Market concentration and technological change: a tale of two firms

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Abstract

This paper develops a micro post-Keynesian dynamic model in which there is a two-way relationship between market concentration and technological change. To encompass both ways of this causality, we extend the post-Keynesian theory of the firm accounting for the relationship between market share, technological change, and the growth of firms inspired by the neo-Schumpeterian approach to technological innovation. The model involves two firms that compete on technological factors. With our formalization, we notice that the stability properties of the system depend on the interactions between innovation, imitation, and market concentration. Different configurations of these interactions yield different scenarios of changes in market domain and technological advantage driven by an exogenous innovation shock. Moreover, this model also contributes to the literature as a basis for other post-Keynesian micro models and more comprehensive macro models of growth and distribution that aim to incorporate changes in the micro-competitive structure.

1 Introduction

The two-way relationship between market structure and technological change has been remarked since the works of Schumpeter (1934, 1942) and is highlighted by the neo-Schumpeterian literature following Nelson and Winter (1982). It is known that market concentration affects the dynamics of technological innovation, but this effect seems to be ambiguous. On the one hand, a more concentrated market can induce innovation by conceding power to innovative firms to avoid or prevent imitation from competitors, assuring a larger appropriability of monopoly profits coming from successful innovation. An oligopolistic market also implies firms with more internal resources to invest in uncertain activities like innovation. On the other hand, firms in very concentrated markets feel less threatened and thus have fewer incentives to innovate (Metcalfe, 1998). Despite the inconclusive results of most of the empirical literature, which are sensitive to industry-specific conditions and the simultaneous determination of these processes, a popular approach encompasses these two views suggesting that market concentration affects innovation following an inverted-U shaped relationship (Aghion, Bloom, Blundell, Griffith,

& Howitt, 2005; Kamien & Schwartz, 1975; Negassi, Lhuillery, Sattin, Hung, & Pratlong, 2019; Scherer, 1967; Tingvall & Poldahl, 2006).[1] Accordingly, innovation would be higher for intermediate levels of concentration, while being lower for low and high ones.

The causality also runs in the opposite direction, that is, from innovation to market concentration. Following the notion of "creative destruction", firms that innovate successfully obtain competitive advantages that allow them to increase their market shares, concentrating the market as long as these advantages last (Dosi, 1988; Nelson & Winter, 1978, 1982). The persistence of these advantages is related to barriers arising from the accumulation of knowledge, which makes imitation harder and enhances R&D expenditures that will generate innovations, and from a possible increase in the optimal scale of production (Levin, 1978; Phillips, 1966). Still, if innovation-related entry is possible and occurs on a large scale, innovation could reduce the concentration of an industry (Mansfield, 1983). Thus, the impact of innovation on market concentration is also mixed and can go either way.

In this paper, we argue that the post-Keynesian theory can benefit from a neo-Schumpeterian inspired analysis of this dynamics between market structure and innovation. The outlined dynamics relies on the concept of "Schumpeterian competition", according to which technological competition is more important than price competition. Therefore, technological enhancements like product differentiation, improvement, and variety yield decisive competitive advantages to innovative firms against its rivals. This non-price competition mechanism is similar to what the post-Keynesian theory has in mind regarding competition, as Lavoie (2014) summarizes. This literature offers a more realistic view of the firm proposing that firms aim at power in an environment with fundamental uncertainty. Firms also operate with planned excess capacity to respond to sudden demand shifts and prices are not market-clearing, which implies imperfect, oligopolistic markets. In this setting, non-price competition prevails. Competition is then driven not by the adjustment of prices, but by adjustments in different branches of innovation, branding, and advertisement. In light of this competition mechanism, kalecki1941theorem, who is aligned with this perspective, highlights how technological change increases the degree of oligopoly of an industry as it propels market concentration. However, the effects of concentration on innovation also need to be considered to evaluate the micro and macro implications of this two-way relationship within this theoretical framework.

Although this microeconomic perspective is assumed in most post-Keynesian macroeconomic models, there are not many formal models of this competition dynamics and how it changes intricately with technological progress.[2] An exception is Lima (2000),

[1] See Kamien and Schwartz (1975), Gilbert (2006), and Cohen (2010) for comprehensive surveys of the empirical works that investigate the effects of market structure on innovation.

[2] In the neoclassical branch of studies, the investigations relating innovation and market concentration have been conducted mainly through endogenous growth models following Aghion and Howitt (1992), like Aghion, Harris, Howitt, and Vickers (2001)'s growth model with step-by-step innovation, which is assessed with experimental economics in Aghion, Bechtold, Cassar, and Herz (2018). Aghion, Akcigit, and Howitt (2014) associate these attempts to the "Schumpeterian growth paradigm", referring to the formalization of the mechanism of creative destruction into growth models. According to the authors, that was done

who develops a post-Keynesian macro model of capital accumulation and distribution, in which the rate of technological innovation depends non-linearly on market concentration, while concentration is endogenous to capital accumulation and technological change. Yet, to the best of our knowledge, the post-Keynesian literature lacks micro models of this relationship.

Therefore, this paper contributes to the post-Keynesian literature by developing a dynamic model on the firm level in which there is a two-way relationship between market concentration and technological change. To encompass both ways of this causality, we extend the post-Keynesian theory of the firm accounting for the relationship between market share, technological change, and the growth of firms inspired by the neo-Schumpeterian approach to technological innovation. The model involves two firms that compete on technological factors. With our formalization, we notice that the stability properties of the system depend on the interactions between the dynamics of innovation, imitation, and market concentration. By exploring different configurations of these interactions, we cast light upon two scenarios of changes in market domain and technological advantage driven by an exogenous innovation shock and how these can be propelled or hindered by firm strategies. Moreover, given the relative scarcity of this discussion in the literature, this model can also serve as a basis for other post-Keynesian micro models and more comprehensive macro models of growth and distribution that aim to incorporate changes in the micro competitive structure.

The paper proceeds as follows. Section 2 describes the structure of the duopolist industry modeled. Section 3 looks at the behavior of the model in the short run, while Section 4 explores its long-run dynamics. Section 5 examines the effects of an exogenous innovation shock on this system and discusses the implications of the results. Finally, Section 6 concludes.

