TOTAL FACTOR PRODUCTIVITY GROWTH AND THE TECHNOLOGICAL ABSORPTION HYPOTHESIS REVISITED: PORTUGAL, 1960-2022

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“First, think. Second, believe. Third, dream. And finally, dare.”

Walt Disney

Abstract

Previous studies have proved that technological absorption, through the imports of machinery and other equipment, was crucial for enhancing the Portuguese total factor productivity from 1960 until the beginning of the twenty-first century. One would expect that as countries transition from less developed to developed economies, the relevance of the absorption of advanced technology and knowledge from abroad diminishes, giving place to a more critical role of high-level internal endowments, such as human capital and indigenous R&D efforts. Despite being considered a high-income, developed economy, Portugal faced, after 2001, several economic and financial crises which resulted in dismal growth and the stagnation (and, in some periods, the decline) of (total factor) productivity.

The present dissertation aimed to assess the extent to which Portugal, a developed economy, observed a change in the relative importance of technology absorption vis à vis internal human capital and / or R&D as engines of total factor productivity (TFP) growth.

Resorting to the Autoregressive Distributed Lag (ARDL) bounds testing methodology, we revisit the absorption hypothesis for Portugal between 1960 and 2022. Estimation results suggest that the absorption of advanced knowledge (through licenses) and technology (embodied in machinery and equipment) from abroad continues to be the most important booster of Portugal's TFP. Foreign Direct Investment (FDI) also emerged as a critical factor in promoting (total factor) productivity. In contrast, the direct impacts of human capital and indigenous business R&D efforts do not appear statistically significant. Notwithstanding, such factors, particularly human capital, are crucial to enhancing the productivity impact of FDI. Higher business R&D intensity boosts productivity via the advanced technology embodied in foreign-acquired machinery and equipment.

Such evidence highlights that high-income, developed countries may continue to rely heavily on the (advanced) knowledge and technology produced elsewhere because the positive evolution in income levels does not necessarily mean, as the Portuguese case demonstrates, domestic technological development.

Keywords: Total Factor Productivity; Technological absorption hypothesis; Human capital; Indigenous business R&D; International Trade

Resumo

Estudos anteriores provaram que a absorção tecnológica, através da importação de máquinas e outros equipamentos, foi crucial para o aumento da produtividade total dos fatores em Portugal desde 1960 até ao início do século XXI. Seria de esperar que, à medida que os países transitam de economias menos desenvolvidas para economias desenvolvidas, a relevância da absorção de tecnologia e do conhecimento do exterior diminuísse, dando lugar a um papel mais crítico dos fatores internos, capital humano e esforços de I&D. Apesar de ser considerada uma economia desenvolvida e de elevado rendimento, Portugal enfrentou, após 2001, várias crises económicas e financeiras que resultaram num crescimento desanimador e na estagnação (e, em alguns períodos, no declínio) da produtividade (total dos fatores).

A presente dissertação teve como objetivo avaliar em que medida Portugal, uma economia desenvolvida, observou uma alteração na importância relativa da absorção de tecnologia face ao capital humano interno e/ou à I&D como motores de crescimento da produtividade total dos fatores (PTF).

Recorrendo à metodologia de teste Autoregressive Distributed Lag (ARDL), revisitamos a hipótese de absorção para Portugal entre 1960 e 2022. Os resultados das estimações sugerem que a absorção de conhecimento avançado (através de licenças) e tecnologia (incorporada em máquinas e equipamentos) do exterior, continuam a ser o mais importante impulsionador da PTF em Portugal. O Investimento Direto Estrangeiro (IDE) também emergiu como um fator crítico no crescimento da produtividade (total dos fatores). Em contrapartida, os impactos diretos do capital humano e dos esforços de I&D das empresas nacionais não parecem ser estatisticamente significativos. Não obstante, estes fatores, em particular o capital humano, são cruciais para potenciar o impacto do IDE na produtividade. Uma maior intensidade de I&D das empresas potencia o aumento da produtividade através da tecnologia avançada incorporada nas máquinas e equipamentos adquiridos ao estrangeiro.

Estes dados demonstram que os países desenvolvidos de elevado rendimento podem continuar a depender fortemente do conhecimento (avançado) e da tecnologia produzidos noutros locais, porque a evolução positiva dos níveis de rendimento não significa necessariamente, como demonstra o caso português, desenvolvimento tecnológico interno.

Palavras-chave: Produtividade total dos fatores; Hipótese de absorção tecnológica; Capital humano; I&D de empresas nacionais; Comércio internacional

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List of Acronyms

ADF	Augmented Dickey Fuller
ARDL	Autoregressive Distributed Lag
DGEEC	Direção-Geral de Estatísticas da Educação e Ciência
ECM	Error Correction Model
EEC	European Economic Community
EFTA	European Free Trade Association
EU	European Union
FDI	Foreign Direct Investment
FRED	Federal Reserve Bank of St. Louis
GDP	Gross Domestic Product
HC	Human Capital
INE	Instituto Nacional de Estatística
IPCTN	Inquérito ao Potencial Científico e Tecnológico Nacional
JNICT	Junta Nacional de Investigação Científica e Tecnológica
MCTES	Ministério da Ciência, tecnologia e Ensino Superior
ME	Ministério da Educação
OECD	Organization for Economic Cooperation and Development
PP	Phillips Perron
R&D	Research and Development
SBIC	Schwarz Bayesian Information Criterion
TFP	Total Factor Productivity
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America

1. Introduction

Early catching-up literature on economic growth associated with the neoclassical growth model suggests that technological transfer is an important origin of technological development for poorer and/or technologically laggard economies (Abramovitz, 1986; Nelson & Phelps, 1966).

A relatively voluminous number of empirical studies has focused on understanding the complex, non-linear, multifaceted links between economic growth and a set of key determinants associated with countries' absorptive capabilities, most notably human capital (HC), Research and Development (R&D), and international trade (e.g., Rossi, 2020; Abdouli & Omri, 2021; Minviel & Bouheni, 2022; Lam et al., 2023).

Studies that address these latter determinants and their impact on long-run Total Factor Productivity (TFP) in technological laggard economies are scarcer. Some recent contributions in this domain include the study by Ali and Akhtar (2024), who assessed the effectiveness of HC, R&D, FDI, and exports on TFP growth in Pakistan, a lower middle-income country, between 1991 and 2021, and the study by Ali et al. (2016), who applied cointegration estimation techniques on 20 European countries from 1995 to 2010 to analyse the effect of FDI-related, as well as import-related spillovers on domestic productivity of 20 EU economies from 1995 to 2010. These studies, however, involve a limited time horizon and do not assess the extent to which human capital or R&D contributes to enhancing the assimilation of knowledge and new technology coming from abroad (via the acquisition of foreign licenses, machinery, or FDI), indirectly promoting TFP. In short, they do not assess the technological absorption hypothesis.

The relation between absorptive capabilities, i.e., the combined effect of HC and local R&D efforts with other important variables related to international trade (e.g., FDI, imports of machinery or acquisition of external knowledge through licenses) on TFP, has been scarcely investigated. Although the work of Teixeira & Fortuna (2010) tested the technological absorption hypothesis for the Portuguese economy, a technologically laggard economy, in the period 1960-2001, evidencing that HC and R&D efforts show a strong contribution to enhance the long run TFP, this study misses important macroeconomic shocks, which occurred after 2001, that are likely to influence the impact of technological absorption on TFP (Bianchi et al., 2019). Indeed, after 2001, both globally and for the Portuguese economy, there were a series of economic, financial, and social shocks and crises that potentially affected countries' TFP and economic growth. These include: the economic crisis of 2002-2003 in Portugal after joining the single European currency (Aguiar-Conraria et al., 2012); the global financial crisis of 2008-2009, which originated in the USA and spread throughout the international financial system (Archibugi & Filippetti, 2011; De Vivo & Rinaldi, 2022); the sovereign debt crisis of 2010-2013, which had devastating effects on Portugal in economic and social terms (Cabral & Castellanos-Sosa, 2019; Kostis, 2022); and the global economic crisis of 2020, caused by Covid-19 pandemic (Ehnts & Paetz, 2021).

