

Aggregate growth models from a Schumpeterian perspective: a review

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ABSTRACT

The paper presents a critical assessment of the Schumpeterian macroeconomic approach to economic growth. Taking as reference a representative sample of important works within this tradition, the paper identifies the main contributions and limitations of the macroeconomic Schumpeterian literature to understanding economic growth. More specifically, the literature review carried out in this paper focuses on three of Schumpeter's ideas that have become particularly influential in macroeconomic growth theory: (i) the role of technological transfer in productivity growth in follower countries; (ii) the importance of research intensity for technical progress; and (iii) the prominence of technological competitiveness for trade performance. The contribution of the paper is twofold: (i) it provides an organized review of the macroeconomic literature until its present state; and (ii) it indicates important gaps in this literature that should be the focus of further research.

KEYWORDS | Technical progress; Economic growth; Technological transfer; International trade; Technological competitiveness

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1. Introduction

The Austrian economist Joseph Schumpeter is known for his seminal works on the importance of innovation for economic growth. His contributions range from the classification of different types of innovation to the analysis of the determinants of innovation, the importance of finance for technical progress, the role of technological competitiveness in trade performance, and the role of imitation and technological transfer in economic growth (see FAGERBERG, 2005).

Schumpeter's (1934, 2003 [1943]) works have inspired research from different perspectives. On the one hand, Nelson and Winter (1982), Dosi (1982), Metcalfe (2005) and others have explored Schumpeter's ideas using an evolutionary framework. This approach, which seeks to follow more closely the ideas of Schumpeter, highlights the importance of disequilibria generated by innovations to foster the process of economic development. Studies from this tradition have used agent-based models (ABM) to analyse the process of economic development, in which heterogeneous actors with bounded rationality interact to form economic systems. On the other hand, Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992, 1998, 2009), Acemoglu, Aghion and Zilibotti (2006) and others have explored Schumpeter's ideas using growth models with endogenous technical progress. In this approach, some of Schumpeter's key insights were incorporated into the neoclassical framework to cope with the clear limitations of the basic Solow (1956) growth model and try to get to a more specific answer to the factors that determine long term growth and technical progress.

In spite of the sharp differences in the microeconomic foundations between the different Schumpeterian traditions, the aggregate macroeconomic application of Schumpeter's insights is considerably similar among them (see VERSPAGEN, 2005). The present paper focuses on these aggregate models and empirical works that seek to represent some of Schumpeter's key insights. In terms of the macroeconomic analysis of the determinants of innovation and growth, authors from both streams emphasise the importance of technological transfer (e.g. GRIFFITH; REDDING; VAN REENEN, 2004; VERSPAGEN, 1991), finance (e.g. LEVINE; LOAYZA; BACK, 2000; FAGERBERG; SRHOLEC, 2008), research and development (R&D) (e.g. MADSEN, 2008A; COHEN; LEVINTHAL, 1990; FAGERBERG; SRHOLEC; KNELL, 2007; ARCHIBUGI; COCO, 2005), technological competitiveness (e.g. FAGERBERG, 1988; ANG; MADSEN; ROBERTSON, 2015), and institutions

(e.g. ACEMOLGU; AGHION; ZILIBOTTI, 2006; AGHION; HOWITT, 2009; LUNDVAL, 1992; NELSON, 1993; METCALFE; RAMLOGAN, 2008).

The objective of this paper is to present a critical assessment of the Schumpeterian macroeconomic approach to economic growth. Taking as reference a representative sample of important works within this tradition, this paper aims to identify the main contributions and limitations of the Schumpeterian literature to understanding economic growth. More specifically, the literature review carried out in this paper focuses on three of Schumpeter's (1934; 2003 [1943]) ideas that have become particularly influential in macroeconomic growth theory: (i) the role of technological transfer in productivity growth in follower countries; (ii) the importance of research intensity for technical progress in leading economies; and (iii) the prominence of technological competitiveness for trade performance.

The main contribution of this paper, therefore, is to identify the gaps in the existing macroeconomic Schumpeterian analyses of economic growth, through a thorough revision of the relevant literature. Thus, this paper contributes to facilitate and guide future works that aim to develop and improve the aggregate Schumpeterian approach to long-term growth. It is important to highlight, however, that the Schumpeterian literature is vast and diverse. Hence, this paper does not seek to provide an exhaustive review, but aims to use some important studies as reference to point out some relevant gaps in the literature. An additional contribution of the paper is to highlight the similarities of the aggregate Schumpeterian approaches in different research areas, despite the marked differences in the micro-foundation across different Schumpeterian traditions.

The remainder of the paper is divided in four sections. Section 2 discusses the importance of research intensity for technological progress within the Schumpeterian tradition. Section 3 discusses the foundations of the Schumpeterian approach to technological transfer. Section 4 analyses the role of technological competitiveness in trade performance from a Schumpeterian standpoint. Section 5 presents the paper's concluding remarks.

2. Research intensity and long-term growth

According to Schumpeter (2003 [1943]), product differentiation (i.e. innovation) gives rise to temporary monopolies, which guarantee abnormal profits to innovators. This creates an incentive for firms to invest in research and development (R&D) in pursuit of innovations. This seminal idea represents the foundation of Schumpeterian

models of economic growth (VALDÉS, 1999). Evidently, other contributions from Schumpeter's (1934; 2003 [1943]) works were also explored in the literature that investigates the determinants of economic growth (e.g. AGHION; HOWITT, 1992; KING; LEVINE, 1993). Still, the importance of R&D, innovation and temporary monopolies (i.e. partial-excludability of innovations – ROMER, 1990) for technical progress and economic growth are the main ideas that characterize Schumpeterian macroeconomic growth models.

In contrast with the seminal endogenous growth models developed by Arrow (1962) and Frankel (1962), where technological progress is an unintentional spillover of capital accumulation, in the Schumpeterian growth model, technology is intentionally accumulated.