2 Framework of the Duopoly Model

The model developed here involves two competing firms A and B.[3] Both firms belong to the same industry and each produces a single good used for both investment and consumption. Each firm combines two factors of production, capital and labor, through a fixed-coefficient technology as the following production functions specify:

$$Y_A = \min\{L_A/a_A, K_A/b_A\}\,, \tag{1}$$

$$Y_B = \min\{L_B/a_B, K_B/b_B\}\,, \tag{2}$$

in two ways: by incorporating the microeconomic aspects of growth and by using more microdata than competing theories to investigate their predictions.

[3]The model involves a duopoly because the aim was to study competition between firms in the simplest way possible. However, this structure could be easily extended to represent an oligopoly. More firms can be added to the model turning it into a larger scale model that to be simulated. Another option is to keep pursuing a leader-follower relationship between firms, as will be explored in this paper, but considering the follower firm as an average of the market that follows the leading firm, thus turning this duopoly structure directly into an oligopoly.

where for each firm $i = A, B$ - as indicated in the subscripts throughout the paper - Y_i is output, L_i is employment, and K_i is capital stock, while a_i and b_i are labor-output and capital-output ratios, respectively. The coefficient a_i is the reciprocal of labor productivity. Thus, it is constant in the short run, when technology remains constant, but it decreases in the long run as productivity grows with technological change. A fixed set of technical coefficients prevails as a consequence of the bureaucratic conventions and work rules that are formed over the most efficient combination of inputs (Eichner, 1976, p. 28–37), as well as because of localized shifts in production derived from the cumulative effects related to the process of technological change (Atkinson & Stiglitz, 1969).

Total employment L is divided between the two firms, formally $L = L_A + L_B$. In the short run, the nominal wage w is fixed, for labor productivity is constant. However, we assume away wage-push inflation, so that nominal wages grow in the long run at the same rate as labor productivity. Moreover, the nominal wage is homogeneous in the industry, fixed through bargaining or government action at a level that ensures consumption at least above subsistence, and labor supply is in excess, both of which imply that there is an infinitely elastic supply of labor. This labor availability means that employment is determined only by production according to demand:

$$L_A = a_A Y_A \,, \tag{3}$$

$$L_B = a_B Y_B \,. \tag{4}$$

Regarding the relationship between production and demand, we assume that firms operate with excess capacity, which for the capital stock means the inequalities

$$K_A > b_A Y_A \,, \tag{5}$$

$$K_B > b_B Y_B \,, \tag{6}$$

while the equality relationships $K_A = b_A Y_A^{fc}$ and $K_B = b_B Y_B^{fc}$ indicate full capacity utilization, with Y_A^{fc} and Y_B^{fc} being each firm's full capacity level of output. As Steindl (1952) argues, planned excess capacity is necessary for firms to respond to demand shifts that cannot be foreseen. Firms want to exploit the opportunity of an increase in selling power, and they want to do it before their current or new competitors to create barriers to entry and prevent a future threat to their market. They also expect their market to grow as goodwill towards their brand gradually extends. However, there are technical reasons that prevent firms to expand their capacity suddenly or alongside the growth of the market. Those reasons relate to indivisibility, durability, scale specifications, and building time of machines and plants, justifying the maintenance of excess capacity.

Since the firms are dividing the sector's demand Y between themselves

$$PY = P_A Y_A + P_B Y_B \,, \tag{7}$$

where Y_A and Y_B represent the demand that each firm attends and the general price level P is an average of the firms' prices $P = \lambda_A P_A + \lambda_B P_B$, where λ_i is constant. Dividing equation (7) by P_B, we have

$$\theta Y = \psi Y_A + Y_B \,, \tag{8}$$

where $\theta = \lambda_A(P_A/P_B) + \lambda_B$ and $\psi = P_A/P_B$.

Previous dynamics determined which share of the market each firm attends given the size of demand, so that each holds a fraction of total demand

$$P_A Y_A = m_A P Y \,, \tag{9}$$

$$P_B Y_B = m_B P Y \,, \tag{10}$$

where m_A and m_B are the market shares of each firm and $m_A + m_B = 1$.

The firms determine prices P_A and P_B by applying a markup τ_i on average variable costs, which in this case are unit labor costs wa_A and wa_B, as follows:

$$P_A = (1 + \tau_A) w a_A \,, \tag{11}$$

$$P_B = (1 + \tau_B) w a_B \,, \tag{12}$$

where $P_A/P_B > 0$. The rates of profit r_A and r_B are derived from the price relationship above

$$r_A = \frac{\tau_A w a_A Y_A}{P_A K_A} = \frac{\tau_A w a_A u_A}{P_A b_A} \,, \tag{13}$$

$$r_B = \frac{\tau_B w a_B Y_B}{P_B K_B} = \frac{\tau_B w a_B u_B}{P_B b_B} \,, \tag{14}$$

where u_i is the rate of capacity utilization, $u_i = Y_i/Y_i^{fc}$.

Aligned with the standard Kaleckian view (Kalecki, 1971), average variable costs are assumed to be constant up to full capacity, while overhead costs are decreasing. Since firms operate with excess capacity, unit labor costs wa_i are constant.[4] As proposed by Sylos Labini (1969),[5] the markup is assumed to be constant and determined to create barriers to entry, a possibility allowed by the high degree of concentration of this market.[6] Consequently, prices are set at a sufficiently low level to prevent the entry of potential competitors.

We also assume that relative prices P_A/P_B and the markups τ_i remain constant, which implies θ and ψ in equation (8) as also constant. This refers to the fact that in this model

[4] According to Lavoie (2014, p. 147) these characteristics (constant average variable costs until full capacity, decreasing overhead costs, and firms operating with reserves of capacity) are the main stylized facts of the post-Keynesian firm.

[5] Beyond Sylos Labini (1969), see Bain (1956) and Steindl (1952) for a more detailed explanation on the relationship between prices and barriers to entry.

[6] Although in this model the market structure is duopolistic, this pricing mechanism could work even in a much more competitive market. This argument is developed by Lavoie (2014, p. 126), who claims that the market does not need to be oligopolistic to be imperfect. He argues that all markets could be considered imperfect markets, where prevails some sort of administered pricing mechanism, even with higher degrees of competition. For example, as aforementioned, in the analysis of Kalecki (1971) the fact that many sectors (like the ones of finished and industrial products) fix prices rely on the firms operating with excess capacity with constant marginal costs, according to their degree of monopoly, which he calls a "semi-monopolistic price formation" (p. 45) mechanism. However, Means (1936) links this pricing mechanism with structural factors of modern technology, while Shapiro and Sawyer (2003) relate prices with the interests of firms, strategically determined.

prices are not market-clearing, they only allow the reproduction of the firms by avoiding new entry and by generating enough profits to finance investments (Lavoie, 2014, p. 167).[7] While the markup and prices are kept constant in demand shifts, an assumption consistent with empirical evidence shown in Sawyer, Aaronovitch, and Samson (1982), Chevalier, Kashyap, and Rossi (2003), and Alvarez et al. (2006), the profit rates vary according to these changes in demand through alterations in the rate of capacity utilization. Therefore, firms would respond to possible demand shifts with adjustments in quantity, not prices.