In this context, the present study seeks to investigate whether the technological absorption hypothesis is still valid for a technological laggard economy over a longer period, 1960-2022, which include post-2001 economic and financial crises and shocks, and also scrutinize the direct effect of HC, internal R&D, trade, FDI and licenses on TFP.

To undertake such endeavour, we resorted to the Autoregressive Distributed Lag (ARDL) bounds testing approach to examine the cointegration relationship between the relevant variables. Unlike other conventional cointegration approaches (e.g., Engle & Granger, 1987; Johansen, 1988), the ARDL technique is adequate even when the variables have different orders of integration (Pesaran et al., 2001) and allows to consider the structural breaks in the data and addresses the matters of endogeneity and serial correlation that may appear in time series data.

The present dissertation is structured as follows. After the introduction, we summarise the literature on the mechanisms through which HC, R&D, Trade, FDI, and Licenses impact on long run TFP. Section 3 details the methodology and data sources, and Section 4 presents the empirical results. Finally, in Section 5, the main conclusions and contributions are summarized, some possible policy implications, as well as the main limitations of the present study are presented, and we suggest a few avenues for future investigation.

2. Literature review

2.1. Mechanisms through which Human Capital, R&D, Trade, FDI, Licenses impact on long run TFP

Despite their distinctiveness and cleavages, new growth/ endogenous and evolutionary approaches to economic growth, both inspired by the work of Schumpeter (1934, 1939, 1943), are increasingly converging in terms of the focus (innovation) provided for explaining the differences between countries in terms of productivity/ economic growth (Castellacci, 2007). Both theoretical approaches identify human, technological and international trade related factors (see Figure 1) as potential determinants of countries' long run total factor productivity (TFP) growth. As detailed in the next sections, these theories give support for the direct effects of HC, R&D indigenous efforts, acquisitions of licenses, FDI, and trade on long run TFP growth (Section 2.1.1.), and indirect effects of HC /R&D on TFP growth via international trade (which includes the acquisition of external knowledge through licenses, acquisition of external technology through the imports of machinery and other equipment and FDI) (Section 2.1.2), i.e., the so-called 'technological (capabilities) absorption hypothesis'.

Figure 1 depicts the theoretical framework that wraps up the relevant linkages between the key variables and identifies the main hypotheses to be tested.

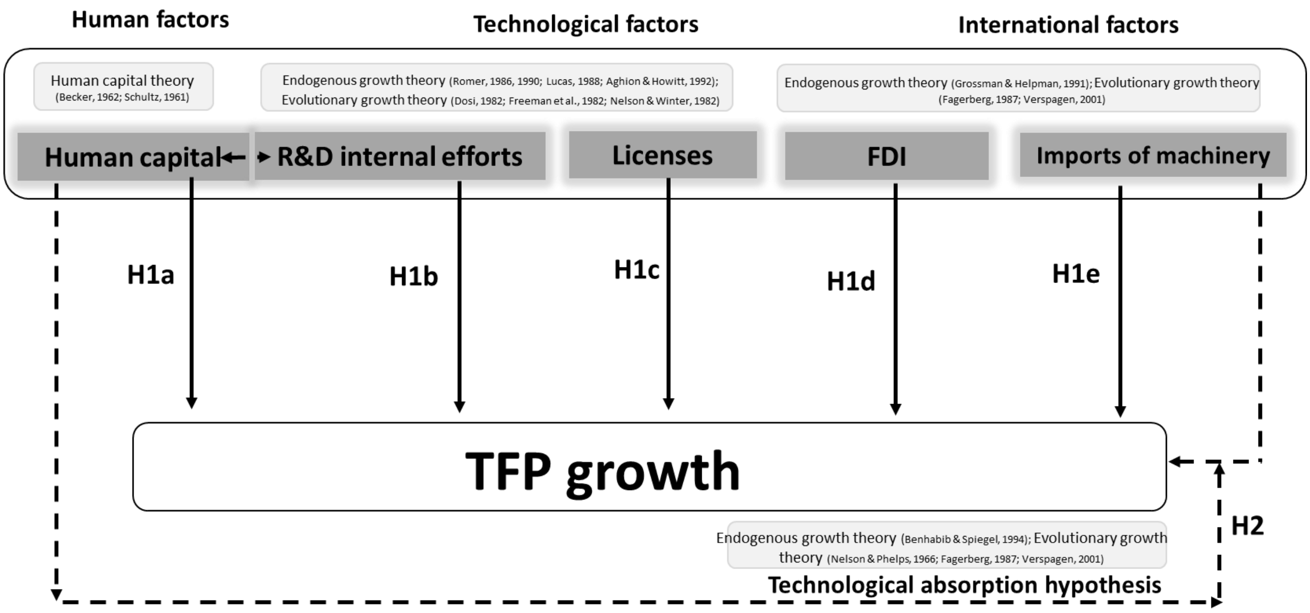


Figure 1: Theoretical framework and main hypotheses to be tested

Source: Own elaboration.

2.2. The direct impact of HC, R&D efforts. License, FDI and trade on long term TFP

According to Goldin (2016, pp. 56), human capital (HC) "… encompasses the notion that there are investments in people (e.g., education, training, health) and that these investments increase an individual's productivity". These resources are linked to knowledge and skills that can be achieved through education, professional practice, and healthcare (Schultz, 1961; Becker, 1962). Investment in HC can include different dimensions (Schultz, 1961): expenses on education, health, national migration when individuals are able to gain from better job opportunities, income lost by students attending school and workers training on their jobs. By investing in themselves, individuals can increase their well-being and economic returns because they expand their skills and capabilities, which are likely to render them more creative, innovative, and productive (Škare & Lacmanovic., 2015). Through education and training, individuals acquire skills and knowledge as a means of capital formation by postponing consumption to increase their future income (Teixeira & Queirós, 2016). HC enhances the quality of labour, thereby increasing its productivity (Mankiw et al., 1992; Wößmann, 2003; Bodman & Le, 2013).

At the aggregate levels, the increased productiveness, creativeness, and innovativeness of each individual directly contributes to countries' economic growth by creating a direct positive impact in new products creation and in factor productivity (Romer, 1990; Benhabib & Spiegel, 1994; ; Teixeira & Fortuna, 2010; Bodman & Le, 2013; Habib et al., 2019). Historically, through health improvements, HC has served to increase income, by improvements in health for children to attend school for more days allowing them to learn more and by these improvements in health also allow adults to work more and reduce absenteeism, in a way that tends to lead to an increasingly growth in productivity and ultimately in economic growth (Goldin, 2016).

Extending the Solow's economic growth model to include HC, Mankiw et al. (1992) evidenced the positive impact of human capital on TFP and its crucial role to explain international economic different performances.

Piazza-Georgi (2002) developed the fundaments brought by Joseph Schumpeter and Theodore Schultz, who demonstrated in the middle of the 20th century "that human resources are now a far more important factor of production than natural resources"(Piazza-Georgi, 2002, pp. 462). Higher value-added entrepreneurship tends to be associated with medium and high levels of education (Pinzón et al., 2022). As such, entrepreneurship, based on education, professional experience, and on natural talent – not easy to be transferred to others –, is understood as another form of human capital, which is at the core of economic dynamics and economic growth (Piazza-Georgi, 2002).

