presents the conclusion.

## 1. Structure of the Model

The economy described in this model is closed and has a government. Only one good is produced, which is used for consumption and investment. The inputs used for its production are capital, $K$, and direct labor, $L_D$. We assume that, in addition to taking on direct labor, the firm invests in the hiring of indirect skilled labor, $L_R$, for research and development, so that the total of labor hired, $L$, is given by:

$$L = L_D + L_R. \tag{1}$$

The production function presents a fixed coefficient technology:

$$Y = min[uK, a(L - L_R)] = min[uK, aL_D], \tag{2}$$

[1] Dutt (2010) designs a model in which human capital plays an important role. Workers with different levels of specialization, low and high-skilled ones, coexist, so that variations in the proportion of these workers and wages have an impact on income distribution and on economic growth.

$$L_D = Y/a, \tag{3}$$

$$L_R = \rho L_D \tag{4}$$

where $0 \leq \rho \leq 1$ is the ratio between indirect skilled labor (researchers) and direct labor, $Y$ is the product, $K$ is the capital stock, $u$ is the degree of productive capacity utilization, and $a$ is the direct labor productivity.

The firms are homogeneous and operate in an imperfect competition environment, where the price of the good is fixed by a markup rule. We assume that both the quantity produced and the direct labor hired in production are subordinate to the effective demand, which at the existing level of prices is lower than what is necessary for the productive capacity to be fully utilized.

In this context, technological innovation is intentionally generated by the firms in an attempt to maintain and/or expand in this way their degree of monopoly. The research activity is treated as an additional expenditure on the indirect labor needed to create technological innovation, whose purpose is to develop productive processes that are more efficient, i.e., processes that are capable of raising direct labor productivity. Supposedly, the rise in direct labor productivity is not accompanied by a rise in capital productivity, that is, innovation produces a technical change called Harrod neutral.

In this model, we consider that the results of expenditure on R&D are directly related to the quality of the human capital engaged in this activity. In this case, a strategic interaction between the two above-mentioned factors emerges, and we assume that, while the firm is responsible for the creation of technological innovation, it is the government's responsibility to raise human capital quality by providing education, which is financed by a tax on the aggregate income.

**1.1 Labor Market**

Following the same definitions by Skott (2006) for labor market, we consider that the labor force is heterogeneous and consists of two types of workers: skilled, $R$, who are the most specialized human capital of the economy, and unskilled, $D$, less specialized workers who perform simple tasks. As mentioned above, the firm takes on labor for two purposes: direct production and R&D. The aim of the research activity is to create innovations capable of improving the productive process, raising direct labor productivity. The hypothesis is that the firm hires only skilled workers for research, whereas the direct labor of the factories can be carried out by two types of workers: skilled and unskilled. We assume that both types have the same productivity in the activity requiring low qualifications.

Education is financed by the government without monetary cost for specialization on the part of workers, although a social cost exists since education is financed by means of tax collection, as described in detail in subsection 1.3. Even though universal access to education is provided, not all workers become skilled due to exogenous reasons, such as different individual aptitudes. Thus, a constant fraction $\delta$ of the labor force becomes more specialized, whereas $(1-\delta)$ becomes less specialized.

To simplify, we assume that the specialization average differential between skilled and unskilled workers remains constant over time. The average quality of human capital of skilled workers, $h$, is a factor observed by the firm when this type of worker is hired to produce innovations.

The quality of human capital can be understood as a series of cognitive abilities present in the specialized labor force. Several factors can be treated as its determinants, such as individual innate abilities, years of schooling, access to health, and the possibility of migration. In this model, the only determining factor that will be taken into account is the government expenditure on education.

We consider that the hiring of skilled labor for research, $L_R$, is an indirect cost of production determined in a discretionary way as a fraction $\rho$ of $L_D$. The magnitude of $L_R$ is decided by the firm. The conditions defining this decision are described in detail in subsection 1.3. On the other hand, the hiring of $L_D$ is a direct cost that is indispensable to production.

The supply of skilled and unskilled workers is decomposed as follows:

$$R = L_R + L_{RD} + U_R$$

$$D = L_{DD} + U_D$$

And the total demand for direct labor is given by:

$$L_D = L_{DD} + L_{RD},$$

where $L_{RD}$ is the total of skilled workers hired as direct ones, $U_R$ is the total of unemployed skilled workers, $L_{DD}$ is the total of unskilled labor hired in production, and $U_D$ is the total of unemployed unskilled workers. We assume that $U_R > 0$ and $U_D > 0$ so that the supply of both types of workers is sufficiently elastic, placing no limitation either to production or research.