Constant relative prices imply that firms do not compete on prices so that, in this setting, competition occurs through non-price factors, like quality, variety, and technology. Thus, we are assuming a neo-Schumpeterian approach to competition, where firms survive, grow, or die given how they differ regarding innovation, imitation, and how diffusion occurs (Metcalfe, 1998, ch. 1). Market competition is crucial to Schumpeter (1934)'s concept of creative destruction, pressing firms to innovate, but it is also a dynamic mechanism of selection, as described by Nelson and Winter (1982). This selection process enhances the firms that have made the best choices - concerning investment, branding, advertisement, R&D, and the production process - under uncertainty. Hence, through innovation firms obtain decisive cost, quality, or variety advantages over their competitors that affect their profits and market shares, threatening the existence of other firms.

This view of competition focused on technological asymmetries between firms implies pronounced variability and inequality in the market. This variability suggests that firms should always be considered heterogeneous agents in their respective industries, as Dosi (1984) proposes.[8] The competition process itself is thus uneven and asymmetric, with a few firms leading the transformation of the economy, whereas the rest follows, trying to adapt.

The described Schumpeterian competition dynamics is incorporated into this duopoly model by taking the firms as technologically heterogeneous and, consequently, unequal in the market. These differences in the level of technology and innovative knowledge between the firms are captured here by the technological gap. We are assuming that previous dynamics have made firm A the leader, which implies firm B as the follower. Firm A being the leader means that this firm is the one equipped with the most efficient techniques of production in this sector, so that we define the gap as

$$T = \frac{E_A}{E_B}\,, \tag{15}$$

where E_A and E_B are the stocks of technology and innovative knowledge of each firm and

[7] Lee (1994, 1999) criticizes the simplicity of the post-Keynesian pricing procedures. In these works, the author proposes a more complex pricing mechanism using a multisector model where industries have different price procedures between themselves. However, since prices in this model are not market-clearing, we consider that it is a good enough approximation to consider that firms fix prices over average variable costs.

[8] Lima (1996) highlights that taking this asymmetry into account from the start in models with innovation is a marked difference of the neo-Schumpeterian approach when compared to the neoclassical tradition, which starts from a point where all firms are identical, as in perfect competition.

$T > 1$.[9]

Being the leader gives firm A some liberty in making production and investment choices, while firm B awaits these decisions to make its plans. This leader-follower relationship implies that firm A is the only one able to make plans about its desired investment rate. Firm B only matches the sector's demand that the leading firm does not or cannot attend with its financial availability. In other words, firm B captures the residual market demand. For this reason, we define hereafter the financial constraints faced by both firms, but we only specify the desired expansion of the leading firm A.

Although in neoclassical economics firms decide to produce at the level that yields them the maximum rate of profit, here we follow the post-Keynesian view that firms aim at power, regardless of size and control scheme, as summarized by Lavoie (2014, p. 128). We follow Penrose (1959), Galbraith (1967), Wood (1975), and Aidar and Terra (2019) in relating power with growth. On the one hand, in a world with fundamental uncertainty, the larger the firm, the easier it is to respond to unpredictable events and to plan and control its operation and environment free from external influences. On the other hand, capacity expansion is important to obtain or maintain a competitive position in the market, since it allows firms to prevent entry by attending the growing demand and to innovate and diversify in production. Hence, it is not just a matter of ultimate control over the market, but how to survive in it. Power, growth, and survival are inevitably intertwined.

In this setting there is no financial sector, which implies profits as the means that enable firms to grow. Therefore, firms finance their expansion with the retention of part of their earned profits. Following the financial frontiers proposed by Sylos Labini (1969) and Wood (1975), we establish a function of the financial constraint faced by the firms with growth as a positive function of profits

$$g_A^F = s_A r_A \,, \tag{16}$$

$$g_B^F = s_B r_B \,, \tag{17}$$

where g_i^F is the growth rate of each firm compatible with its financial constraint, r_i is the firm's rate of profit, and s_i is its retention ratio, $0 < s_i < 1$. Equations (16) and (17) indicate that an increase in the firms' growth rate demands a higher rate of profit, given an admissible retention ratio.[10] This assumption is also supported by empirical evidence showing a significant role of availability of internal finance for investment (Brown, Fazzari, & Petersen, 2009; Fazzari & Mott, 1986).

[9]This feature of the model can be expanded to incorporate more firms. For instance, in an oligopolistic setting with three or more firms, T can be represented as $T = E_x/\bar{T}$, where E_i is the technological content level of each firm x, $x = [1, 2, \ldots]$, and $\bar{T}$ would be the average technological content of the remaining sector. Therefore, firms with $T > 1$ would be more competitive than firms with $0 < T < 1$.

[10]See Stockhammer (2005-6) for a discussion on how financialization and the reported increase in shareholder's power have impacted the retention ratio, investment, and other related decisions of the firm, based on an extension of a standard post-Keynesian micro model and a Kaleckian macro model. He shows that the presence of high shareholder power reduces investment and output but increases profits. Rabinovich (2020) also elaborates on the effect of financialization on the detachment of firms' profitability and investment by analyzing the supply side of the investment-profit puzzle.

Since power is related to growth, the leader firm A can make decisions on how much it wants to grow, so that the desired expansion frontier of this firm can be defined as an investment function with the following configuration:

$$g_A^E = \gamma_0 + \gamma_1 r_A - \gamma_2 m_A + \gamma_3 T \,, \tag{18}$$

where γ_j are positive parameters, $j = [0, 3]$, with γ_0 representing animal spirits, g_A^E is firm A's desired rate of investment in capital stock, m_A is firm A's market share, and T is the technological gap between the firms. As we are dealing with a one-good sector, the same good can be used for consumption, investment, and innovation activities. This means that technological innovation is not taken a separate production process, similar to what is proposed in Lima (2004).