The Schumpeterian growth model divides the economy into two sectors, a final output sector and a research sector. The research sector uses a fraction of the labour force (L_A) and the existing stock of technical knowledge to produce new technology, while the final goods sector uses the other fraction of the labour force ($L_Q = L - L_A$) and capital to produce final output. Thus, the model can be described using a production function and a technology progress function, respectively:²

$$Y = AK^\alpha L_Q^{1-\alpha} \quad (1)$$

$$g_A = \delta \left(\frac{L_A}{L} \right)^\sigma A^{\phi-1} \quad (2)$$

where Y is the level of output, K is the capital stock, $L = L_Q + L_A$ is labour, A is the level of technology, α is the share of capital in output, $g_A \stackrel{\text{def}}{=} \dot{A}/A$ is the rate of technical progress, ϕ is the degree of returns to scale in knowledge, β is a coefficient of product proliferation, σ is the coefficient of research duplication, and δ reflects research efficiency.³

The defining characteristics of the Schumpeterian growth model are expressed in the parameters of the technology progress function given by equation (2). First, the coefficient of product proliferation is assumed to be equal to one, i.e. $\beta = 1$. Following Young (1998), this means that in a larger economy the number of firms that can create similar products is also larger, which results in more horizontal

2 The term technology progress function used here should not be confused with Kaldor's (1957) technical progress function, which is expressed in a different form and is used to avoid separating movements along the production function from movements of the production function

3 See Ha and Howitt (2007).

innovations. Thus, the idea is that the growth-enhancing effect of larger R&D is offset by the deleterious effect of product proliferation.⁴ This is the key assumption of the Schumpeterian growth model, which indicates that it is research intensity that leads to higher technical progress and productivity growth, and not the total amount of inputs devoted to research. Second, the degree of returns to knowledge accumulation is assumed to be equal to one, i.e. $\varphi = 1$. Following Romer (1990), this means that knowledge accumulation faces constant marginal returns. Third, the coefficient of research duplication is assumed to be one as well, i.e. $\sigma = 1$. Consequently, combining these assumptions leads to the following Schumpeterian technical progress function: $g_A = \delta \left(\frac{L_A}{L} \right)$.

Nonetheless, the interesting aspect of the technical progress function expressed in equation (2) is that it incorporates the ideas of previous growth models. In the neoclassical growth model developed by Solow (1956) and Swan (1956), as growth is exogenous, research intensity has no impact on technical progress (i.e. $\sigma = 0$), while it still assumes constant marginal returns to knowledge accumulation (i.e. $\varphi = 1$), which makes technical progress positive and constant ($g_A = \delta$). Schumpeterian growth models of first generation (e.g. ROMER, 1990; GROSSMAN; HELPMAN, 1991; AGHION; HOWITT, 1992), in turn, assumed that knowledge faces constant marginal returns (i.e. $\varphi = 1$) and that there is no research duplication (i.e. $\sigma = 1$), while assuming that there is no product proliferation (i.e. $\beta = 0$). In this model, therefore, the decreasing marginal productivity observed in the accumulation of each input is offset by the introduction of new inputs. Thus, the greater the division of labour is, the greater the levels of output and productivity are. Hence, determining the growth of technical knowledge (A) becomes crucial to determine the economy's growth rate (ROMER, 1990, p. S84). This leads to the prediction of ever increasing output per capita, as long as the resources devoted to R&D are positive (i.e. $g_A = \delta L_A$).⁵ Finally, the semi-endogenous growth models (e.g. JONES, 1995) assume that even without research duplication (i.e. $\sigma = 1$) and product

4 In Young's (1998, p. 45) words: "increases in the market size, in the profitability of inventing a solution to a problem, might call forth a greater variety of potential solutions to that problem, raising the average level of consumer utility. If, however, the continued improvement of this increased variety of technologies requires additional research input, the equilibrium level of R&D expenditure might rise, without necessarily being associated with an increase in the rate of product quality improvement, that is, growth".

5 According to Romer, although human capital, or labour (JONES, 1995), is bounded by the amount of time a person can invest in learning, the stock of technical knowledge is unbounded, since it is accumulated and passed on from one generation to the other. The cumulative circuit of growth in the model, therefore, works as follows. As technical knowledge grows, it facilitates the creation of knowledge, perpetuating growth. Consequently, the growth of the stock of technical knowledge is responsible for the scale effects observed in the model. Several other endogenous models are based on assumptions similar to Romer's.

duplication (i.e. $\beta = 0$), returns to knowledge accumulation are decreasing (i.e. $\varphi < 1$) due to increased difficulty in innovating. This leads to the pessimistic prediction that technical progress and output growth will eventually cease (i.e. $g_A = \delta L_A / A^{1-\phi}$).

The Schumpeterian growth model implicitly assumes that the stock of technical knowledge in the economy is equally available to all firms. Hence, in this model, technical knowledge is considered a public good within the domestic economy and there are perfect and evenly distributed knowledge spillovers. More precisely, following Romer's (1990) seminal paper, the model assumes that while technical knowledge for research is a public good, knowledge for the production of differentiated inputs is non-rivalrous but excludable due to patent property rights. This assumption creates an incentive to innovate at firm level while the entrance of new firms in the market ensures that there are no abnormal profits (see MCCOMBIE, 2002, p. 86). The assumption of perfect and evenly distributed knowledge spillovers prevents one firm from dominating the market, but it is a clear limitation of the model. In fact, differences in knowledge absorptive capacity might be actually the source of important differences in firm performance.

The impact of research intensity on technical progress was tested in a variety of forms.⁶ In some works, output growth is used as the dependent variable, assuming that research intensity explains technical progress, which impacts on output growth (e.g. FAGERBERG, 1987; JAFFE, 1988; FAGERBERG; VERSPAGEN, 2002). In other works, total factor productivity (TFP) growth is used as the dependent variable, in a direct test of the impact of research intensity on productivity growth, assuming this impact works via innovation (e.g. HA; HOWITT, 2007; MADSEN, 2008a; CHANG *et al.*, 2013). Finally, other works use a two-step estimation to test the impact of research intensity on TFP growth, and of TFP growth on output growth (e.g. ZACHARIADES, 2004).⁷ In spite of these differences, the vast majority of works find that research intensity exerts a positive impact on output and productivity growth.⁸ Furthermore, some works have also found that institutions impact on patenting, which suggests that indeed research intensity indirectly captures, at least partially, the importance of institutional arrangements for technological progress (e.g. WAGUESPACK; BIRNIR; SCHROEDER, 2005; VARSAKELIS, 2006; ALLARD; MARTINEZ; WILLIAMS, 2012).