The ratio between nominal wages of researchers and those of direct workers is given by $s$, so that:

$$W_{L_R}/W_{L_D} = s > 1 \qquad (5)$$

where $W_{L_R}$ and $W_{L_D}$ are the wages of researchers and direct workers, respectively, and $s$ is a constant salary premium paid to researchers. The justification for the salary premium is the fact that, when hired for research, skilled workers have to put their qualification differential into practice, and since the qualification differential between skilled and unskilled workers is hypothetically constant over time, so will be the salary premium, $s$. Thus, $W_{L_R}$ and $W_{L_D}$ always vary in the same proportion.

**1.2 Creation of innovation and human capital**

Since the purpose of hiring high-skilled workers for R&D activities is to make process innovations that raise labor productivity, we argue that the latter varies according to the proportion of researchers hired as an additional labor, $\rho$, that is, $a = a(\rho)$, where $a'(\rho) > 0$, $a''(\rho) < 0$ and $a(0) > 0$, so that the sensitivity of the direct labor productivity in relation to variations in the proportion of hired researchers is given by:

$$\frac{a'\rho}{a} = \varepsilon_\rho. \qquad 0 \leq \varepsilon_\rho < 1 \tag{6}$$

We suppose that the value of $\varepsilon_\rho$, in level, is proportional to the average quality level of human capital, $h$, embedded in skilled workers. Formally,

$$\frac{a'\rho}{a} = \varepsilon_\rho = \beta h. \tag{6a}$$

where $\beta$ is a non-negative constant. Given that the percentage comparison in the calculation of elasticity is made between two very distinct variables, i.e., labor productivity and expenditure on research, we assume, in monetary terms, that gain in productivity is higher than expenditure on research whenever $0 \leq \varepsilon_\rho < 1$.

At a certain point in time the direct labor productivity is given, but varies over time according to the $\rho$ level:

$$\hat{a} = \chi_0 + \chi_1\rho. \tag{7}$$

where $\chi_0$ and $\chi_1$ are positive parameters.

### 1.3 Distribution of Income

The income of the economy is divided among workers and firms, and taxed by the government as follows:

$$Y = \left(W_{L_D}/P\right)L_D + \left(W_{L_R}/P\right)L_R + rK + \tau Y. \tag{8}$$

where $r$ is the profit rate and $\tau$ is a constant income tax totally spent on education. Substituting equations (4) and (5) into equation (8) yields:

$$Y = v_{L_D}L_D(1 + s\rho) + rK + \tau Y. \tag{9}$$

where $v_{L_D} = \left(W_{L_D}/P\right)$ is the real wage of direct workers, which is considered the reference wage. Wages are fully spent on consumption, and the wage share of income, or the variable production cost per unit (from the firm's perspective), $\sigma$, is given by:

$$\sigma = v_{L_D}\frac{(1 + s\rho)}{a(\rho)(1 - \tau)} \tag{10}$$

The firm decides how much will be spent on research by choosing the proportion of additional labor in relation to direct labor (expenditure on innovation) that minimizes the wage share, which is its variable cost of production. Equation (10) yields the following first order condition:

$$\rho = \frac{\beta h}{s(1-\beta h)}, \tag{11}$$

Since $s$ is a constant and $\partial\rho/\partial s = 0$, the hiring of additional labor for research is entirely determined by the quality level of human capital available, where $\partial\rho/\partial h > 0$. As $\beta h$ represents the sensitivity of $a$ in relation to $\rho$, it follows that $\rho = 0$ if $\beta h = 0$, and $\rho$ will be positive otherwise.

Substituting (11) into (10) yields the wage share according to the average quality of human capital:

$$\sigma = \frac{v_{L_D}}{a(\rho\,)(1-\tau)(1-\beta h)}. \tag{12}$$

Hence, the effect of an increase in $h$ on the wage share when $0 < \beta h < 1$ is given by:

$$\frac{\partial\sigma}{\partial h} = \sigma_h = \frac{-v_{L_D}[a'(\rho(h))(1-\tau)(1-\beta h) - \beta a(1-\tau)]}{[a(\rho)(1-\tau)(1-\beta h)]^2} \gtreqless 0 \tag{13}$$

where $a'(\rho(h)) = \frac{\partial a}{\partial\rho}\frac{\partial\rho}{\partial h} = a'(\rho)\frac{\beta}{s(1-\beta h)^2} > 0$

With some algebraic manipulation, we arrive at the expression below, which is, however, inconclusive as to the signal of the derivative:

$$\frac{\partial\sigma}{\partial h} = \sigma_h = \frac{v_{L_D}[(\beta h)^2 - \beta h + \beta\rho]}{a\rho(1-\tau)(1-\beta h)^2} \tag{13a}$$