The assumption that investment depends positively on the rate of profit is derived from the formalization of Dutt (1984) following Robinson (1956). An upward shift in expected profits leads firms to decide to undertake a greater amount of investment. For simplicity, current and expected rates of profit are taken as equal, with the former assumed to be a good enough approximation of the latter.

Desired investment is also taken as a function of the market share firm A holds, implying that changes in the market structure affect the investment rate. Although market share could either be positively or negatively related to investment depending on the strategy of the firms, here we are assuming a negative relationship. This assumption indicates that firm A has a strategy of maintaining its market share. If firm A obtains a higher market share, it holds a better competitive position in the industry and feels less threatened, so that it does not need to keep expanding to increase its power. We also assume that this strategy does not change with changes in the concentration of the industry.[11] Nelson and Winter (1982) also propose in their model with oligopolistic competition that firms with large market shares realize that expansion can ruin their market since they need great financial resources to expand proportionally. In this case, higher investment would lead only to a bad use of resources. Gilbert and Lieberman (1987), reinforced by Wood (2005) and Scheibl and Wood (2005), provide empirical evidence of this pattern of investment consistent with market share maintenance for large firms. Thus, their strategy would be to increase investment if they encounter a significant reduction in their market shares.

Finally, in this model a higher technological gap T, which implies a higher relative level of technological content of firm A, increases firm A's desired investment rate. On the one hand, Kalecki (1971) claims that technological innovation would result in new machines and production routines more productive than the old ones. This causes the costs

[11]Changes in firm's strategies due to interactions with the micro and macro environment are best incorporated in simulation models like Agent-Based Models (ABMs). For example, Possas, Koblitz, Licha, Oreiro, and Dweck (2001) incorporate neo-Schumpeterian microfoundations into a macrodynamic model with effective demand along Keynesian lines. The authors propose a model in which feedback between agents' strategic decisions and the environment produces endogenous industrial dynamics that will determine market structure and innovative performances. One of the possible extensions of the present work is to insert the double-sided dynamics between market concentration and technological change in a more complex modeling approach.

of the old methods to rise, which spurs new investment. On the other hand, technological innovation changing the dynamics of the economy and unfolding opportunities that influence investment is a central aspect of the theories of Schumpeter (1934, 1942) and the neo-Shumpeterians, as Nelson and Winter (1982), and is empirically supported by works such as Lööf and Heshmati (2006) and Corsino and Gabriele (2011).

3 Short-Run Equilibrium

The short run is a period in which the capital stock, the price level, the nominal wage, labor and capital output ratios, firms' market shares, and the technological gap are all taken as given. Firm A will produce according to demand, matching its investment plans with the available financial funds through adjustments in its rate of capacity utilization. Thus, in the short-run equilibrium $g_A^F = g_A^E$, which reflects the firm's highest possible growth position. This equality can be solved for the short-run equilibrium value of the rate of capacity utilization u_A^* given in equation (13), obtaining:

$$u_A^* = \frac{P_A b_A(\gamma_0 - \gamma_1 m_A + \gamma_3 T)}{\tau_A w a_A(s_A - \gamma_1)}\,. \tag{19}$$

We assure stability for the short-run equilibrium value of capacity utilization assuming that the Keynesian stability condition holds. In formal terms, it means that the financial frontier is more responsive to changes in the capacity utilization than capital accumulation, that is, $s_A > \gamma_1$.

From expression (19), we can examine the impact of changes in market share and technological advantage on firm A's rate of capacity utilization through the following partial derivatives:

$$\frac{\partial u_A^*}{\partial m_A} = -\frac{P_A b_A \gamma_2}{\tau_A w a_A(s_A - \gamma_1)}\,, \tag{20}$$

$$\frac{\partial u_A^*}{\partial T} = \frac{P_A b_A \gamma_3}{\tau_A w a_A(s_A - \gamma_1)}\,. \tag{21}$$

Hence, a higher market share of firm A decreases its capacity utilization, following the firm's strategy, which operates lowering investment. However, a higher technological gap implies a higher capacity utilization in the short run, since firms want to incorporate the new technology, increasing investment.

From (19), (13), and (16), we obtain the short-run equilibrium rate of growth of firm A:

$$g_A^* = \frac{s_A}{s_A - \gamma_1}(\gamma_0 - \gamma_2 m_A + \gamma_3 T)\,. \tag{22}$$

Firm A's rate of growth moves in the same direction as its rate of capacity utilization when faced with changes in market share and technological advantage, as shown by

$$\frac{\partial g_A^*}{\partial m_A} = -\frac{s_A \gamma_2}{s_A - \gamma_1}\,, \tag{23}$$

$$\frac{\partial g_A^*}{\partial T} = \frac{s_A \gamma_3}{s_A - \gamma_1}\,. \tag{24}$$

In this framework, firm B would capture the residual demand of the market, the one that the leader firm A does not or cannot capture. Therefore, u^*_A will determine the equilibrium rate of capacity utilization of firm B, u^*_B, constrained by the size of the industry's maximum rate of capacity utilization, $\bar{u}$. We can formalize this mechanism by setting the sector's demand, in equation (8), in terms of capacity utilization:

$$u^*_B = \delta\bar{u} - \rho u^*_A \,, \tag{25}$$

where $\delta = \theta Y^{fc}/Y^{fc}_B$ and $\rho = \phi Y^{fc}_A/Y^{fc}_B$, and we assume both δ and ρ as constant. We also take $\bar{u}$ as constant and exogenously determined in a level that prevents the entrance of other competitors in the sector.

For firm B, the effect of an increase in the market share of firm A on u_B can be examined by the following partial derivative:

$$\frac{\partial u^*_B}{\partial m_A} = -\frac{\rho \partial u^*_A}{\partial m_A} \,, \tag{26}$$

which indicates a positive effect. This follows the way that firm A's strategy works, implying that firm B has a chance of increasing its capacity utilization when firm A adopts a less aggressive investment plan. On the other hand, a higher technological gap has an effect given by

$$\frac{\partial u^*_B}{\partial T} = -\frac{\rho \partial u^*_A}{\partial T} \,, \tag{27}$$

decreasing u_B, since a higher technological advantage increases the rate of capacity utilization of firm A, which necessarily decreases the one of firm B.