6 Research intensity is generally measured by patents per worker or by the ratio of R&D to output (see GRILICHES, 1990).

7 O'Mahony and Vecchi (2009) used a similar strategy but employing R&D stocks instead of research intensity in their tests.

8 See Ha and Howitt (2007) and Madsen (2008a) for discussion and evidence in favour of the Schumpeterian growth model in comparison with the neoclassical growth model developed by Solow (1956) and Swan (1956), and with the semi-endogenous growth model developed by Jones (1995).

Nonetheless, there are factors that influence innovation that are not captured by the degree of research intensity (e.g. the levels of accumulated knowledge and of knowledge spillovers). In an attempt to address this limitation, Chang *et al.* (2013) adopted the strategy used in the empirical literature on technological transfer. The authors used an interaction term between an index of patent protection and research intensity to assess the effect of property rights on TFP growth, and found that the higher patent protection is, the higher is the constraint on knowledge spillovers, and the lower is the effect of research intensity on TFP growth.

In a macroeconomic approach, research intensity captures the aggregate effort devoted to generate technological progress. Differences in research intensity between economies can result from differences in the efficiency of industrial policies to foster the increase of high-tech industries, entrepreneurial capacity, government regulation, access to finance, access to inputs, average firm size, market size, education systems, amongst other factors. Consequently, the better the macroeconomic incentives for firms to invest in R&D are, the higher is the innovation/absorption effort in the economy.

The degree of research intensity, therefore, depends on the institutional arrangement set up in each economy. Indeed, R&D is not only carried out inside firms, but also in research institutes, universities, and technological parks. Thus, the aggregate investment in R&D is normally higher than the sum of firms' individual expenses in research. Moreover, some industries tend to invest more (on average) in R&D than others. Hence, the emphasis on the importance of research intensity for technological progress and productivity growth indirectly takes into account, at least partially, the importance of institutions and the structural composition of each economy for technological progress.

In a broader approach to the determinants of technical progress, however, research intensity is considered necessary but not sufficient (e.g. FREEMAN, 1995). Following Gerschenkron's (1962) seminal work, the generation and effective use of technology is assumed to depend on the institutional set up of each economy, which determines to what degree the capabilities required to generate technical progress are available (e.g. ABRAMOVITZ, 1986; LALL, 1992; LUNDVALL; JOHNSON, 1994). These institutional arrangements are often called National Innovation Systems (NISs) (e.g. LUNDVALL, 1992; NELSON, 1993; ALBUQUERQUE, 1999; LEE; VON TUNZELMANN, 2005). Still, using North's (1990) terminology, the NISs literature tends to put more emphasis on the importance of certain government policies (e.g. industrial policies – NELSON; PACK, 1999) and certain organizations

(e.g. research institutes and universities – NELSON, 2008) than on the importance of institutions (e.g. property rights – METCALFE, 2005). Furthermore, as Verspagen (2005) highlights, an important limitation of this approach is its difficulty in producing clear policy recommendations.

Empirical studies associated with the evolutionary stream of the Schumpeterian literature normally use composite indexes to measure the degree of development of NISs or of technological capabilities. Archibugi and Coco (2005) have surveyed, summarized, and compared different indexes of technological capabilities used in the works of this tradition. The authors emphasise that, in spite of the different compositions of the indicators, most of them are highly correlated with each other and take into account similar variables, such as patents per worker, R&D to output ratio, education, telephone lines, internet, scientific papers and medium and high-tech exports. Not surprisingly, the studies that adopt this strategy find similar results, which suggest the importance of technological capabilities and NISs for economic growth (e.g. FAGERBERG, SRHOLEC; KNELL, 2007). Fagerberg and Srholec (2008), for example, have calculated four principal components that they associate with NISs, governance institutions, political institutions, and openness. They found that governance institutions and the levels of development of NISs are positively and significantly associated with income growth, while political institutions and openness are only significant when poorer countries are excluded from the sample.

Despite the increasing number of works that highlight the importance of building strong innovation systems to increase research intensity, innovation and productivity growth, there is still little explanation about the specific institutions that constitute a mature National Innovation System (e.g. NELSON, 2008). As Sharif (2006) points out, some authors in this tradition argue that it is not possible to identify the specific institutional structure of a mature innovation system, because these institutional arrangements vary between countries and through time. Some other authors, however, argue that it is indeed important to try to get to a general proposition of the components of a mature innovation system. In spite of this debate, however, the explanations for the determinants of research intensity have not yet been fully explored.

Furthermore, there is also relatively little work on the different impacts of research intensity and other variables on technical progress across sectors. Most of the empirical works have analysed the determinants of productivity at the aggregate level, but it is very likely that different sectors present different responses to different variables such as property rights, education, research intensity, demand, etc.

3. Technological catch-up

The transposition of Schumpeter's (1934) microeconomic ideas on innovation and imitation to a macroeconomic setting led to the development of the technological catch-up hypothesis (POSNER, 1961). This approach involves two propositions. First, it postulates that countries in the technological frontier rely more heavily on innovation than on imitation to generate productivity growth, while the opposite applies to countries behind the technological frontier. Second, it postulates that follower economies can benefit from their backwardness and achieve higher growth rates than leading economies through imitation, given that absorbing (imitating) foreign technology is easier (cheaper) than innovating. According to this approach, therefore, the existence of productivity gaps between countries opens up the opportunity for technological transfer from frontier to follower countries, which increases the growth rates of productivity and output of the latter.

3.1 Simple technological catch-up model

The technological catch-up model can be interpreted as a complement to the Schumpeterian growth model, which emphasises the importance of research intensity for productivity growth. While the latter investigates the determinants of innovation, the former investigates the determinants of the absorption of foreign technology. In the simplest version of the technological catch-up hypothesis, the existence of a technology gap is assumed to exert a positive effect on the rate of growth of productivity of follower economies, creating the potential for catch-up in productivity levels.