Since $0 < \beta h < 1$ and $(\beta h)^2 < \beta h$, it remains to be known whether $\beta\rho > \beta h$. If so, $\rho > h$ and $\sigma_h > 0$. Furthermore, if $\beta\rho < \beta h$ and $(\beta h)^2 + \beta\rho > \beta h$, then $\sigma_h > 0$. On the other hand, if $(\beta h)^2 + \beta\rho < \beta h$ or $\beta h + \frac{\rho}{h} < 1$, then $\sigma_h < 0$, that is, for this derivative to be negative, it is not enough that $\rho < h$. In other words, for the impact of an increase in human capital to reduce the share of wages in income, it is required that the elasticity of the productivity-proportion ratio of researchers combined with the ratio between the proportion of researchers and the human capital of these same researchers is lower than one. Finally, there is the possibility that this derivative will be null in the case where $(\beta h)^2 + \beta\rho = \beta h$ or $\beta h + \frac{\rho}{h} = 1$. Note also that if $\beta h = 0$, then $\rho = 0$ (equation 11) and the workers' participation in the income (equation 10) will be:

$$\sigma = \frac{v_{L_D}}{a(1-\tau)} \tag{10a}$$

So, in this case, we will also have $\sigma_h = 0$.

The rate of profit is expressed by:

$$r = \pi u = (1-\sigma)(1-\tau)u, \tag{14}$$

where $\pi = (1-\sigma)(1-\tau)$ is the profit share of income, and $u$ is the degree of capacity utilization.

The price of the good is determined by the firms, based on a markup rule for variable direct cost:

$$P = (1 + Z)\frac{W_{L_D}}{a}, \tag{15}$$

where $Z > 0$ is the firm's markup. The level of prices is given at a point in time, but increases over time according to the desire for higher markups on the part of the firms. Whenever the current markup is lower than the one desired, the firm will raise prices using the following rule:

$$\hat{P} = \theta(\sigma - \sigma_f), \tag{16}$$

where $\theta$ is a positive parameter, $\sigma$ is the wage share of income, and $\sigma_f$ is the wage share desired by the firms. Given the labor productivity, the markup is inversely proportional to the wage share of income, so that a gap between the current markup and the one desired can be measured by the gap between the current wage share and the one desired. In this model we assume the firm has two strategies to raise the markup: creating innovation and raising prices.

The markup desired by the firms depends on the state of the goods market and on a high capacity utilization rate, which reflects the dynamics of demand, inducing the firms to desire higher profitability. The corresponding wage share to the markup desired by the firms can be described as:

$$\sigma_f = \varphi_1 - \varphi_2 u, \tag{17}$$

where $\varphi_1$ and $\varphi_2$ are positive parameters. The greater the degree of capacity utilization is, the higher the markup desired by the firms will be. As detailed in Lima (2004), several arguments can be used to explain the prociclicity of markups, such as the need for higher markups to stimulate investment during the expansion period of the economic cycle (Eichner, 1976).

The reference nominal wage, $W_{L_D}$, on the other hand, varies according to the difference between the wage share desired by workers, $\sigma_w$, and the current wage share. As in Dutt (1994) and Lima (2004), the wage adjustment equation can be described as follows:

$$\widehat{W}_{L_D} = \psi(\sigma_W - \sigma), \tag{18}$$

where $\widehat{W}_{L_D}$ is the growth rate of the reference nominal wage, $(dW_{L_D}/dt)(1/W_{L_D})$, and $\psi$ is a positive parameter that represents the speed of adjustment. We consider that the wage share desired by workers varies according to the employment growth rate of direct workers[2] as well as the growth rate of their labor productivity:

$$\sigma_W = \lambda_0 + \lambda_1 \hat{L}_D + \lambda_2 \hat{a} \tag{19}$$

where $\lambda_0, \lambda_1$ and $\lambda_2$ are positive parameters. The employment growth rate of direct workers is given by:

$$\hat{L}_D = \hat{Y} - \hat{a} = g - \hat{a} \tag{20}$$

where $g$ is the economic growth rate.

We note that the growth rate of labor productivity has an ambiguous effect on the growth rate of nominal wages. On the one hand, it causes the reduction of the growth rate of demand for direct labor, thus reducing the production cost of the firms. On the other hand, the workers demand higher salaries whenever they perceive themselves to be more productive. The final result will depend on the relative magnitude of these two effects. It follows from this that the appropriation of gains in labor productivity by direct workers will be proportional to their bargaining power.

Considering that the firms save all their profits and the workers spend all their wages, saving as a proportion of capital stock is given by:

$$\frac{S}{K} = g_s = r. \tag{21}$$

The desired investment as a proportion of capital stock keeps a positive relationship with the degree of capacity utilization.

$$\frac{I_K}{K} = g_d = \eta_0 + \eta_1 u. \tag{22}$$

where $\eta_0 > 0$ and $0 < \eta_1 < (1 - \sigma)(1 - \tau)$.