Based on the above, we conjecture that

H1a: The accumulation of HC enhances long-term TFP.

According to Habib et al. (2019), R&D can be described as the actual capital expenses, both private and public, on creative activities that started in a systematic way to raise the level of knowledge and innovation, including knowledge for the overall society and the use of that knowledge for new applications. R&D provides individuals, companies, and countries the capacity to develop new products, services, processes, and technology through innovation (Tian, 2017).

The study by Coe & Helpman (1995), based on the panel analysis of 21 OECD countries plus Israel, encompassing aggregate data on R&D and productivity for the period of 1971-1990, found that internal R&D capital and foreign R&D spillovers significantly impact on countries' productivity, supporting the knowledge-based growth models (Khan et al., 2010). More related to the evolutionary paradigm, the recent study by Soete et al. (2022) analysed the relations between TFP and public and private R&D for 17 OECD countries, concluding that expenditures in public R&D has a positive impact on TFP in most of the countries, and that public and private R&D investments complementarity has a relatively strong impact on productivity.

The direct and positive impact of R&D efforts on productivity growth is further supported by the evidence gathered in several studies that have resorted to international panel data ((e.g., Diwakar & Sorek, 2016; Yang, 2018; Habib et al., 2019). Albeit, in general, it is suggested that R&D investments promote new technologies that potentially enhance productivity (Griffith et al., 2004), their impact may differ according to countries' development level, with the highest impact being observed in high-income countries that can allocate substantial more funds to R&D activities (Habib et al., 2019).

Based on the above, we conjecture that

H1b: The Indigenous R&D efforts tend to promote long-term TFP.

Although it is recognized that the acquisition of licenses can promote industries and countries' performance (Kim & Dahlman, 1992), the impact of the licensing trade channel is expected to weaken as countries develop efforts to integrate more advanced industries based on newer technologies (Mowery & Oxley, 1995). According to Ulku and Pamukcu (2015), an increase in technology licencing increases firms' productivity in a significant extension, but only above a certain threshold of technological capability. Another, more recent, study by Rigo (2021), based on the World Bank's Enterprise Surveys, using a sample of 18 developing and emerging economies, investigated the possibility of global value chains as a vehicle for the transfer of technology and demonstrated that there is a positive impact of firms being involved in two-way trading on the licensing of international technology and that global value chains participation tends to enhance firm's performance, suggesting that the acquisition of foreign technology through licensing has a significant positive impact on firms' and, ultimately, on countries' productivity.

Based on the above, we conjecture that

H1c: The acquisitions of licenses tend to increase long term TFP.

Foreign Direct Investment (FDI) has strong links with new technologies adaptation, enhancements in competitiveness, and improvements of production efficiency, and therefore is likely to impact on TFP (Hwang & Wang, 2012). According to Ghosh & Parab (2021), FDI leads to long-run economic growth through scale effects and through efficiency effects. The authors also found a long-term positive impact of FDI on productivity growth. Some studies (e.g., Grossman & Helpman, 1991; Hermes & Lensink, 2003; Batten & Vo, 2009; Teixeira & Loureiro, 2019; Zamani & Tayebi, 2022; Kumari et al., 2023; Marasco et al., 2023) argue that FDI plays a relevant role in modernizing the economy and in stimulating economic growth in host countries, particularly in developing ones. FDI brought by multinational corporations embodies a significant share of global R&D, which is a potential channel that provides access to advanced technologies on the global market (Zhu & Jeon, 2007). Several theoretical studies have shown that FDI impacts positively economic growth through technology transfer and diffusion (Wang & Blomstrom, 1992), spillover effects (Wang & Yu, 2007), productivity gains, and introduction of new processes, managements competences and know-how in recipient countries (Girma, 2005), workforce turnover (Gershenberg, 1987), or backward and forward production connections (Markusen & Venables, 1999).

Based on the above, we conjecture that

H1d: FDI tends to promote long-term TFP.

Endogenous growth theory argues that international factors, namely foreign trade and, more specifically, the imports of machinery and other equipment, yield important supply-side effects, which bring efficiency improvements for businesses and, ultimately, lead to increased countries' productivity and economic growth (Grossman & Helpman, 1991). Specifically, the import of products from other countries with higher technological level can spurt laggards' countries' technological progress through imitation and absorption (Rivera-Batiz et al., 1993; Darku, 2021; Wang et al., 2023). Several empirical studies for different countries (e.g., Dollar, 1992; Ben-David, 1996; Ekanayake et al., 2023; Wang, 2007) have demonstrated that foreign trade is productivity enhancing and promotes countries' economic growth. According to Coe & Helpman (1995), Coe et al. (1997) and Ali et al. (2016), foreign trade is considered a vehicle of knowledge and tends to reflect the importance of foreign technology introduction into internal production, stimulating in this way TFP. These authors consider that a country that is more open to imports of foreign products (most notably, machinery and other equipment) will benefit more from foreign R&D, achieving faster growth in TFP. Imports from technological frontier countries tend to embody advanced technology, particularly technology that is not available to firms in technological laggard countries (Teixeira & Fortuna, 2010; Ekanayake et al., 2023). International trade impacts TFP growth positively through new technology by enhancing scales of production, and improving competitiveness (Kumari et al., 2023; Marasco et al., 2023; Teixeira & Loureiro, 2019; Zamani & Tayebi, 2022) and production efficiency (Hwang & Wang, 2012).

Based on the above, we conjecture that

H1e: Foreign trade, specifically the acquisition of foreign machinery and other equipment, is likely to boost long-term TFP.

2.3. The indirect impact of HC-R&D through international trade: The technological absorption hypothesis

Human capital theory (e.g., Schultz, 1961; Becker, 1962) and evolutionary theory approaches to economic growth (Nelson & Phelps, 1966; Abramovitz, 1986; Fagerberg, 1987) have identified the role of human capital, in particular, education as a critical factor to boost individuals' and countries' ability to receive, decode, and understand information, especially in a context of adaptation to change, where it is vital to learn to follow and to understand new developments in technology. According to Nelson & Phelps (1966), education is likely to speed technology diffusion and, through this, contribute to the (TFP) convergence process of technological laggard countries.

Verspagen (2001), in line with evolutionary growth theory, argues that convergence based on technological absorption capability from foreign countries is becoming more relevant, with R&D internal efforts being critical for catching up, which supports the contend that the absorption of foreign technology by technological laggard countries demands more intensive R&D efforts.

Developments on the theory of endogenous technological progress have enhanced and renewed the importance of the interactions between trade, technological change, human capital, and economic growth (Teixeira & Fortuna, 2010). In this context, more recent literature (e.g., Banerjee & Roy, 2014; Lam et al., 2022) suggests that trade has important supply-side implications that interact with human capital and capacity-building activities that bring efficiency enhancement in the business sector and ultimately tends to lead to productivity and economic growth (Grossman & Helpman, 1991).

According to Teixeira & Queirós (2016), human capital is the driver of R&D, meaning that the more educated a country's working force, the greater the benefits from R&D activities will be in terms of economic performance, as HC enhances the absorption capacity of technology embodied in products imported from other countries which will allow a faster convergence of economies by trading equipment and technologies (Benhabib & Spiegel, 1994; Bodman & Le, 2013; Nelson & Phelps, 1966). This absorption capacity promoted by HC, leads to an acceleration of the technological diffusion process within the economy, and through this mechanism, leads to higher economic growth (Teixeira, 1999).