The technological catch-up hypothesis was formalised by Nelson and Phelps (1966) using a technical progress function that takes into account the impact of the technology gap on productivity growth:

$$g_A \stackrel{\text{def}}{=} \frac{\dot{A}}{A} = \Phi\left[\frac{T-A}{A}\right] \rho \quad (3)$$

where T is the level of best practice technology, often interpreted as the technology level of the leading economy, Φ is a function representing the absorptive capacity of the following country, and A is the follower country's level of technology.⁹

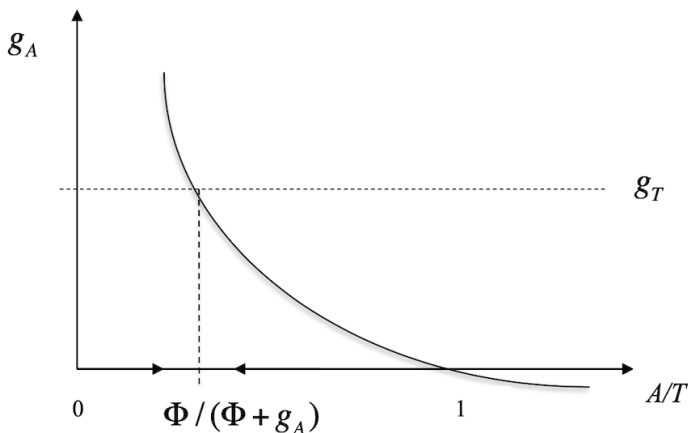
9 As Rogers (2003, p. 49-50) argues, technological catch-up can be represented by other functional forms, generating similar implications (e.g. $\frac{\dot{A}}{A} = \Phi(\ln(T/A))$).

This is a model of technological transfer that does not take into account the possibility of technology creation (or innovation) in the follower country. Thus, the growth rate of best practice technology in the leading economy (g_T) is assumed to be exogenous (i.e. $T_t = T_0 e^{g_T t}$). In the long run, therefore, the growth rate of technology in the follower economy must equal the growth rate of technology in the leading country, i.e. $g_T = g_A$. Hence, rearranging the terms of equation (3) gives the equilibrium rate of technical progress in the follower country:

$$\frac{A}{T} = \Phi / (\Phi - g_A) \quad (4)$$

This equilibrium growth rate is depicted in Figure 1. Following equation (3), countries with a distance to the frontier (A/T) lower than the equilibrium level will experience higher growth rates than the leading economy. The opposite holds for countries with a distance to the frontier above the equilibrium rate. It is important to note, however, that in equilibrium the level of technology in the following economy (A) is below the level of technology in the leading economy (T). This is necessary because in this model technological growth in the follower economy only takes place through technological transfer, i.e. when there is a gap. The equilibrium, however, is determined by the magnitudes of the absorptive capacity (Φ) and of the growth rate of technology in the frontier country (g_T).

FIGURE 1
Simple technological catch-up model



Source: Author's elaboration based on Rogers (2003, p. 49).

The implications of this model are straightforward. First, if $A=T$, there is no catch-up process, given that there is no technology gap between the two countries, so that equation (3) becomes zero. Second, when the absorptive capacity (Φ) tends to infinity (i.e. with perfect knowledge transmission), equation (4) shows that the levels of technology will be the same in both countries and the gap will be equal to one. Hence, in this case, the model becomes equal to the basic neoclassical model developed by Solow (1956) and Swan (1956), which assumes that technology is a public good. Thus, the introduction of this parameter in the model is crucial to describe the difficulties associated with technological catch-up. Third, the smaller the absorptive capacity is, the larger is the gap at equilibrium. This means that when absorptive capacity is very low, differences in technology must be extremely large to generate equal growth rates of technology in both leading and following economies. Fourth, if A tends to zero, the gap (i.e. $(T-A)/A$) tends to infinity and the backward country's growth rate will be higher than the leading country's growth rate, as long as $\Phi > 0$. Still, through time, the gap will reduce, returning the growth rate of technology to its equilibrium. In spite of the simplicity of this model, this brief discussion shows how it represents fairly well a number of important ideas from Schumpeterian theory.¹⁰

The simple relationship between technological absorption and output and productivity growth emphasised in the technological catch-up literature has been tested in a number of works. In cross-country analyses, the level of productivity in the beginning of the period under investigation is used as a proxy for the technology gap or for distance to the technological frontier (e.g. SINGER AND REYNOLDS, 1975; FAGERBERG, 1987). In cross-country panels, in turn, the technology gap is often measured as the ratio of productivity in the country to the productivity of the frontier country (e.g. AMABLE, 1993; FAGERBERG; VERSPAGEN, 2002; GRIFFITH; REDDING; VAN REENEN, 2004). In both types of studies, the vast majority of works find a negative relationship between productivity growth and the magnitude of the gap, which suggests a connection between growth and technological transfer.

Finally, it is important to note that technological catch-up is compatible with conditional convergence (e.g. BAUMOL, 1986; BARRO, 1991; BARRO;

10 The model's production function framework was later criticised by Nelson and Winter (1982) as well as other authors associated with the evolutionary stream of the Schumpeterian literature (e.g. Nelson; Pack, 1999; Verspagen, 2005). Nonetheless, since the core ideas of the model are associated with equation (2), and not with the model's initial production function, it is straightforward to observe that the macroeconomic ideas presented in the model are compatible with the capabilities and NISs approaches used in the evolutionary Schumpeterian tradition.

SALA-I-MARTIN, 1991; MANKIW; ROMER; WEIL, 1992). In neoclassical growth models conditional convergence results from transitional dynamics, while technology is assumed to be the same across countries. Still, since the assumption of technology homogeneity cannot be tested, the evidence of conditional convergence based on neoclassical growth models cannot dismiss the Schumpeterian hypothesis of convergence via technological catch-up, or vice-versa (see AGHION; HOWITT, 2009, chap. 7).

3.2 Extended technological catch-up model

A simple way of testing the importance of different factors for technological catch-up is to use interaction terms between additional variables and the technology gap. Formally, this simply means making the technological catch-up parameter endogenous:

$$\Phi = \Omega S \quad (5)$$

where S is the (unspecified) determinant of learning capacity and Ω is a parameter.¹¹

Thus, substituting equation (5) into (3) yields:

$$g_A = \Omega SG \quad (6)$$

where $G=(T - A)/A$.