Aggregate investment in human capital, $I_h$, normalized by capital stock is given by:

$$\frac{I_h}{K} = \frac{\tau Y}{K} = \tau u. \tag{23}$$

The aim of this investment made by the government is to qualify the entire labor force. However, due to the heterogeneity that exists among workers, a constant fraction of the labor available $\delta$ (as described in subsection 1.1) becomes more skilled in relation to the rest of the workers.

## 2. Behavior of the Model in the Short Term

The short term is defined as a period of time in which capital stock, $K$, nominal wage, $W_{LD}$, prices, $P$, labor productivity, $a$, and human capital quality, $h$, are given. The equilibrium in the goods market is given by:

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[2]The employment rate of the economy is given by $e = uk$, in which $k = \frac{K}{N}\frac{1}{a}$, where $k$ is the per capita capital stock measured by the ratio between aggregate capital stock, $K$, and labor supply, $N$, in productivity units. In this model, we assume that the growth rate of labor supply adjusts itself so that the employment rate becomes constant over time.

$$S + C + T = C + I_K + I_h. \tag{24}$$

Since the total of taxes collected is completely spent on investment in education $T = I_h$, where $I_h = \tau Y$, we obtain:

$$S = I_K. \tag{25}$$

Normalizing both sides with capital stock yields $g_s = g_i$, so that substituting equation (14) into equation (21), equaling the result to equation (22), and solving it for $u$, yields the short-term equilibrium value of the degree of capacity utilization:

$$u^* = \frac{\eta_0}{(1-\sigma)(1-\tau) - \eta_1} \tag{26}$$

As this is a demand-led model, we assume that the capacity utilization varies in order to adjust itself to excess demand in the goods market. The denominator of the equation must be positive, which means that saving must be more sensitive to variations in $u$ than investment. This is the condition for the equilibrium value of $u$ to be stable. The tax on income, $\tau$, and the wage share of income, $\sigma$, are between 0 and 1. Variations in the wage share of income are accompanied by variations in the same direction in the degree of capacity utilization:

$$\frac{\partial u^*}{\partial \sigma} = u^*_\sigma = \frac{\eta_0(1-\tau)}{[(1-\sigma)(1-\tau) - \eta_1]^2} > 0. \tag{27}$$

This result follows the tradition of post-Keynesian models à la Kalecki-Steindl, Dutt (1984, 1990), and Rowthorn (1982), in which a redistribution of profits in the direction of wages raises the product by an increase in demand. The effective growth rate is obtained substituting $u^*$ into (21) or (22), yielding:

$$g^* = r^* = \frac{\eta_0(1-\sigma)(1-\tau)}{(1-\sigma)(1-\tau) - \eta_1}. \tag{28}$$

The positive partial derivative of equation (28) with respect to $\sigma$ indicates that the rate of accumulation varies positively with the increase in the wage share of income, as shown below:

$$\frac{\partial g^*}{\partial \sigma} = g^*_\sigma = \frac{\eta_0 \eta_1(1-\tau)}{[(1-\sigma)(1-\tau) - \eta_1]^2} > 0 \tag{29}$$

Equation (29) shows the stagnationist nature of the model through the inverse relationship between $g^*$ and $\pi$. A rise in profit share raises the level of saving, reducing the aggregate demand, the degree of capacity utilization, and therefore the economic growth.

The impact of variations in the average quality level of human capital on the degree of capacity utilization and economic growth, when $0 < \beta h < 1$ and $\rho > 0$, occurs through variations of $\sigma$ according to the level of $h$ and is given by:

$$u_h^* = \frac{\eta_0(1-\tau)\sigma_h}{[(1-\sigma)(1-\tau)-\eta_1]^2} \gtreqless 0 \tag{30}$$

and by

$$g_h^* = \frac{\eta_0\eta_1(1-\tau)\sigma_h}{[(1-\sigma)(1-\tau)-\eta_1]^2} \gtreqless 0 \tag{31}$$

On the other hand, when $\beta h = 0$ and $\rho = 0$, the impact of the level of $h$ on $\sigma$ will be null, and consequently the impact of $h$ on the degree of capacity utilization and economic growth will be also null.

Based on this result, the strategic interaction that exists between human capital and technological innovation is confirmed. Innovation requires skilled human capital, and, at the same time, variations in human capital may have an impact on the macroeconomic variables of the system if and only if there is technological innovation. In case innovation occurs, the rise of the average quality level of human capital through public expenditure on education may result in the rise of the degree of capacity utilization and growth rate, depending on the conditions described by the expression (13). In case it does not, public expenditure on human capital will be ineffective.