Furthermore, since firm B's profit rate depends on its rate of capacity utilization, as given by (14), and the rate of profit will determine the retained funds that allow firm B to grow, as stated in (17), the short-run equilibrium growth rate of firm B will be determined by the rates of capacity of utilization of the sector and firm A. Substituting (27) in (14) and (17) yields

$$g^*_B = \frac{s_B \tau_B w a_B}{P_B b_B}(\delta u - \rho u^*_A) \,. \tag{28}$$

Therefore, firm B expands to accompany the residual demand that it attends. In this regard, firm B's rate of growth also accompanies its rate of capacity utilization with increases in firm A's market share and technological advantage, as shown by:

$$\frac{\partial g^*_B}{\partial m_A} = -\frac{s_B \tau_B w a_B}{P_B b_B}\frac{\rho \partial u^*_A}{\partial m_A} \,, \tag{29}$$

$$\frac{\partial g^*_B}{\partial T} = -\frac{s_B \tau_B w a_B}{P_B b_B}\frac{\rho \partial u^*_A}{\partial T} \,. \tag{30}$$

However, the expansion of both firms is restrained by the growth of the demand of this industry. Each firm attends the demand growth proportional to the size of the market it holds, as shown in the equations (8), (9), and (10), which describe the sector's demand and define the market shares, respectively. Thus, the prevailing relationship between the growth of demand, the growth of firms, and their market shares is obtained by taking equation (8) in rates of change:

$$\bar{g} = m_A g_A + m_B g_B \,, \tag{31}$$

where $\bar{g}$ is the rate of growth of the sector's demand, taken as constant. As we are assuming short-run stability of the firms' rate of capacity utilization, we assure that the rates of change of the firms' product $\dot{Y}_i/Y_i$ are equal to their rates of growth of the capital stock g_i, as indicated by (31). Firms can grow at different rates, but in this case, their market shares will have to adjust in the long run to maintain the duopoly in equilibrium.

4 Long-Run Dynamics

In the described industry, it is reasonable to think that there will be mismatches between the growth rates of the firms as they enter a competitive process. In this case, in the long run, the industry will achieve the short-run equilibrium values of the variables by changes in the market shares m_A and m_B and the technological gap T. Therefore, we examine the dynamics of these variables in the long run to characterize the behavior of the system.

From the definition of firm A's market share in (9), we take rates of change obtaining the following state transition function for m_A:

$$\dot{m_A} = m_A(1 - m_A)[g_A(m_A, T) - g_B(m_A, T)]\,, \tag{32}$$

where $m_A \in (0, 1)$, expressing that the model developed here does not involve the case where one firm drives the other completely out of the market and becomes monopolist. This function reflects the already established view that firms aim at growing and they do so to keep or increase their share of the market. We see that if firm A has a higher growth rate than firm B, it obtains a larger share of the market.

Given (15), the technological gap T expressed in rates of change yields

$$\dot{T} = T(\dot{E}_A/E_A - \dot{E}_B/E_B)\,, \tag{33}$$

from which we define the dynamics of the innovative knowledge stocks in the following way:

$$\dot{E}_A/E_A = \alpha_A + \beta_A g_A - \sigma_A T\,, \tag{34}$$

$$\dot{E}_B/E_B = \alpha_B + \beta_B g_B + \sigma_B T\,, \tag{35}$$

where α_i, which designate the autonomous component of technological progress, β_i, and σ_i are positive parameters. Each growth rate has a positive impact on the respective technological change through a Verdoorn channel. Investment expands and renews the capital stock with new and more productive capital goods. In that way, it introduces innovations in the production process, while also uncovering other possibilities of innovation, according to how the knowledge inherent to the firm allows further improvements in productivity and the final quality of production, as claimed by Palley (1996, p. 124) and Possas (2008, p. 290). The level of the technological gap bears different signs for each firm conveying a common view that nonetheless affects the firms differently. Following Abramovitz (1986), a larger gap means that the leader is closer to the technological frontier, making innovations harder to be achieved. At the same time, a larger gap also gives more opportunities for the follower to catch up through imitation, slowing down the technological change of the leader while increasing the one of the follower.

We substitute (34) and (35) in (33) obtaining:

$$\dot{T} = T[\alpha + \beta_A g_A(m_A, T) - \beta_B g_B(m_A, T) - \sigma T]\,, \tag{36}$$

where $\alpha = \alpha_A - \alpha_B$, $\sigma = \sigma_A - \sigma_B$, and we take α and σ as positive parameters without loss of generality. The parameter α represents the autonomous component of relative technological change. Since the gap illustrates the relative technological positions of the firms, favoring firm A, changes in both the growth rates of firms and the level of the gap result in the same causalities for the dynamic changes in the gap as for the individual technological change, but now those causalities are taken as relative. Thus, both an increase in g_A and a decrease in g_B are related to a more rapid expansion of the gap as the investment process brings more innovations to one firm and makes the other lag behind, respectively. Besides, a decrease in the level of the gap reflects at the same time the two aforementioned mechanisms of innovation and catching up that also accelerate the expansion of the gap.

Equations (32) and (36) form a two-dimensional plane autonomous system of differential equations in which the rates of change of m_A and T depend on the levels of these variables and the parameters of the system. Solving (32) for the long-run equilibrium with $\dot{m}_A = 0$ yields a locus of points relating the firm A's market share and the technological gap:

$$T = \frac{W - (h+Z)\gamma_0 + (h+Z)\gamma_2 m_A}{(h+Z)\gamma_3}\,, \tag{37}$$

where $W = s_B \tau_B w a_B \delta \bar{u}/P_B b_B$, $h = s_A/(s_A - \gamma_1)$, and $Z = s_B \tau_B w a_B \rho u_A^*/P_B b_B$. Thus, we obtain an isocline with a positive slope, so that along the $\dot{m}_A = 0$ locus a higher market share of firm A is associated with higher levels of the technological gap.

On the other hand, solving (36) for the locus $\dot{T} = 0$ yields

$$T = \frac{-\alpha - (\beta_A h + \beta_B Z)\gamma_0 + \beta_B W + (\beta_A h + \beta_B Z)\gamma_2 m_A}{(\beta_A h + \beta_B Z)\gamma_3 - \sigma}\,, \tag{38}$$

which is an isocline either upward or downward sloping according to the values of the parameters.