Based on the above, we conjecture that

H2: Internal absorption capabilities (i.e., HC and R&D Indigenous efforts) are likely to boost the impact of international trade (acquisitions of foreign licenses, FDI, and the imports of machinery and other equipment) on long-term TFP.

3. Methodology and data

3.1. Selected methodological procedure and technique

The main goal of this study is to evaluate the impact of the evolution of HC, internal R&D, and foreign trade via Licenses, FDI, and imports of machinery and other equipment on Portugal's TFP.

Given this purpose, the Autoregressive Distributed Lag (ARDL) bounds testing approach is applied to the time series data to examine the cointegration relationship between the variables. Unlike other conventional cointegration approaches (e.g., Engle & Granger, 1987; Johansen, 1988), the ARDL technique is adequate even when the variables have different orders of integration (Pesaran et al., 2001). Other advantages of this model include (Pesaran et al., 2001; Nyasha & Odhiambo, 2017; Wang et al., 2020): i) it considers the structural breaks in the data; ii) it avoids pretesting for bias; iii) the resulting estimates remain robust despite sample size and endogeneity; iv) it helps to generate the error correction model (ECM) with a simple linear transformation; and v) it addresses the matters of endogeneity and serial correlation that may appear in time series data. Considering these advantages, and for our estimation objective, the ARDL representation of the model used in this study can be expressed as follows, according to Pesaan et al., (2001):

$$\Delta TFP_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} \cdot \Delta TFP_{t-i} + \sum_{i=0}^{q} \beta_{2i} \cdot \Delta HC_{t-i} + \sum_{i=0}^{r} \beta_{3i} \cdot \Delta RD_{t-i} + \sum_{i=0}^{s} \beta_{4i} \cdot \Delta LIC_{t-i} + \sum_{i=0}^{t} \beta_{5i} \cdot \Delta FDI_{t-i} + \sum_{i=0}^{u} \beta_{6i} \cdot \Delta IMPMACH_{t-i} + \sigma_1 \cdot TFP_{t-1} + \sigma_2 \cdot HC_{t-1} + \sigma_3 \cdot RD_{t-1} + \sigma_4 \cdot LIC_{t-1} + \sigma_5 \cdot FDI_{t-1} + \sigma_6 \cdot IMPMACH_{t-1} + \gamma \cdot D_t + \mu_t$$

Where *t* represents time; Δ represents the first difference operator; *D* is the structural break dummy; μ is a white noise error term; the lag length is denoted by *p, q, r, s*, t, and *u*; long-run coefficients for each variable are shown through σ, whereas β are the short-run dynamic parameters. The variables $TFP_{\square}$, $HC_{\square}$, $RD_{\square}$, $LIC_{\square}$, $FDI_{\square}$, and $IMPMACH_{\square}$stand, respectively, for the Total Factor Productivity, Human Capital, Indigenous R&D, Licenses, Foreign Direct Investment, and Imports of Machinery and Other Equipment, all of them in logarithm form. In the estimated models, to account for the lags associated with the diffusion of foreign knowledge and foreign technology, we considered, in line with Teixeira and Fortuna (2010), a six-year lag.

Table A1 in the Annex presents the values for the relevant variables.

3.2. Description of the variable proxies and data sources

3.2.1. Total Factor Productivity

Portugal's Total Factor Productivity (TFP) presents a very irregular pattern until 1991, observing a steady decline after this year, albeit a relatively positive evolution between 2020 and 2022 (Figure 2).

Throughout the total period of our study, 1960-2022, Portuguese TFP's average annual rate of change was 0.4%, which reflects a stagnating performance. Nevertheless, there were two periods of clear and vigorous growing trends: between 1960-1973, and between 1985-1991. The first period was characterized by the country's abandonment of its post-war isolationist approach, its industrialization, integrating itself into the world economic system, its openness to external markets (namely its adhesion to EFTA), and developing a set of economic measures and policies that allowed Portugal to achieve remarkable levels of economic growth (Lains, 2003). The second period of clear growth occurred after the privatization of major financial and industrial firms that started in 1982 and following Portugal's accession to the European Economic Community (EEC), in 1986.

The decline in the TFP seems intimately related to the multiple economic, political, and financial crises that Portugal faced after 1973, as depicted in Figure 2.

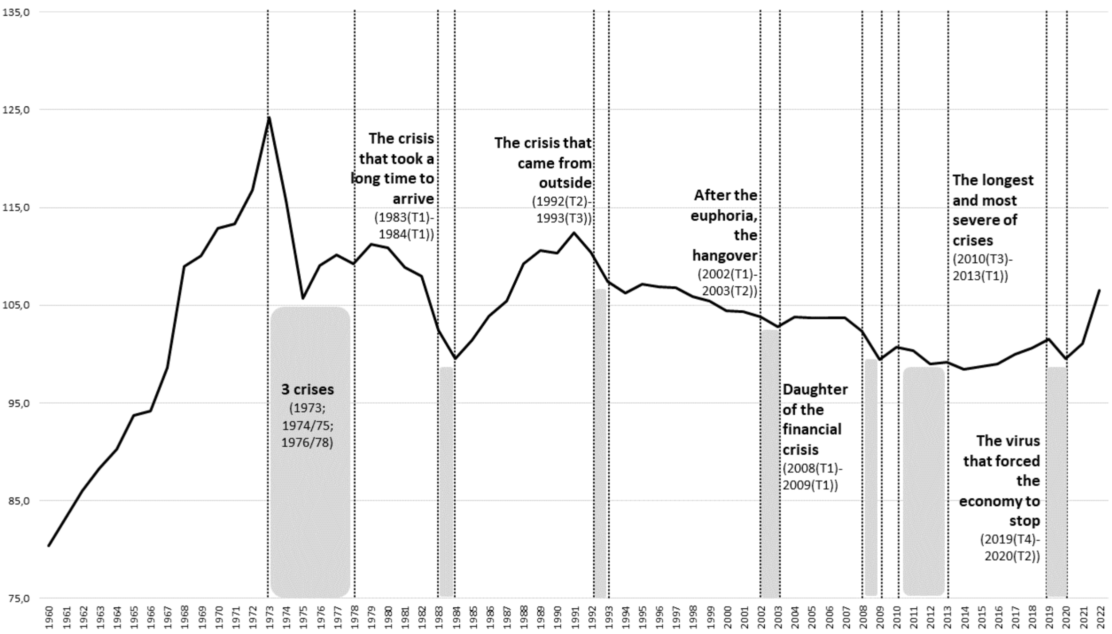


Figure 2: Total Factor Productivity, Portugal, 1960-2022.

Note: The crisis designation and periods were drawn from the book "Crises na Economia Portuguesa: de 1910 a 2022" (FFMA, 2023)
Source: The index of TFP (2017=100) is at constant prices and not seasonally adjusted, being retrieved form FRED (Federal Reserve Bank of St. Louis), for the period between 1960 and 2019. The values for 2020-2022 were estimated by linear interpolation assuming the growth rate of TFP conveyed by the OECD data.