## 3. Behavior of the Model in the Long Term

The dynamics of the economy occurs through variations in the level of prices, nominal wage, labor productivity and average quality of human capital. The dynamic behavior of the economy will be analyzed using a system of differential equations for variables $\sigma$ and $h$. We will seek to observe the dynamics between the average quality of human capital and the wage share of income, which is the determining variable of the degree of capacity utilization and long-term economic growth in models inspired by Kalecki.

### 3.1 Dynamics with the Creation of Innovation

When the level of human capital is skilled, so that $0 < \beta h < 1$ and $\rho > 0$, the dynamic behavior of the wage share, obtained from equation (12), will be:

$$\hat{\sigma} = \widehat{W}_{L_D} - \hat{P} + \frac{\beta\dot{h}}{(1-\beta h)} - \hat{a}. \tag{32}$$

We assume that the growth rate of human capital is positively related to economic growth, as income growth raises tax collection, and therefore public expenditure on education. On the other hand, the growth rate of $h$ is negatively related to its own level, formally:

$$\hat{h} = \gamma_0 g - \gamma_1 h\,, \tag{33}$$

where $\gamma_0$ and $\gamma_1$ are positive parameters.

Making the substitutions related to equations (7), (16), (17), (18), (19), (20) and $\dot{h} = \hat{h}h$ yields:

$$\hat{\sigma} = -(\psi+\theta)\sigma - (\psi\lambda_1\chi_1 - \psi\lambda_2\chi_1 + \chi_1)\left(\frac{\beta h}{s(1-\beta h)}\right) + \frac{(\beta\gamma_0 g^* h - \beta\gamma_1 h^2)}{(1-\beta h)} + \psi\lambda_1 g^* - \theta\varphi_2 u^* + (\psi\lambda_0 - \psi\lambda_1\chi_0 + \psi\lambda_2\chi_0 - \chi_0 + \theta\varphi_1), \tag{34}$$

where $u^*$ is given by (26) and $g^*$ is given by (28).

Equations (33) and (34) form a two-dimensional system of non-linear differential equations, in which the rate of change of $\sigma$ and $h$ depends on the levels of $\sigma$ and $h$ and the parameters of the system. The Jacobian matrix of partial derivatives for this dynamic system is given by:

$$J_{11} = {}^{\partial\hat{\sigma}}/_{\partial\sigma} = -(\psi+\theta) + \frac{\beta\gamma_0 g_\sigma^* h}{(1-\beta h)} + \psi\lambda_1 g_\sigma^* - \theta\varphi_2 u_\sigma^* \tag{35}$$

$$J_{12} = {}^{\partial\hat{\sigma}}/_{\partial h} = -(\psi+\theta)\sigma_h - (\psi\lambda_1\chi_1 - \psi\lambda_2\chi_1 + \chi_1)\frac{\beta}{s(1-\beta h)^2} + \frac{\beta(\gamma_0 g_h^* h + \gamma_0 g^* - 2\gamma_1 h)(1-\beta h) + \beta^2 h(\gamma_0 g^* - \gamma_1 h)}{(1-\beta h)^2} + \psi\lambda_1 g_h^* - \theta\varphi_2 u_h^* \tag{36}$$

$$J_{21} = {}^{\partial\hat{h}}/_{\partial\sigma} = \gamma_0 g_\sigma^* > 0. \tag{37}$$

$$J_{22} = {}^{\partial\hat{h}}/_{\partial h} = \gamma_0 g_h^* - \gamma_1. \tag{38}$$

Equation (35) is ambiguous, showing that the impact of a variation in the level of $\sigma$ on its growth rate will depend on its impact on growth and on the degree of capacity utilization. A high wage share, by virtue of the rise in the degree of capacity utilization, raises the markup desired by the firms, exerting negative pressure on the growth rate of $\sigma$. Nonetheless, the increase in $\sigma$, by impacting the growth rate of the economy positively, raises the employment rate of direct workers, the wage desired and consequently the growth rate of nominal wages. The sign of $J_{11}$ will depend on the relative magnitude of these effects. Equation (37) shows that variations in wage share have a positive effect on the growth rate of human capital quality by virtue of a positive relationship that exists between growth and income distribution.

Equation (36) shows the impact of the quality level of human capital on the growth rate of wage share. This derivative presents ambiguous results. With an increase in the quality of human capital ($h$), there is a positive influence on the rate of productivity growth, and this, in turn, on the rate of change of nominal wages, while a rise in the rate of productivity growth may have an adverse effect on the rate of employment growth. With high bargaining power, the appropriation of productivity gains by workers will be high, and the signal of $J_{12}$ will be positive. Otherwise, with little bargaining power, $J_{12}$

will be negative, which is a favorable situation for the firm, in the sense that its cost of production will be effectively reduced with the expense of labor-saving innovation.