Using this strategy, a number of works have investigated the factors that increase technological absorption. Griffith, Redding and Van Reenen (2004) found that countries with higher research intensity indeed manage to better exploit the technology gap, as suggested by Cohen and Levinthal (1990). Acemoglu, Aghion and Zilibotti (2006) found evidence that high regulation increases technological absorption when countries are far from the frontier, but it slows down technological progress as countries approach the frontier. Vanderbusch, Aghion and Meghir (2006), testing Nelson and Phelps' (1966) original insight, found that skilled human capital has a stronger effect on growth in countries that are closer to the technological frontier.¹² In addition, it is also interesting to note that other works have also found evidence

11 Rogers (2003, p. 61) argues that higher absorptive capacity reduces the costs of imitation. Nonetheless, it is possible to argue that the acquisition of higher absorptive capacity requires higher costs.

12 As Nelson and Phelps (1966: 75) stressed, if Φ is determined by education, this variable becomes a crucial factor determining the speed of growth of productivity (A), while expanded Solow models (e.g. MANKIW; ROMER; WEIL, 1992) become "a gross misspecification of the relation between education and the dynamics of production".

of international R&D spillovers (e.g. DEL BARRIO-CASTRO; LÓPEZ-BAZO; SERRANO-DOMINGO, 2002; GRIFFITH; HARRISON; VAN REENEN, 2006).

3.3 Non-linear technological catch-up model

In spite of the relatively wide explanatory capacity of the simple technological catch-up model, as a number of authors have stressed, in a more elaborated framework, technological catch-up depends on the institutional factors that create the required capacity for absorbing foreign technology (e.g. GERSCHENKRON, 1962; ABRAMOVITZ 1986; COHEN; LEVINTHAL, 1990; VERSPAGEN, 1991; LUNDVAL, 1992; NELSON, 1993; GRIFFITH; REDDING; VAN REENEN, 2004; ACEMOGLU; AGHION; ZILIBOTTI, 2006). Although these factors implicitly determine the value of the technological catch-up parameter (Φ), a number of studies have sought to explicitly formalise and test this hypothesis.

Empirical evidence suggests that extremely poor countries might not be able to catch-up (i.e. might not grow at faster rates than developed countries), in spite of the existence of a large technology gap. To formalise the possibility of falling behind, Verspagen (1991) proposed a non-linear function of technological catch-up:

$$g_A = aGe^{-G/\vartheta} \quad (7)$$

where $0 < aG \leq 1$ represents the potential catch-up rate, which is proportional to the size of the technology gap (G) and to the absorptive capacity $\Phi = e^{-G/\vartheta}$.

In this formulation, absorptive capacity is a function of the gap and the intrinsic learning capacity $\vartheta > 0$. The possibility of falling behind, therefore, is introduced in this model by including the gap in the absorptive capacity function. In other words, countries with high intrinsic learning capacity facing a relatively small technology gap (i.e. $G < \vartheta$) will catch-up, while countries with low learning capacity facing a large gap (i.e. $G > \vartheta$) will fall behind. Hence, equation (7) implies that technological transfer (or imitation) becomes zero when the technology gap is closed and when the gap is too wide (VERSPAGEN, 1991, p. 363).¹³

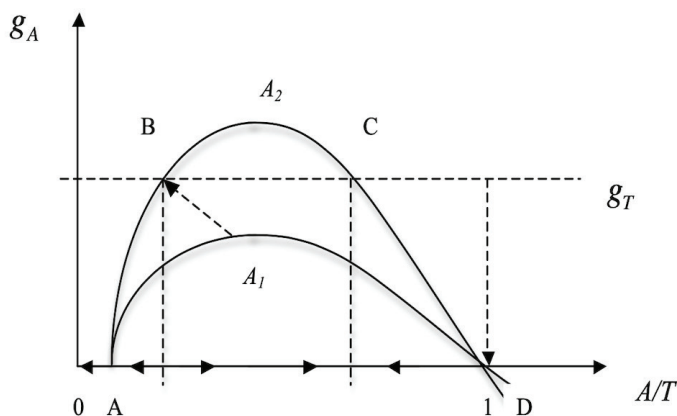
Figure 2 summarizes the alternative development trajectories (i.e. catching-up and falling behind), in Verspagen's model. In this figure, along the curve A_1 , technological catch-up will converge to zero, since the gap is too large and learning capacity is too low (i.e. $G > \vartheta$). Thus, the shift from A_1 to A_2 represents what

¹³ Verspagen's non-linear model can also be represented in a quadratic formulation: $\frac{\dot{A}}{A} = \Phi(G - cG^2)$ (ROGERS, 2003, p. 50).

Verspagen (1991) called the “pre catch-up phase”, which is associated with the necessary increase in the intrinsic learning capacity (ϑ).

Note, however, that between points A and B the technology gap will still converge to zero. The passage from point B to point C on the curve A_2 indicates the actual catch-up phase, when the follower country absorbs technology from the leading country (i.e. when $G < \vartheta$). The difference in technology creation in each country, in turn, is given by the line g . Hence, the passage from point C to point D indicates the last development phase, when this difference decreases and the line g shifts downwards until there is no technology gap (i.e. $A/T=1$).

FIGURE 2
Non-linear technological catch-up model



Source: Author's elaboration based on Verspagen (1991, p. 364) and Rogers (2003, p. 51).

The most important feature of this model, therefore, is its capacity to explain both catching-up and falling behind. On the one hand, the model indicates that the existence of a technology gap might benefit follower countries if they are capable of absorbing foreign technology. On the other hand, the model also warns that if this gap is too large and learning capacity is too low, then the country might face difficulties in exploring the gap. Nelson and Phelps' (1966) simple catch-up model, therefore, can be interpreted as a particular case within Verspagen's model. Thus, Figure 1 is captured in Figure 2 as the equilibrium gap given by point C.