The period of 1973-1976 observed a marked decline in TFP, with an average annual rate of change of-4.3%, due to three main crises: the first World oil shock (1973), which posed a lot of difficulties to industrialized, oil-dependent countries such as Portugal; the Portuguese 1974 Carnation/25 April Revolution, a military coup that deposed the dictatorship of Estado Novo on 25 April 1974, producing major social, economic, territorial, demographic and political conflicts; and the accumulation of external imbalances which culminated in a balance of payments crisis in 1977 and requests for IMF support in 1977 and 1978, with the corresponding policy austerity measures; the economic crisis of 2002-2003, an internal crisis characterized by a decline in economic sentiment, accompanied by a sharp fall in private and public investment, period in which the TFP average annual rate of change was -1.0%; the global financial crisis of 2008-2009, which originated in the USA and spread throughout the international financial system, immediately followed by the sovereign debt crisis of 2010-2013, period in which the TFP average annual rate of change was -0.6%; and finally the global economic crisis of 2019-2020, caused by Covid-19 pandemic, an external shock to economic life that affected the global economy, when the TFP average annual rate of change dropped 2.0%. This was the most abrupt recession in the Portuguese economy since 1980, observing the largest drop in real GDP per capita on record, concentrated in consumption and international trade, which was followed by a vigorous recovery that began in the third quarter of 2020 (Aguiar-Conraria et al., 2024).

3.2.2. Human capital

Human capital (HC) tends to be poorly represented, and significant challenges exist in its accurate measurement (Wößmann, 2003). Alternative proxies for HC include adult literacy rates (Romer, 1990), school enrolment ratios (Mankiw et al., 1992), level of educational attainment and average years of schooling (Benhabib & Spiegel, 1994), the money value of human capital stock (Laroche & Mérette, 2000), and international test scores of students.

According to Teixeira (2005), information on educational attainment is still considered the best proxy for human capital stock for several countries and for a given country over a period. In this context, the present study uses the average years of schooling of the working-age population as a proxy for human capital stock. We use the continuous time series from Teixeira & Fortuna (2010) for 1960-1997, and UNESCO data for 1998-2020. We resorted to linear interpolation to obtain the missing values for 2021-2022. Compared to the study of

Barro & Lee (2013), the data shows that the trend is similar (albeit the levels are distinct) – Figure 3.

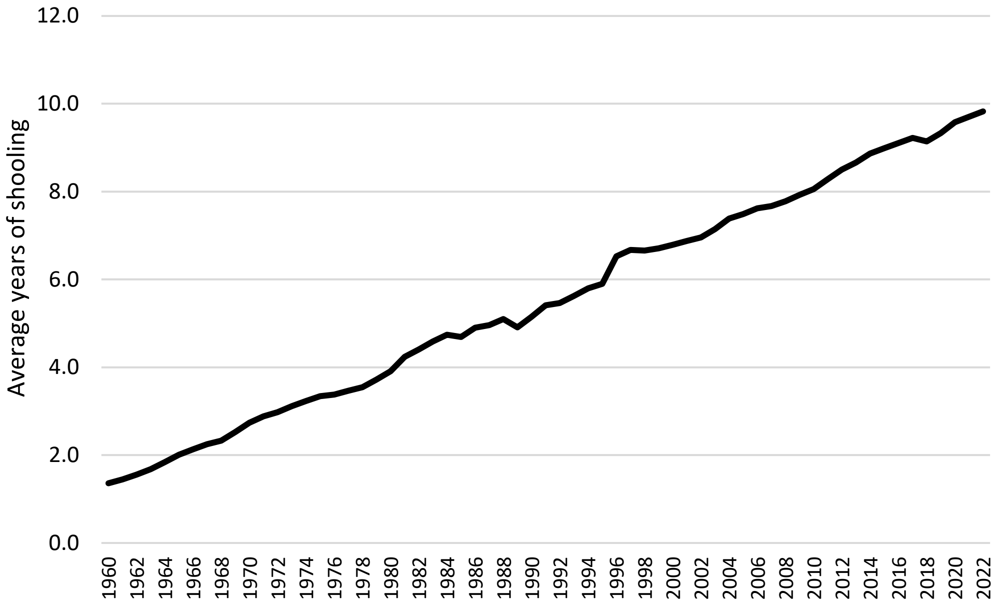


Figure 3: Human capital stock, Portugal, 1960-2022

Source: Own computation based on data from Teixeira & Fortuna (2010) and UNESCO (1960-2020); linear interpolation for estimating the missing values for the period 2021-2022.

The data shows a significant growth in the average years of schooling of the working-age population in Portugal since 1960. At the beginning of the period, a working-age adult in Portugal had on average, 2 years of formal schooling, whereas in 2022, that figure was approximately 10 years. Despite the positive evolution, international evidence shows that Portugal is still far behind the more developed countries (OECD, 2024).

3.2.3. Indigenous R&D efforts

Several measures have been used to proxy R&D efforts. Amongst them, we can find patented inventions (Fagerberg, 1987), the number of scientists and engineers (Jones, 1995), the R&D to the GDP ratio (Griliches, 1988), and total expenditure on R&D (Coe et al., 1997). Fagerberg (1987) divides measures of technological level and technological activities into technological input measures and technological output measures. The input measures are expenditures on education, expenditures on R&D, and employment of scientists and engineers and are related to the innovation capability of a country as well as its capacity for imitation, such that the country's science base needs to achieve a certain level for that imitation process to be effective and successful. The output measures are based on patents and related to innovation activities, namely those linked to innovation of methods of production and output.

In this study, we favour technological input measures because economic growth in Portugal has been more characterized by the absorption and diffusion of knowledge, rather than knowledge creation (Verspagen, 1993). More precisely, we use the ratio of business R&D expenditure to GDP as a proxy for Indigenous R&D efforts.

The data shows that despite the positive trend observed in the last six decades (Figure 4), only by 2021 did Portugal reach 1% of business R&D expenditure in terms of the GDP, which reflects its technological backwardness in relatively more industrialized and developed countries. Figure 4 evidences the relatively sharp fall in the ratio of Business R&D to GDP after the global financial crisis of 2008-2009 and during the sovereign debt crisis of 2010-2013.

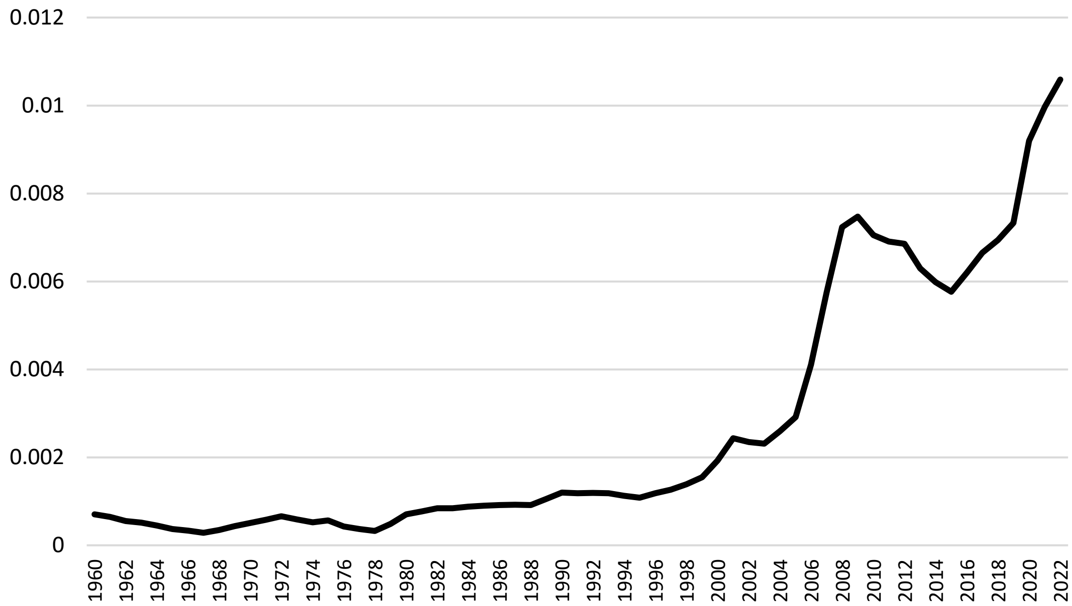


Figure 4: Ratio of business R&D to GDP, Portugal, 1960-2022

Source: Own computation based on the following data - for national business R&D expenditures at current prices, the data source used was DGEEC/ME-MCTES – "Inquérito ao Potencial Científico e Tecnológico Nacional (IPCTN) – and PORDATA. For the data on GDP at current prices, we use data from INE – "Contas Nacionais Anuais (base 2016).