Equation (38) is also ambiguous. In this case, the impact of a variation in the level of human capital quality is intermediated by its impact on the growth rate. If this impact is sufficiently big, so that $\gamma_0 g_h^* > \gamma_1$ and $g_h^* > 0$, a rise in the level of $h$ will be accompanied by a rise in its growth rate. On the other hand, if the impact of a rise in $h$ on the growth rate of the economy is negative, a rise in the level of $h$ will result in a reduction of its growth rate. As the impact of $h$ on $g$ is intermediated by $\sigma$, we conclude that the bigger the positive effect of $h$ on the distribution of income is, the greater $g_h^*$ will be.

The qualitative characteristics of the dynamic interaction between $\sigma$ and $h$ can be verified in the analysis of the phase diagrams. We observe that the signs of $J_{11}$ and $J_{12}$ are directly related to the magnitude of the direct workers' bargaining power. In case of relative high (low) bargaining power, the signs of the partial derivatives will be positive (negative).

The corresponding Jacobian matrix to the dynamic system is given by:

$$J = \begin{bmatrix} \pm & \pm \\ + & \pm \end{bmatrix}$$

The conditions of stability for the equilibrium, given by the negative trace of the matrix and the positive determinant, are necessarily satisfied with the following combination of signs:

$J_{11} < 0, J_{12} < 0$ and $J_{22} < 0$.

That is, the long-term equilibrium will be stable in case the workers' relative bargaining power is low. As a result, the following matrix is obtained:

$$J_1 = \begin{bmatrix} - & - \\ + & - \end{bmatrix}$$

The qualitative analysis of $J_1$ is done in the phase diagram of Figure 1, whose equilibrium is a stable focus or node, depending on the slope of the two isoclines. Considering $J_{11} < 0$ and $J_{12} < 0$, the slope of isocline $\hat{\sigma} = 0$, given by $-(J_{11}/J_{12})$, is negative. Since $\partial\hat{\sigma}/\partial\sigma$ is negative, an increase in $\sigma$ implies a reduction of its growth rate, which explains the direction of the horizontal vectors. The slope of isocline $\hat{h} = 0$, given by $-(J_{21}/J_{22})$, is positive. Since $\partial\hat{h}/\partial h < 0$, a variation in $h$ implies a variation in the opposite direction in $\hat{h}$, which explains the direction of the vertical vectors.

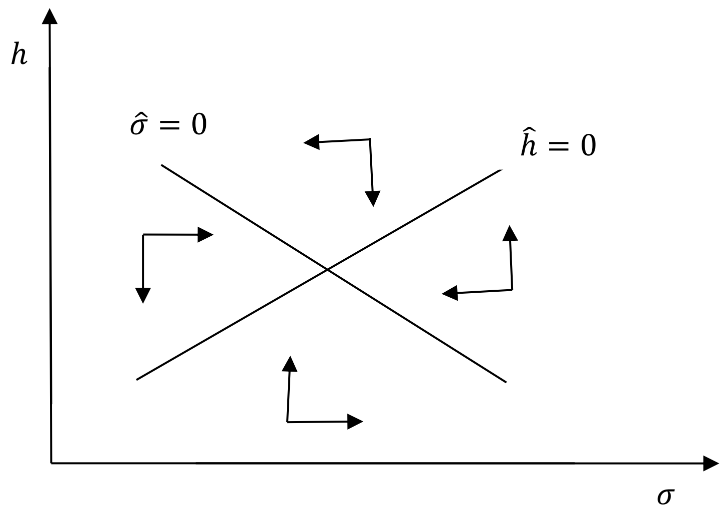


**Figure 1 - Equilibrium with the creation of innovation and workers' relative low bargaining power**

Figure 1 illustrates the case in which workers' relative bargaining power is low, so that the effect of a rise in $\sigma$ on the degree of capacity utilization and growth has a bigger effect on the markup desired by firms than on the wage desired by workers. The largest share of gains in labor productivity, given the low bargaining power, is appropriated by the firm.

The situation in which workers' relative bargaining power is high with $J_{11} > 0$ and $J_{12} > 0$ and the impact of $h$ on economic growth is significant ($J_{22} > 0$) can be analyzed using the following Jacobian matrix:

$$J_2 = \begin{bmatrix} + & + \\ + & + \end{bmatrix}$$

Since the elements of the main diagonal of the matrix $J_2$ are both positive, the equilibrium of the system, in case it exists, will be unstable. As it is not possible to know the exact value of the determinant of the matrix, we conclude that two situations are possible. That is, if $Det\,J > 0$, the equilibrium will be unstable (a node or focus). On the other hand, if $Det\,J < 0$, the result will be the existence of another unstable equilibrium (a saddle point). In this case, the economy will converge into equilibrium by pure chance. If not, it will diverge from it permanently.