The local stability of the unique non-trivial long-run equilibrium (m_A^*, T^*) in the loci $\dot{m}_A = 0$ and $\dot{T} = 0$ is examined with the Jacobian matrix of partial derivatives given by:

$$J_{11} = \frac{\partial \dot{m}_A}{\partial m_A} = m_A^*(1 - m_A^*)\left(\frac{\partial g_A^*}{\partial m_A^*} - \frac{\partial g_B^*}{\partial m_A^*}\right) < 0\,, \tag{39}$$

$$J_{12} = \frac{\partial \dot{m}_A}{\partial T} = m_A^*(1 - m_A^*)\left(\frac{\partial g_A^*}{\partial T^*} - \frac{\partial g_B^*}{\partial T^*}\right) > 0\,, \tag{40}$$

$$J_{21} = \frac{\partial \dot{T}}{\partial m_A} = T^*\left(\beta_A \frac{\partial g_A^*}{\partial m_A^*} - \beta_B \frac{\partial g_B^*}{\partial m_A^*}\right) < 0\,, \tag{41}$$

$$J_{22} = \frac{\partial \dot{T}}{\partial T} = T^*\left(\beta_A \frac{\partial g_A^*}{\partial T^*} - \beta_B \frac{\partial g_B^*}{\partial T^*} - \sigma\right) \lesseqgtr 0\,. \tag{42}$$

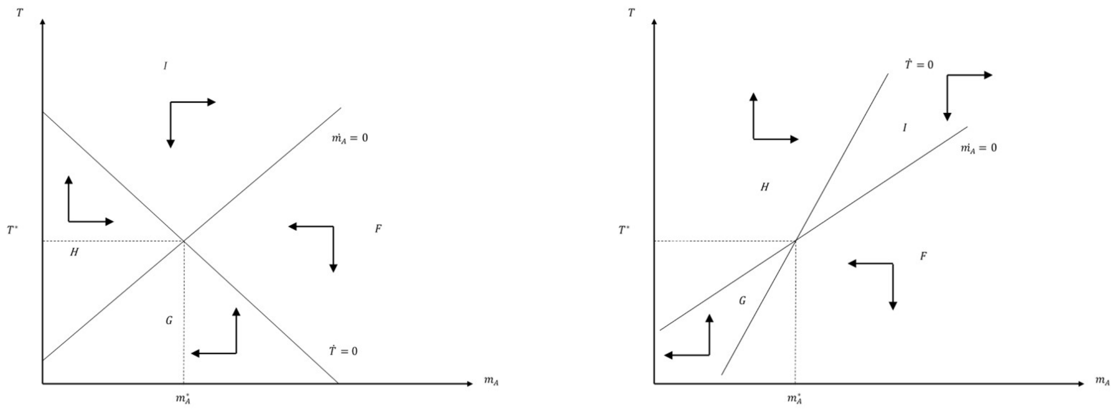
Only the last partial derivative is ambiguously signed. Equation (39) shows that an increase in the concentration of the industry with firm A, by decreasing the growth rate that this firm will pursue, will slow down the rate of increase of its market share. Equation (40), in turn, shows that the market share of firm A will raise with a higher rate when there is an increase in the technological gap since this gives firm A a competitive advantage that raises its rate of growth. This causality describes a sort of "creative destruction" competition mechanism according to which a higher technological advantage leads to a higher rate of change of concentration of the market with the leader. However, equation (41) indicates that when firm A obtains a higher market share it will invest less, thus slowing down the rate of relative technological change. This result is compatible with Geroski (1990)'s findings using different measures of market concentration and the empirical evidence that shows an inverted-U relationship between concentration and innovation, such as Blundell, Griffith, and Van Reenen (1999), Aghion et al. (2005), Tingvall and Poldahl (2006), and Negassi et al. (2019).[12] Since this market is already concentrated, it would be located at the downward part of the curve, where a higher concentration discourages innovation.

Finally, equation (42) indicates that an increase in the technological gap can either raise or reduce the rate of relative technological change depending on the values of the parameters. For instance, if the parameter σ, that measures the sensitivity of the relative technological change to the level of the technological gap, measuring the potential for imitation and catching up by the follower, is high enough the effect is negative. Therefore, a higher gap would slow down the relative rate of technological change both because of the difficulties of innovation and the large space to catch up through imitation. However, if investment is more responsive to the gap than the catching up, the effect is positive, and a higher gap indicates higher technological advantages that stimulate growth, which will increase the rate of relative technological change.

The direction of this relationship between the level of the gap and its rate of change is also important to determine the local stability properties of the equilibrium solution. Since the determinant of the Jacobian matrix, given by $Det(J) = J_{11}J_{22} - J_{12}J_{21}$, is always positive, the stability depends on the respective trace, given by $Tr(J) = J_{11} + J_{22}$. The higher the catching-up parameter σ, the smaller the value of J_{22} and, hence, the more likely it is that the system is stable.

The trace of the matrix is negative suggesting local stability both when $J_{22} < 0$ and $J_{22} > 0$ but $|J_{11}| > J_{22}$. In the first case we have a downward-sloping $\dot{T} = 0$ isocline, so that in this locus a higher market share of firm A is associated with a lower technological gap. In the second one, the $\dot{T} = 0$ isocline has a positive slope, associating higher market

[12]As Metcalfe (1998, p. 100–103) highlights, although small firms with in highly competitive markets have larger incentives to innovate since they need innovation to gain power, most of the times they lack the resources to do so. Firms with larger shares of the market, however, have little or no incentive to innovate, because they do not need to obtain any more competitive advantage. This argument is reinforced by Lima (2000), as he points out that although this empirical evidence needs to be relied on with caution, most studies suggest that an intermediate market structure, between monopoly and perfect competition, would promote higher innovative activity. With that in mind, he proposes a concentration-quadratic innovation function in his macroeconomic model dealing with technological innovation and market concentration.



(a) Panel 1 (b) Panel 2

Figure 1: Long-run dynamics: stable equilibria

shares of firm A with higher technological gaps. These two cases are depicted in the phase diagrams in Figure 1.

The stability refers to the following dynamics. If the equilibrium solution shifts to a point in the area F of Figure 1a, given that $\partial\dot{T}/\partial m_A$ is negative $\dot{T}$ undergoes a steady fall as m_A increases, because this firm has now fewer incentives to invest and innovate. However, the smaller technology gap means that firm B is catching up through imitation, which would decrease firm A's market share again, reversing its incentives to innovate. This innovation occurs in phase H, increasing again the technological gap, which increases firm A's market share. This process continues until the equilibrium m_A^* and T^* is reached again.