3.2.4. Licenses, FDI, and Imports of Machinery and Other Equipment

Led by the literature on R&D endogenous growth models and innovation systems, we assess the impact of three primary channels of technology diffusion on total factor productivity (TFP): technology transfer through embodied means (imports of machinery and other equipment), and disembodied means, i.e., the acquisition of foreign licenses and royalties, as well as foreign direct investment (FDI).

The proxies used for assessing these channels are conventional and widely accepted, being computed as percentages of the country's GDP: imports of machinery and equipment to GDP (Kim et al., 2009), inward FDI flows to GDP (Zhu & Jeon, 2007), and the acquisition of foreign licenses and royalties to GDP (Mendi, 2007).

The six-year lagged acquisitions of foreign licenses (to the GDP), albeit characterized by some irregularity, showed a marked increase until 2000. Still, afterward, there was a decline that was only inverted after the exit of the Troika program (Figure 5).

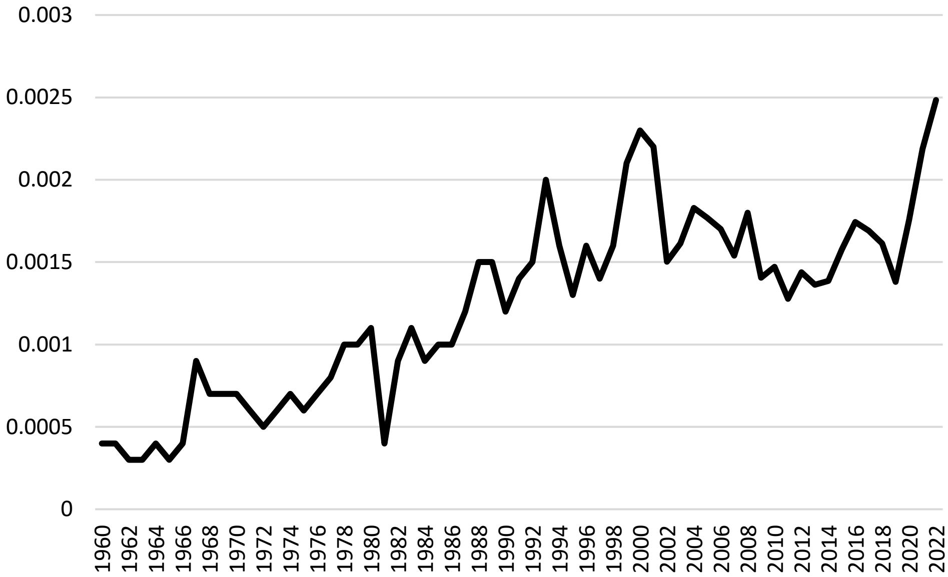


Figure 5: Licenses and royalties to GDP ratio in t-6, Portugal, 1960-2022
Source: Authors computation based on data from Teixeira & Fortuna (2010) (1960-2001), Banco de Portugal (Balança de pagamentos tecnológica) and INE – Contas Nacionais Anuais (Base 2016) (GDP) (2002-2022).

The inward (liquid) foreign direct investment as a share of the GDP presents a very volatile evolution (Figure 6). Although relatively inexpressive before the 1960s, it started to have some relevance in the 1960s when Portugal abolished the nationalization law. In the 1980s, it increased consistently attracted by Portugal's adhesion to the European Economic Community (EEC). The ratio kept growing until the Portuguese economy defaulted in 2011, following the sovereign debt crisis of 2010-2013. The nature of the FDI changed substantially over this long period (Lopes & Simões, 2020): in the 1960s, 1980s and 1990s, FDI was mainly driven by the manufacturing industry, especially the automotive industry in the 1980s and beginning of the 1990s. In the 2010s, FDI was more linked to a privatisation wave in energy, insurance, and airport management and less associated with greenfield investment. There were, however, some positive developments, related to the attraction of

R&D activities by multinational firms, especially the innovation initiatives by Portuguese subsidiaries, which resulted in the setting up of centres of excellence in Portugal (e.g., the case of Siemens).

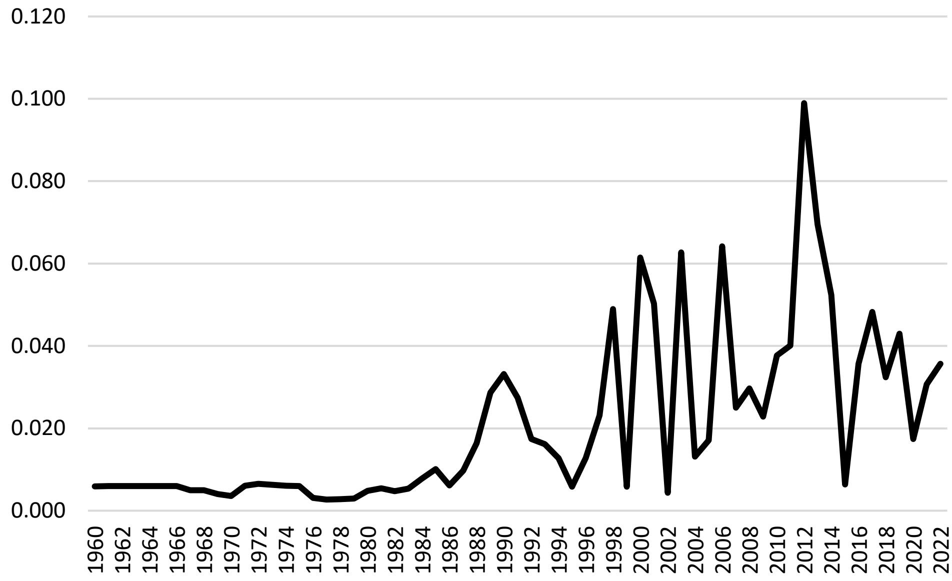


Figure 6: Inward FDI to GDP ratio, Portugal, 1960-2022
Source: Authors computation based on data from Teixeira & Fortuna (2010) (1965-1969) and World Bank (1970-2022).

In 1960, the six-year lagged machinery and other equipment imports represented nearly 3% of Portugal's GDP. There was a clear upward trend until 2008 (Figure 7). Still, the World financial crisis and austerity policy measures and credit constraints faced by economic agents, especially firms, explain the sharp decrease in investments and, consequently, the imports of machinery and other equipment.