Another possible situation is the coexistence of workers' high bargaining power with the low impact of $h$ on the growth rate, so that $J_{22} < 0$. Thus, the corresponding Jacobian matrix will be given by:

$$J_3 = \begin{bmatrix} + & + \\ + & - \end{bmatrix}$$

Since the determinant of $J_3$ is negative, this equilibrium will be a saddle point. The qualitative analysis is done in the phase diagram of Figure 2.

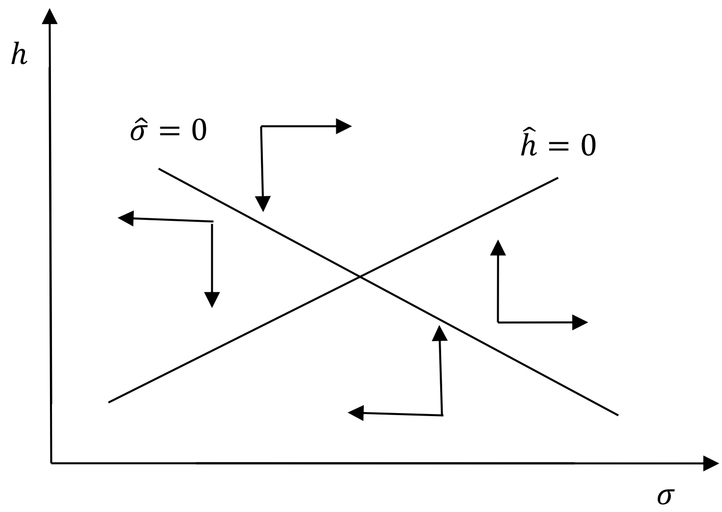


**Figure 2 - Equilibrium with the creation of innovation and workers' relative high bargaining power**

In the long run, when there is innovation, the only possible stable equilibrium occurs when increases (decreases) in the wage share generate (i) reductions (increases) in its growth rate and (ii) increases (decreases) in the growth rate of human capital quality; and when increases (decreases) in $h$ reduce (increase) (i) its growth rate and (ii) the growth rate of the wage share. Any change in any of these conditions will lead the system to imbalance.

**3.2 Dynamics without the Creation of Innovation**

When the level of human capital is unskilled, so that $\rho = 0$, and therefore $\beta h = 0$, i. e., the sensitivity of labor productivity-proportion of the researchers is negligible, then the dynamic behavior of the wage share obtained by equation (12) will be:

$$\hat{\sigma} = \widehat{W}_{L_D} - \hat{P} - \hat{a} \tag{39}$$

Making the substitutions related to equations (7), (16), (17), (18), (19), and (20) yields:

$$\hat{\sigma} = -(\psi + \theta)\sigma - \theta\varphi_2 u^* + \psi\lambda_1 g^* + \psi(\lambda_0 - \lambda_1\chi_0 + \lambda_2\chi_0) + \theta\varphi_1 - \chi_0 \tag{40}$$

where $u^*$ is given by (26) and $g^*$ is given by (28).

As the elasticity of labor productivity in relation to the proportion of researchers is zero, it follows that the rate of growth of labor productivity is given by variables exogenous to the model, captured by the parameter $\chi_0$.

The equation that sets the growth rate of human capital quality is:

$$\hat{h} = \gamma_0 g - \lambda_1 h, \tag{33a}$$

where $\gamma_0$ and $\lambda_1$ are positive parameters.

Equations (40) and (33a) form a two-dimensional system of non-linear differential equations, in which the rate of change of $\sigma$ and $h$ depends on both the levels of $\sigma$ and $h$ and the parameters of the system. The Jacobian matrix of partial derivatives for this dynamic system is given by:

$$J_{11} = {}^{\partial \hat{\sigma}}/_{\partial \sigma} = -(\psi + \theta) - \theta \varphi_2 u_\sigma^* + \psi \lambda_1 g_\sigma^* \tag{41}$$

$$J_{12} = {}^{\partial \hat{\sigma}}/_{\partial h} = 0 \tag{42}$$

$$J_{21} = {}^{\partial \hat{h}}/_{\partial \sigma} = \gamma_0 g_\sigma^* > 0. \tag{43}$$

$$J_{22} = {}^{\partial \hat{h}}/_{\partial h} = -\lambda_1 < 0 \tag{44}$$

Equation (41) is ambiguous, similarly to equation (35). The signal of the partial derivative, as in (35), will depend mainly on the relative effects of $\sigma$ on the degree of utilization and rate of growth.