However, if σ is low enough, the upward-sloping $\dot{T} = 0$ isocline is flatter. Since in this case J_{22} is smaller, when $|J_{11}| < J_{22}$ the trace is positive, so that the system becomes locally unstable. Thus, the equilibrium will be unstable if the decrease in the rate of change of firm A's market share, given by a slow down of this firm's growth rate when faced with an increase in its market share, is not large enough to offset an increase in its growth rate caused by a larger technological gap. In this case, a deepening of the technological gap leads to such a great increase of the rate of growth of firm A when compared with firm B as to create a vicious circle of increases in technological advantage, firm growth and market share that asymptotically tends to concentrate the market with firm A. This happens because the catching up parameter is too small, so that firm B cannot accompany the leader and catch up, which allows the market to concentrate. The phase diagram in Figure 2 illustrates this dynamics.

Therefore, the equilibrium will be stable or not depending of the interaction between the processes of market concentration, technological change, and catching up. The equilibrium will be locally stable, maintaining the system as a duopoly, only if the follower firm has enough catching up and imitation capacity to overcome the tendencies of the market to concentrate with the leader. On the other hand, a sufficiently low catching-up capacity reduces the survival chances of firm B.

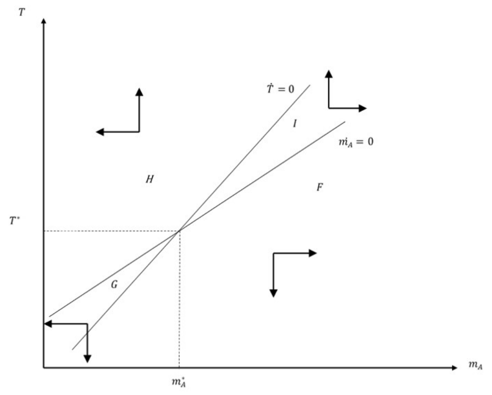


Figure 2: Long-run dynamics: unstable equilibrium

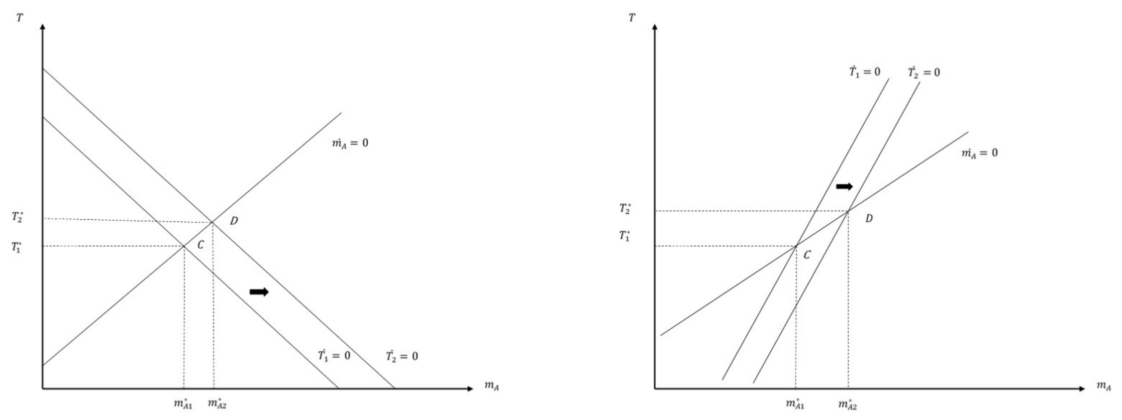
5 Comparative Statics of an Innovation Shock

Let us now analyze the effects on the system of an "innovation shock". An innovation shock is taken as an exogenous shock in the autonomous component of relative technological progress, which is the parameter α in equation (36). This exogenous innovation shock can be defined as an innovation that is independent of the firms' resources. An example is technological innovation coming from the public sector, most likely derived from university R&D. However, in this setting firm A can absorb it better than firm B, or even only firm A has the capabilities to absorb it at all.

An increase in the parameter α raises the intercept of the $\dot{T} = 0$ isocline when it is downward sloping and decreases the intercept when the isocline is upward sloping. In the unstable case, any deviation of the equilibrium makes the system diverge in a direction that depends on the parametric conditions of the system. The increase in the rate of change of the technological gap could increase the rate of growth of firm A faster than firm B can imitate and catch up, allowing firm A to continually expand its advantage in the technology race, eventually being able to cast firm B completely out of the market.

However, in both stable cases, this shock will shift the $\dot{T} = 0$ isocline along the $\dot{m}_A = 0$ isocline, as depicted in Figure 3. In both configurations, along the path to the new equilibrium, the exogenous increase in the rate of change of the gap leads to an increase in firm A's market share. This power gain decreases the rate of growth of this concentration, allowing firm B to do some catching up, although not enough to reach firm A. Therefore, firm A maintains its acquired advantage so that the new equilibrium point is marked by increases in both the technological gap and the market share of firm A.

These results agree with most of the theoretical work on innovation and competition, which suggests a dynamic of market concentration with the leading firm after a technology shock as the typical one in a capitalist economy. Despite that, it is interesting to notice how even different configurations of the system provide the same competition dynamics following a technology shock. In either case, if firm B could seize this catching-up opportunity and imitate fast enough, it could reduce its market share distance from firm A and its



(a) Panel 1

(b) Panel 2

Figure 3: Effects of an innovation shock

technological backwardness.

This long-run result is reflected in how the firms' growth rates are subject to innovation-related changes. The exact effect of the innovation shock on the growth of the firms is given by how changes in the technology gap and the market shares affect these rates. Formally, the total magnitudes of these changes are given by the following total derivatives:

$$\Delta g_A = \frac{\partial g_A}{\partial T}\Delta T + \frac{\partial g_A}{\partial m_A}\Delta m_A\,, \tag{43}$$

$$\Delta g_B = \frac{\partial g_B}{\partial T}\Delta T + \frac{\partial g_B}{\partial m_A}\Delta m_A\,, \tag{44}$$

so that the net change of this result depends on the parametric conditions of this industry and the magnitude of the changes in the technological gap and the market share of firm A. Therefore, the exact effect of innovation on growth depends on these conditions and it is related to which of the two possible described dynamics prevail.