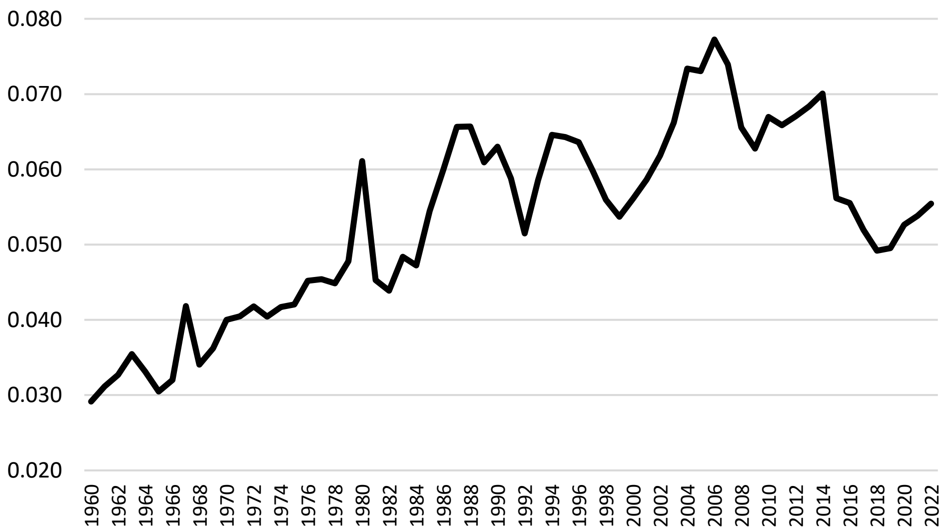


Figure 7: Imports of Machinery and Other Equipment to GDP ratio in t-6, Portugal, 1960-2022
Source: Banco de Portugal, "Séries Longas" (1954-1995) and INE (1996-2020).

4. Empirical results

4.1. Unit root tests

The empirical analysis begins by checking the stationarity of the data. Although the ADRL model allows mixed integration among the variables, I(0), I(1), or a combination of both, it is a precondition that none of them should be integrated order 2, i.e. I(2). Otherwise, it will not be reliable to justify the F-statistic for the model (Wang et al., 2020).

The graphic inspection of the relevant variables in levels and in differences (Figure 8) suggests that the variables are non-stationary in levels but stationary in the first differences.

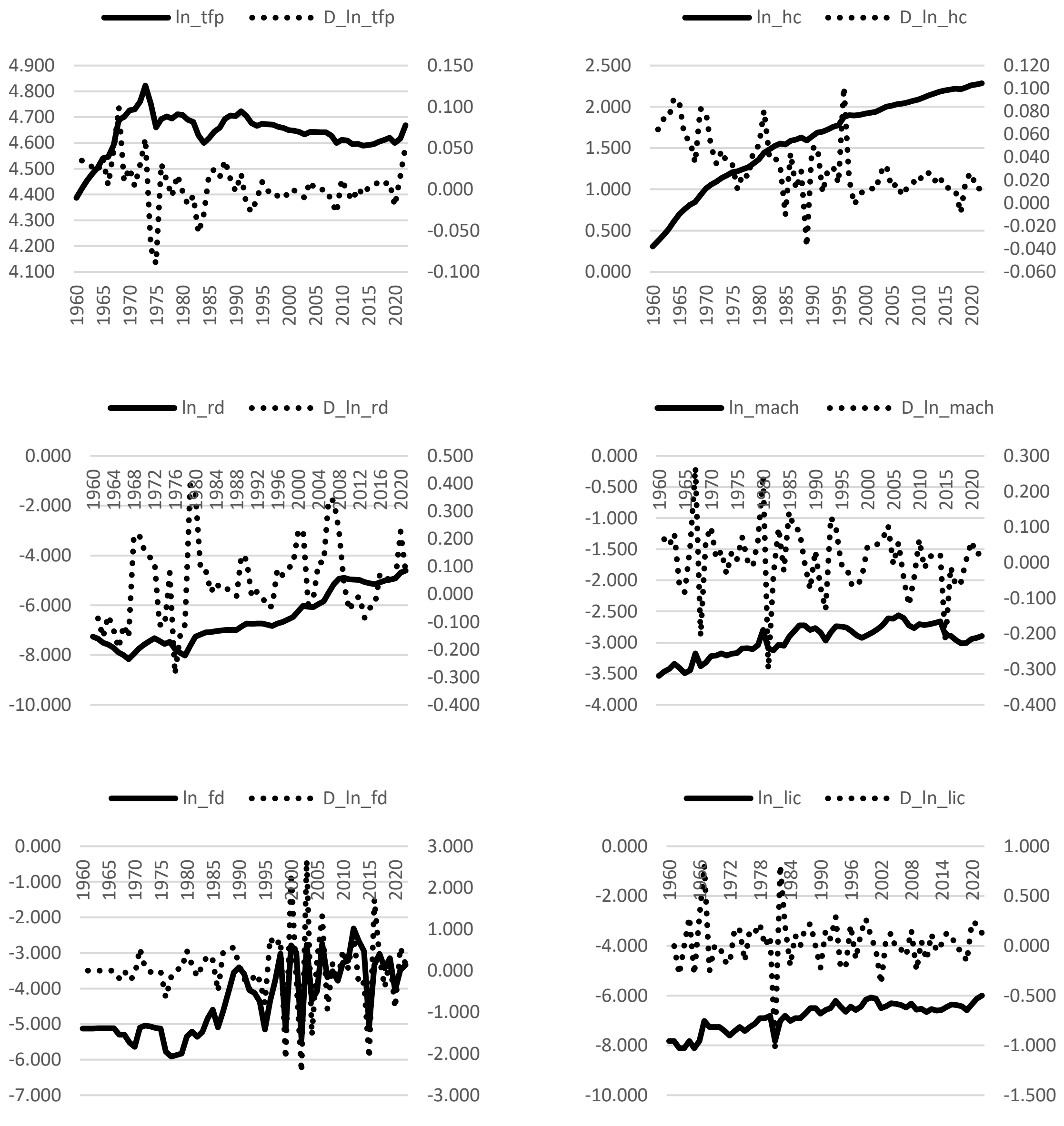


Figure 8: Relevant variables in levels and in first differences

To assess this issue more rigorously, we performed the two most widely used conventional unit root tests, the Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests, and the Zivot and Andrew's (1992) tests, which ensure reliable and accurate results by providing a robust unit root test in the presence of a structural break.

In levels, ADF and PP tests produce mixed results, with total factor productivity, human capital, R&D-FDI and R&D-licenses interaction variables being stationary (at 5% of significance, we cannot reject the null hypothesis of a unit root in levels) – Table 1. However, after accommodating structural breaks (Zivot-Andrews test), all the variables, excluding licenses and R&D-licenses interaction variable, have a unit root in levels. That is, the variables in levels are non-stationary (we cannot reject the non-stationary hypothesis at the standard levels of statistical significance). Thus, excluding the licenses and R&D-licenses interaction variable, which are stationary/ integrated of order zero (I(0)), the remaining variables can be integrated of order 1 or above.