In addition, another important feature of this model is the association between growth paths and country's effort to increase learning capacity. Although in the model it is not explicit what “intrinsic learning capability” represents, in his tests,

Verspagen (1991, p. 369) adopts a new formulation of equation (7), where intrinsic learning capacity is determined by the country's learning effort:

$$g_A = aGe^{-\rho\left(\frac{G}{S}\right)} \quad (8)$$

where S is the effort and ρ is a parameter.

In Verspagen's (1991) empirical investigation, he adopted measures of education and infrastructure as proxies for learning effort. The results he found using this specification were consistent with the theory. However, Amable (1993) found that Verspagen's non-linear specification is not significant when a different sample is used. Thus, the evidence about the validity of this model is mixed.

In sum, despite the considerable progress observed in the literature that investigates the determinants of technological absorption, there seems to be still some room for further research. More specifically, further work is still required to establish whether technological absorption follows a linear or non-linear path. Moreover, further research is also necessary to generate a consensus about the main determinants of technological absorption. In this regard, it would be important to carry out investigations that compare the impacts of different variables on absorptive capacity.

4. Technological competitiveness, trade and growth

Notwithstanding the fact that Schumpeter's (2003 [1943]) discusses the importance of technological competitiveness for trade and growth only very briefly, his position about the topic is very clear. According to Schumpeter (2003 [1943], p. 84-85), "this kind of competition is as much more effective than the other [price competition] as a bombardment is in comparison with forcing a door". Following this idea, a vast number of Schumpeterian studies investigates the importance of technological competitiveness for trade performance and growth.

4.1 Seminal Schumpeterian trade and growth model

The literature on the determinants of trade estimates export and import demand functions in which income and prices are the main explanatory variables (e.g. HOUTHAKKER; MAGEE, 1969; GOLDSTEIN; KAHN, 1985). This approach assumes that differences in non-price competitiveness are captured in the magnitude

of the income elasticities of demand (MCCOMBIE; THIRLWALL, 1994).
Formally:

$$\hat{X} = -\theta(\hat{P} - \hat{P}_w) + \varepsilon\hat{Y}_w \quad (9)$$

$$\hat{M} = \bar{\theta}(\hat{P} - \hat{P}_w) + \pi\hat{Y} \quad (10)$$

where θ and $\bar{\theta}$, and ε and π , are the price and income elasticities, respectively, \hat{P} is price inflation, \hat{Y} is the growth rate of income, and \hat{X} is the growth rate of exports. The subscript W indicates world variables.

The emphasis of the Kaldorain tradition on the importance of international trade for long-term growth stems from the fact that without balance-of-payments equilibrium, growth is jeopardized due to the necessity to reduce internal income in order to re-equilibrate the external accounts, so that income growth becomes determined by trade results (THIRLWALL, 1979).

Nonetheless, using only income and relative prices as determinants of export demand is clearly a second-best option only adopted due to the difficulty in observing and measuring differences in product quality, given that consumers take into account prices as well as quality when deciding what and how much to consume. Moreover, other non-price competitiveness variables should also be taken into account, such as marketing, distribution networks, etc.

In this context, especially from the 1980s onwards, Schumpeterian works on the determinants of trade performance sought to bring more attention to the importance of technological competitiveness for trade. Using patent and R&D data as proxies for technological competitiveness in empirical investigations, many of the trade-related Schumpeterian works established direct connections with the Keynesian/Kaldorian literature that has empirically studied the determinants of trade performance since the 1930s (e.g. HARROD, 1933).

Fagerberg's (1988) model presents the key features of the literature that studies the relationship between technology and trade from a Schumpeterian perspective. The full model is composed of six equations, which form a system that determines the six endogenous variables in the model. Fagerberg's (1988, p. 335) model associates international competitiveness with the ability of a country to increase income and employment without running into balance-of-payments difficulties. Consequently, although the importance of balance-of-payments constraint is not usually stressed

in the Schumpeterian approach, the model incorporates an important aspect of the Kaldorian approach to growth.

The model is composed of the following equations:

$$\hat{S}_X = \alpha \hat{C} + \beta(\hat{T} - \hat{T}_w) - \theta(\hat{P} - \hat{P}_w) \quad (11)$$

$$\hat{S}_M = -\bar{\alpha} \hat{C} - \bar{\beta}(\hat{T} - \hat{T}_w) + \bar{\theta}(\hat{P} - \hat{P}_w) \quad (12)$$

$$\hat{P} = \hat{U} \quad (13)$$

$$\hat{C} = \mu - \gamma G + \phi \hat{K} - \varphi \hat{Y}_w \quad (14)$$

$$\hat{X} + \hat{P} = \hat{M} + \hat{P}_w \quad (15)$$

$$\hat{K} = \hat{Y} - \widehat{GOV} \quad (16)$$

where α , γ , φ , ϕ and μ are positive parameters, \hat{T} is the growth rate of technological competitiveness, $\hat{S}_M = \hat{M} - \hat{Y}$, and $\hat{S}_X = \hat{X} - \hat{Y}_w$.

Equations (11) and (12) indicate that the growth rate of export share is determined by the country's price competitiveness, technological competitiveness, and capacity to attend to growing demand. Equation (13) indicates that price inflation grows at the same rate of unit labour costs U , given that prices are formed following a mark-up rule (i.e. $P=UV$, where U is the unit labour cost ($U=W/Q$) and V is the mark-up (1+%)), which is assumed to be fixed and exogenous). Equation (14) indicates that growth in productive capacity (\hat{C}) depends on the growth of: (i) the technology gap (G); (ii) physical equipment (\hat{K}); and (iii) world demand (\hat{Y}_w). The negative sign associated with world demand results from the fact that in case the country is not able to meet demand, another one will, which reduces the first country's share in trade. Equation (15) is a standard balance-of-payments equilibrium condition that assumes that countries cannot continually increase their debt to finance balance-of-payments disequilibria (THIRLWALL, 1979). And finally, equation (16) represents a simple accelerator mechanism linking investment (\hat{K}) to local demand growth (\hat{Y}) minus the growth of government expenditure (\widehat{GOV}), assuming that there is a crowding out effect (FAGERBERG, 1988, p. 362).