After an exogenous innovation shock, there will be a disequilibrium between the growth rates of both firms, with different possible consequences. In the unstable case, firm A could keep growing more than firm B, asymptotically dominating the market. In this scenario, this extreme concentration could lead to stagnation. When firm A dominates the market by maintaining $g_A > g_B$, if it keeps growing at one point we will have $g_A > \bar{g}$, where $\bar{g}$ represents the rate of growth of the demand as specified in equation (8). This implies a different dynamics for firm A than the one described in this model. This firm will need to change its strategy towards innovation since the demand constraint will prevent it to increase its growth rate further. Therefore, in this case, demand could restrict growth possibly leading to stagnation, unless innovation becomes related to purposes other than competitive gains.

However, in the stable case, the long-run stability of the system of differential equations (32) and (36) requires that variations in g_A and g_B be compensated by adjustments in m_A and T to keep $\dot{m}_A = 0$. Thus, eventually, the growth rates equalize again. In this case, after the shock the growth rate of firm A increases. If demand continues to grow at a constant rate, the greater growth rate of firm A necessarily implies firm B growing at a smaller rate. But since the system tends to equilibrium, it eventually shifts to a new combination of m_A and T that equalizes both growth rates. To reach this new point, the growth rate of firm A decreases, while the rate of growth of firm B increases as the latter catches up. The speed of the catching-up process of firm B will limit how much more market share firm A will obtain while it maintains a higher growth rate.

Therefore, the process of market concentration that can come along with technological change can be counteracted by a higher imitative capacity of the follower, given that the effects of innovation on concentration are not so great as to offset these attempts. If the heterogeneity and specific capabilities of firm B allow it to copy the new technologies fast enough, fewer competitive gains would come from innovation for firm A. In the scope of our model, parameter σ in equation (36) indicates the amount by which the rate of technological change decreases with an increase in the level of the gap. A higher absolute value of σ would mean a greater decrease in the rate of technological change, thus giving firm B a greater opportunity to pursue imitation. Imitation is what then makes the system go back to an equilibrium, as depicted in Figure 3.

In sum, the two situations show how the processes of innovation, imitation, and market concentration are closely related, being their interplay responsible to make the system unstable or stable. This pattern agrees with some predictions of the neo-Schumpeterian approach. For instance, Iwai (1984a)' evolutionary model is focused on analyzing the interactions between the disequilibrating effects of innovation and the equilibrating effects of imitation and how these interactions determine the pattern of evolution of an industry. Meanwhile, Iwai (1984b) also proposes how firms grow comparatively faster with innovative and imitative success. In the simulation model of Nelson and Winter (1982), weaker appropriability derived from the rival's higher ability to imitate the other's advances can also attenuate market concentration. We observe the same patterns with our much simpler model.

Innovation implies disequilibrating forces, following Schumpeter (1934)'s concept of creative destruction. The firm that implements innovation increases its market power and obtains monopoly profits, changing the landscape of the market. Imitation, in turn, is equilibrating since it mitigates the previous increase in market power, lowering the technological gap, which brings the system back to a stable path. Thus, the success of the follower firm in imitation, not the success of the leading firm to pursue advantages, is crucial for the industry to settle down to a static equilibrium. Nonetheless, as Lima (1996) highlights, as innovations are constantly being introduced, consequently upsetting the equilibrium tendency, the system could be permanently being put in a state of disequilibrium.

However, the effects of innovation and imitation are relative since their outcome still depends on how the concentration of the industry is evolving. As we have seen in the unstable case of our industry, the instability caused by innovation could prevail if imitation is not strong enough to offset the effects of technological advantage on market concentration. If the effects of technological change in market concentration are high, and the effects of concentration is slowing down the rate of change of concentration with the leading firm are low, it would be more difficult for imitation to succeed. Hence, the interaction between the processes of growth, concentration, innovation, and imitation, not each process individually, is responsible for either maintaining the relative configuration of the sector or making it change rapidly.

6 Concluding Remarks

This paper develops a duopoly model based on the post-Keynesian theory of the firm that incorporates the neo-Schumpeterian double-sided relationship between market concentration and technological change. Firms are taken as technologically heterogeneous in the competitive scenario and their growth is restrained by the growth of demand. This specification implies a leader-follower relationship between the firms, with the follower capturing the residual demand of the market. Concentration and relative technological advantage determine the growth of the firms negatively and positively, respectively. In the short-run equilibrium, firms will produce and invest according to demand through adjustments in the rate of capacity utilization, which also responds to changes in market share and technological advantage in the same direction as their investment rates.

Market share and technological change have an explicit and two-way relationship in the long-run dynamics of this industry. The paper's investigation of the two-dimensional system featuring market share and the technological gap conveys that in the long-run equilibrium a higher market share slows down technological change, whereas a higher relative technological advantage leads to a faster concentration of the industry with the leading firm. The stability properties of the system depend on the direction and relative strength of the innovation effects compared to the effects of imitation and catching up, as well as on the rate of concentration of the market. In sum, the system is more stable, the higher the imitative capacity of the follower firm.

The interplay between innovation, imitation, and market structure is seen in the comparative statics exercise, which results in two different scenarios for the industry following an exogenous innovation shock. The sudden technological advantage for the leader could asymptotically concentrate the market with the leading firm when imitation is relatively so weak as to allow the leader to keep innovating and growing. However, the market could also remain a duopoly, although a more concentrated one with a larger technological advantage with the leading firm. If the follower firm can do some catch up to accompany the greater advantage of the leader, it can prevent a higher increase in concentration. Therefore, according to this model, the concentration implied by technological change can be partially counteracted if the follower firm has high imitative and catching-up capacities, so that developing these capacities can be a strategy for such firms to survive.

However, these conclusions apply only to this industry and cannot be extrapolated to the macroeconomic scenery with this formulation. Yet, as we are implicitly arguing that post-Keynesian macroeconomic models should be grounded in sound microeconomic theory, this model can serve as a basis for more complex micro models and more comprehensive macro models that incorporate changes in the micro competitive structure. On the one hand, further works could rely on flexibilizations and extensions of this simple model into the micro setting. Other aspects of firms' decision to innovate can be incorporated and firms' strategies can be taken as interactively determined, as altered by changes in the competitive landscape of the market. On the other hand, the relationship between technological change and market concentration outlined in this model can also be extended to analyze how this dynamics affects certain macroeconomic variables, such as income distribution.

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