The result of a variation in the level of $h$ on the growth rate of $\sigma$ (equation 42) is zero, so that in the absence of technological innovation, the average quality of human capital has no effect on the distribution of income in the long run. Equation (43) shows that variations in wage share have a positive effect on the growth rate of human capital level for the same reason described at equation (37). Equation (44) shows that the impact of the quality level of human capital on its own rate is negative as $g_h^* = 0$.

The qualitative characteristics of the dynamic interaction between $\sigma$ and $h$ can be verified in the analysis of the phase diagram. The corresponding Jacobian matrix to the dynamic system is given by:

$$J_4 = \begin{bmatrix} \pm & 0 \\ + & - \end{bmatrix}$$

The conditions of stability for the equilibrium, given by the negative trace of the matrix and the positive determinant, are met when $J_{11} < 0$. That is, the long-term equilibrium will be stable in case workers' relative bargaining power is low.

As a result, the following matrix is obtained:

$$J_5 = \begin{bmatrix} - & 0 \\ + & - \end{bmatrix}$$

The qualitative analysis is done using the phase diagram of Figure 3. Considering $J_{11} < 0$ and $J_{12} = 0$, the slope of isocline $\hat{\sigma} = 0$, given by $-(J_{11}/J_{12})$, is infinite. As $\partial\hat{\sigma}/\partial\sigma$ is negative, an increase in $\sigma$ implies a drop in its growth rate, which explains the direction of the horizontal vectors. The slope of isocline $\hat{h} = 0$, given by $-(J_{21}/J_{22})$, is positive. Since $\partial\hat{h}/\partial h < 0$, a variation in $h$ implies a variation in the opposite direction in $\hat{h}$, which explains the direction of the vertical vectors. The equilibrium is a stable node.

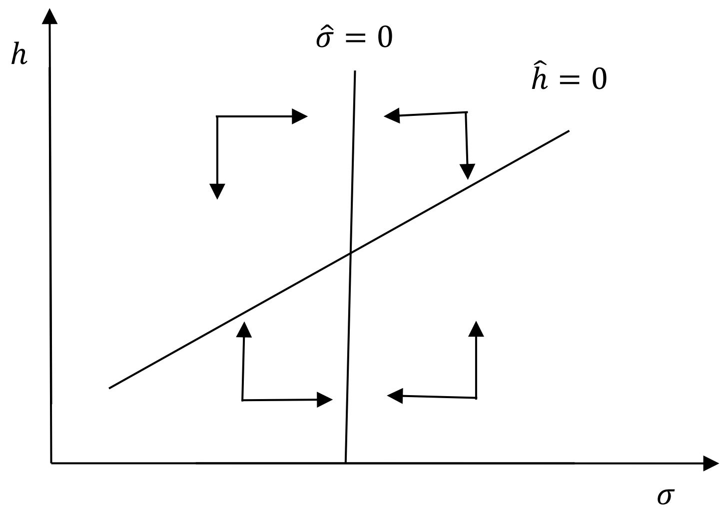


**Figure 3 – Equilibrium without the Creation of Innovation**

When there is no technological innovation, it is noteworthy that, just as in the case of innovation generation, only a single stable equilibrium is possible, which is compatible with a weak relative bargaining power of the workers.

**Final Considerations**

This essay has contributed to the Kaleckian growth literature with the design of a macrodynamic model of income distribution and economic growth, in which technological labor-saving innovation emerges as an intentional action of the firm seeking greater monopoly power. In parallel with that, we argue that, although an effort to innovate is made, the higher the quality of human capital involved in this activity is, the greater the final result of innovation will be. In this respect, a strategic interaction between the above-mentioned factors emerges. While the firm is responsible for the creation of technological innovation, the government is responsible for the rise of human capital quality by providing education financed by a tax on the aggregate income.

The elasticity of labor productivity in relation to expenditure on innovation is proportional to the quality of human capital used in R&D. When elasticity is positive and less than one, the firm innovates. It follows that innovation requires skilled human capital. At the same time, qualitative variations in human capital may have an impact on the macroeconomic variables of the system if and only if there is technological innovation. In case innovation occurs, the rise of the average quality level of human capital through public expenditure on education may result in a rise of both the degree of capacity utilization and the growth rate in the short term. If not, public expenditure on human capital is ineffective.

In the long run, when innovation occurs, the only stable equilibrium is possible under very restrictive conditions. We observe that, in the stable long-term equilibrium, firms will own most of the labor productivity gains due to a relative low bargaining power of workers. In the absence of technological innovation, equilibrium stability also requires a relative low bargaining power of workers.

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