In this model, output growth raises both imports' share and physical capital. Hence, if the first effect is higher than the second, then the net effect on subsequent growth will be negative. Therefore, long-term growth depends on the income-elasticities of imports and investment. Consequently, Fagerberg (1988, p. 371) points out the crucial role played by investment in creating new productive capacity and exploiting the potential for growth associated with the technology gap.

The most interesting feature of the model, however, is the introduction of terms associated with non-price competitiveness in the export and import functions. This introduces the importance of technological competitiveness in the dynamics of international trade, so that the balance-of-payments constraint becomes endogenously determined and progressively less relevant as the country increases its technology level. The effect of technology on trade in the model is twofold: (i) it impacts the exports' share directly through technological competitiveness (\hat{T}); and (ii) it impacts the exports' share through its effect on productive capacity (\hat{C}). Hence, although stressing the importance of investment for growth, technology is the central variable determining long-term growth in Fagerberg's (1988) model.

Fagerberg (1988) found evidence of the validity of the relationship between technological competitiveness and trade using data from OECD countries. Moreover, several other works have tested similar versions of equation (11) using patent and R&D data to measure technological competitiveness, and most of these studies found evidence that technological competitiveness has a positive impact on trade performance (e.g. SOETE, 1981; HUGHES, 1986; LEÓN-LEDESMA, 2005; SHARMA; GUNAWARDANA, 2012). Furthermore, Schumpeterian works have also investigated the existence of differences in the relevance of technological competitiveness for trade across different sectors (e.g. GREENHALGH, 1990; LALL, 2000; MAGNIER; TOUJAS-BERNATE, 1994; AMABLE; VERSPAGEN, 1995). In general, the results of these studies indicate that although price competitiveness is more important in low-tech sectors, technological competitiveness presents a relevant impact on the exports of most sectors.

4.2 A modern Schumpeterian trade and growth model

Several recent works have been seeking to improve the evidence on the importance of technological competitiveness for trade and refine models that formalize the interplay between technological progress, trade and growth (e.g. LEÓN-LEDESMA, 2002; ANG; MADSEN; ROBERTSON, 2015).

As Romero and McCombie (2018) have shown, Fagerberg's (1988) export and import demand functions implicitly assume that the income elasticities of demand are equal to one. Alternatively, equations (11) and (12) could be changed to arrive at more general demand functions by transferring the growth of income from the left side to the right side of the equations and abandoning the implicit assumption that the income elasticities are equal to one:

$$\hat{X} = \alpha\hat{C} + \beta(\hat{T} - \hat{T}_w) - \theta(\hat{P} - \hat{P}_w) + \varepsilon\hat{Y}_w \quad (17)$$

$$\hat{M} = -\bar{\alpha}\hat{C} - \bar{\beta}(\hat{T} - \hat{T}_w) + \bar{\theta}(\hat{P} - \hat{P}_w) + \pi\hat{Y} \quad (18)$$

According to Romero and McCombie (2018), estimating equations (17) and (18) allows to test and to compare the Kaldorain and the Shumpeterian approaches to trade performance. Using the growth of total factor productivity (a measure of economic efficiency) as proxy for technological progress, the authors show that indeed technological competitiveness has a high impact on export growth even when controlling for price and income effects. Moreover, the paper's regressions indicate that technological competitiveness is more relevant in high-tech industries than in low-tech industries. The results show also that introducing technological competitiveness into export demand functions leads to changes in the income elasticity of demand due to omitted variable bias.

Interestingly, Funke and Ruhwedel (2002) and Ang, Madsen and Robertson (2015) used an endogenous growth model to arrive at equation (17). The fact that the micro-foundations used in their papers leads to the same aggregate macro specification indicates once again that there is considerable similarity between aggregate Schumpeterian models from different traditions. Ang, Madsen and Robertson (2015) used patent stocks to calculate measures of technological competitiveness for a sample of Asian countries. Their results are very similar to Romero and McCombie's (2018), reinforcing the importance of technological competitiveness for trade performance and indicating that introducing this variable leads to changes in the income elasticities.

Regarding the role of productive capacity in determining trade performance, Romero and McCombie (2018) highlight that it is problematic to use the capital stock to measure the capacity constraint C . According to them, introducing the growth of the capital stock in the regressions of equations (17) and (18) implies that this variable generates higher export growth and lower import growth when all else is constant, which is clearly not the same as arguing that export growth might

be constrained by insufficient productive capacity. Romero and McCombie (2018) argue that the signs of the changes in the capacity constraint \hat{C} in equations (17) and (18) are actually the opposite: negative in the export function and positive in the import function. Moreover, they state that some measure of changes in the capacity utilization should be used instead of the growth of the capital stock. Using the difference between the trend of output growth and its actual value to measure the capacity constraint, with negative values set to zero, they find that the capacity constraint is not statistically significant.

Based on these expanded equations, Romero (2019) proposed a Kaldor-Schumpeter model that combined technical progress and trade performance to determine long-term growth.¹⁴ The model is composed of the following equations:

$$\hat{X} = \hat{M} \quad (19)$$

$$\hat{X} = \varepsilon \hat{Y}_w + \gamma(\hat{Q} - \hat{Q}_w) \quad (20)$$

$$\hat{M} = \pi \hat{Y} + \delta(\hat{Q}_w - \hat{Q}) \quad (21)$$

$$\hat{Q} = \rho + \lambda \hat{Y} + \beta G \quad (22)$$

$$\hat{Q}_w = \rho + \lambda_w \hat{Y}_w \quad (23)$$

$$\lambda = \alpha + \tau T \quad (24)$$

$$\lambda_w = \alpha + \tau T_w \quad (25)$$

where T is research intensity, Q is productivity and λ is the Verdoorn Coefficient, that captures the magnitude of the response of productivity growth to demand growth (KALDOR, 1966). As before, circumflexes indicate growth rates.

In order to focus on technological progress and quality changes, the model assumes that relative prices are stable in the long-term, consistently with the evidence on relative PPP. Equation (19) is the trade balance condition. Equations (20) and (21) are export and import functions similar to equations (17) and (18)

¹⁴ León-Ledesma (2002), Ribeiro, McCombie and Lima (2016) have also sought to combine different Kaldorian and Schumpeterian insights to build more complete models of economic development.

but excluding relative prices and capacity constraints. Moreover, in these equations, relative productivity is used as a proxy for technological competitiveness. Equations (22) and (23) indicate that productivity growth responds positively to demand growth in both economies, while the world economy is interpreted as the technological frontier, and the domestic economy is an underdeveloped economy. Consequently, the domestic economy can benefit from its technology gap G to obtain higher growth rates by absorbing foreign technology. Finally, equations (24) and (25) indicate that the magnitude of the response of productivity growth to demand growth depends on the level of research intensity of the economy. The higher the research intensity, the higher will productivity grow in response to demand stimuli.

Substituting equation (24) into (22) gives the model's productivity curve (PR):

$$\widehat{Y} = -\left[\frac{\rho + \beta G}{\alpha + \tau T}\right] + \left[\frac{1}{\alpha + \tau T}\right]\widehat{Q} \quad (26)$$

In addition, substituting equations (20) and (21) into (19), and then substituting equations (5) and (7) into it yields the balance-of-payments constrained growth rate (BP):

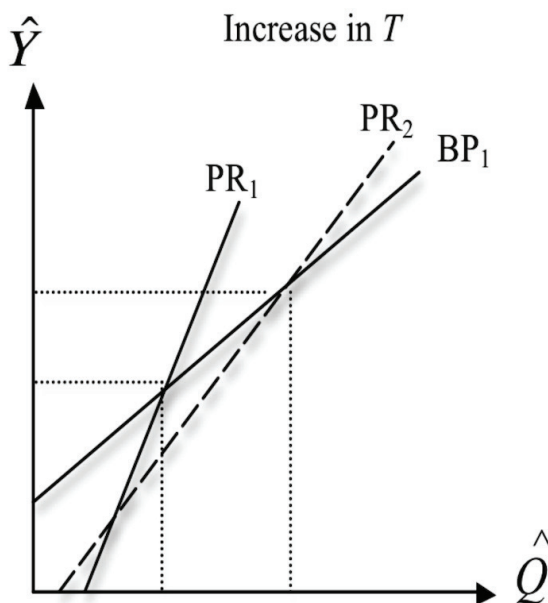
$$\widehat{Y} = \left[\frac{\varepsilon\widehat{Y}_w - (\gamma + \delta)[\rho + (\alpha + \tau T_w)\widehat{Y}_w]}{\pi}\right] + \left[\frac{\gamma + \delta}{\pi}\right]\widehat{Q} \quad (27)$$

Equilibrium is found substituting equation (27) into equation (26):

$$\widehat{Y}^* = \left[\frac{\varepsilon\widehat{Y}_w + (\gamma + \delta)[\beta G - (\alpha + \tau T_w)\widehat{Y}_w]}{\pi - (\gamma + \delta)(\alpha + \tau T)}\right] \quad (28)$$

In the model, higher productivity growth reflects higher technological progress, which leads to higher trade performance, relaxing the balance-of-payments constraint and allowing higher output growth rates. Productivity growth, in turn, depends not only on demand growth but also on research intensity. Consequently, among the different implications of the model, increasing research intensity generates higher productivity growth, better trade performance and higher output growth rates, as illustrated in Figure 3. Analogously, the model indicates also that an increase in research intensity abroad harms the trade performance of the domestic economy, tightening its balance-of-payments constraint and reducing its growth rate.

FIGURE 3
Output and productivity growth rates: increase in research intensity



Source: Romero (2019).

Despite the fact that this model does not explicitly account for the determinants and the effects of investment growth, as in Fagerberg's (1988) model, it incorporates the roles of research intensity for productivity growth and of technology absorption for trade and growth. Moreover, Romero (2019) proposed a multi-sectoral version of the model discussed above, in which inter-sectoral relationships are explored.

Similarly to the investigation regarding the importance of research intensity for productivity growth, in the Schumpeterian literature on technological competitiveness, trade and growth, there is still room for work estimating expanded export demand functions for different sectors. Moreover, to the best of my knowledge, no research has yet analysed the role of inter-sectoral relationships between prices and technological progress in the trade performance of different industries.

5. Concluding remarks

The discussion presented in this paper sought to summarize the key ideas of the Schumpeterian macroeconomic approach to economic growth, while identifying its

shortcomings. The analysis focused on three of Schumpeter's (1934; 2003 [1943]) ideas, which have become particularly influential in macroeconomic growth theory: (i) the role of technological transfer in productivity growth in follower countries; (ii) the importance of research intensity for technological progress in leading economies; and (iii) the relevance of technological competitiveness for trade performance.

This paper's discussion demonstrated that in spite of the contributions of the Schumpeterian literature to understanding the dynamics of technological progress, international trade, and economic growth, there are still some important limitations in this framework.

Regarding the importance of research intensity for economic growth, the shortcoming of this approach lies in the explanation of why some countries have difficulty in increasing their levels of research intensity, and how this issue should be addressed. As the literature on National Innovation Systems emphasises, innovation depends on the institutional arrangements of each country. Still, there are few guidelines for what particular institutions foster higher research intensity. Thus, there is considerable room for improvement in the analysis of the relationship between institutions, technical progress and output growth. Furthermore, there is relatively little work on differences in the importance of research intensity and other variables on technical progress between sectors. More specifically, the impact of income growth on technical progress, although mentioned in some Schumpeterian works, is more often neglected in the econometric studies associated with this tradition.

Similar questions surround the literature that analyses the determinants of technological transfer and its impact on technical progress and economic growth. Although it is recognized that institutions and policies influence the pace of technological absorption, and in spite of the fact that a number of works have recently been focusing on understanding the particular variables that influence absorptive capacity, more research is still necessary in this area as well.

As for the studies that investigate the relationship between technological competitiveness and trade, the importance of different sectors for trade performance still needs further development. Finally, the impact of income growth on technical progress, although mentioned in some Schumpeterian works, is more often neglected in the econometric studies associated with this tradition. As such, this is yet another area that could benefit from more empirical work. Finally, research is still required to understand the role of inter-sectoral relationships between prices and technological progress in the trade performance of different industries.

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