Table 1: Testing the unit roots of the relevant time-series

Variable	Number of lags; option (process under H0)	ADF test (p-value)	PP test (p-value)	Zivot-Andrews test [break year]
Levels				
tfp	4; constant	-3.334** (0.013)	-3.479*** (0.009)	-4.083 [1971]
tfpg	1; constant	-5.182*** (0.000)	-5.530*** (0.000)	-4.263 [1976]
hc	1; trend	-3.466** (0.043)	-3.466** (0.043)	-3.299 [2013]
rd	2; trend	-3.173* (0.090)	-3.038 (0.122)	-4.314* [1992]
lic	1; trend	-3.075 (0.112)	-3.660** (0.025)	-5.479*** [1994]
fdi	3; trend	-3.381* (0.054)	-6.671*** (0.000)	-3.331 [2013]
mach	1; trend	-1.986 (0.609)	-2.240 (0.467)	-4.313* [2006]
HC×lic	1; trend	-3.419** (0.005)	-3.573** (0.032)	-3.500 [1990]
RD×lic	2; trend	-1.428 (0.852)	-1.019 (0.941)	-4.981*** [1997]
HC×fdi	3; trend	-3.805** (0.016)	-7.305*** (0.000)	-8.248*** [1978]
RD×fdi	1; trend	-1.565 (0.806)	-2.041 (0.579)	-4.837** [1998]
HC×mach	1; trend	-2.366 (0.398)	-2.246 (0.464)	-3.400 [2007]
RD×mach	3; trend	-0.758 (0.969)	-0.527 (0.982)	-4.434** [1999]
1st differences				
tfp	1; constant	-5.290*** (0.000)	-5.570*** (0.000)	-4.363* [1976]
tfpg	4; constant	-4.478*** (0.000)	-12.369*** (0.000)	-10.616*** [1972]
hc	1; constant	-3.277** (0.016)	-4.588*** (0.000)	-7.555*** [1977]

Variable	Number of lags; option (process under H0)	ADF test (p-value)	PP test (p-value)	Zivot-Andrews test [break year]
rd	1; constant	-4.464*** (0.000)	-4.355*** (0.000)	-4.673** [1970]
mach	0; constant	-8.608*** (0.000)	-8.608*** (0.000)	-7.051*** [1987]
fdi	2; constant	-5.078*** (0.000)	-15.732*** (0.000)	-10.203*** [1989]
lic	2; constant	-6.019*** (0.000)	-10.536*** (0.000)	-8.332*** [2012]
HC×mach	0; constant	-7.202*** (0.000)	-7.202*** (0.000)	-7.179*** [1986]
RD×mach	1; constant	-4.025*** (0.001)	-3.753*** (0.003)	-4.847** [2013]
HC×fdi	2; constant	-6.187*** (0.000)	-16.248*** (0.000)	-10.237*** [2007]
RD×fdi	0; constant	-9.894*** (0.000)	-9.894*** (0.000)	-10.227*** [2013]
HC×lic	0; constant	-8.497*** (0.000)	-8.497*** (0.000)	-8.750*** [2013]
RD×lic	1; constant	-3.782*** (0.003)	-3.602*** (0.006)	-4.232* [2013]

Notes: *** (**)[*] reject H0 at 1% (5%)[10%] significance level; All the variables are in logarithms; The period of analysis is 1960-2022. In the ADF and PP tests the null hypothesis is that the variable contains a unit root, and the alternative is that the variable was generated by a stationary process. In the Zivot-Andrews Unit Root Test the null hypothesis is that the variable includes a unit root with structural break in the intercept. *Source*: Own computation using STATA 18.

The results of the tests for the variables in the first differences evidence that all variables are stationary at the standard levels of significance. Therefore, unit root tests show that none of the variables is integrated of order two (I(2)). In this context, the ARDL bounds testing approach to cointegration can be applied to test whether cointegration exits or not among total factor productivity, human capital, R&D, imports of machinery, FDI and acquisitions of foreign licenses in Portugal for the period 1960-2022, given that ARDL models can be employed when we have a combination of variables I(0) and I(1). ARDL models are relatively more efficient when we have a small and finite sample data size. By applying this technique, we obtain unbiased long-run estimates.

4.2. The ARDL models

4.2.1. Bounds and diagnosis tests

The appropriate lag length of the variables was selected based on the Schwarz Bayesian Information Criterion (SBIC), which performs slightly better in most of the experiments (Pesaran, 1997). This is followed by the application of bounds F-test to examine the hypothesis that there exists a long-run equilibrium relationship between total factor productivity and the selected determinants (i.e., human capital, R&D, imports of machinery, FDI, and acquisition of foreign licenses). If the computed F-statistic, generated by Pesaran et al. (2001), exceeds the upper critical bound, then the series are cointegrated. Therefore, a dynamic ARDL-ECM can be derived through a simple linear transformation, integrating both short and long-run equilibrium without losing any information.

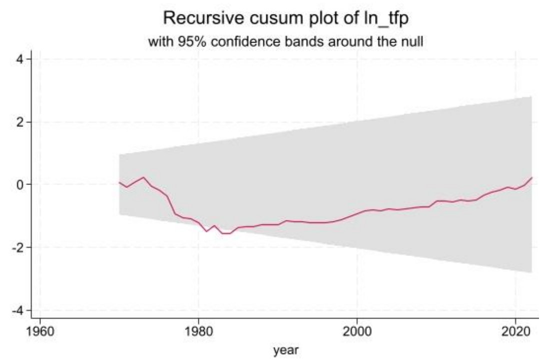
The result reported in Table 2 reveals a stable long-run cointegration among human capital, R&D, imports of machinery, and TFP throughout 1960-2022 in the case of Portugal. Indeed, according to the computed F-statistic, i.e., at a 10% significance level, the null hypothesis of no cointegration is rejected. In addition, some diagnostic and stability tests were conducted, and the results are presented in the lower bound of Table 2 and Figure 9.

Regarding the baseline model without structural breaks, the diagnostic tests seal the goodness of fit of our ARDL estimated model. For instance, the Breusch-Godfrey LM test for autocorrelation (ARCH) does not reject the null hypothesis and allows us to ascertain no serial correlation in the error terms. The Ramsey RESET test result allows us to conclude that the model does not suffer from omitted variable bias; the Jarque-Bera test accepts the hypothesis for normality on residuals. Finally, the stability of the coefficients was examined by performing the cumulative sum of the recursive residuals (CUSUM). According to the graphical representation in Figure 9, it can be assumed that the estimated coefficients are not stable over time since the statistic goes at the beginning of the 1980s of the 5% significance band. The bounds test of the baseline model with a structural break in 1983/84 evidences a long-run relation among the relevant variables. Moreover, excluding the rejection of the normality of the residuals, all the remaining diagnosis tests suggest that the model is a good fit.

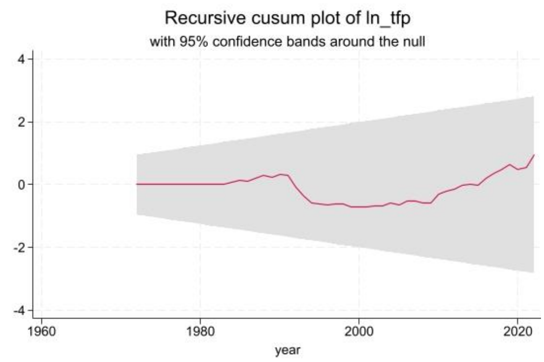
Table 2: ARDLbounds testing analysis

	Baseline model	**Baseline model with a structural break**	**Model with HC interaction**	**Model with R&D interaction**
	$tfp_t=f(hc_t, rd_t, lic_t, fdi_t, mach_t)$	$tfp_t=f(hc_t, rd_t, lic_t, fdi_t, mach_t,$ D_1983/84)	$tfp_t=f(hc_t, rd_t, lic_t, fdi_t, mach_t, hc_t \times lic_t, hc_t \times fdi_t, hc_t \times mach_t$	$tfp_t=f(hc_t, rd_t, lic_t, fdi_t, mach_t, rd_t \times lic_t, rd_t \times fdi_t, rd_t \times mach_t$
Lag length	(2,0,0,2,0,2)	(1,0,0,0,0,2,0)	(2,0,0,2,0,2,0,0,1)	(2,0,0,2,0,0,0,0,2)
F-Statistic	2.597[a]	4.356[d]	2.571 [a]	2.849 [a]
χ^2_{SERIAL}	0.130 (0.719)	0.990 (0.320)	0.084 (0.772)	0.064 (0.800)
χ^2_{ARCH}	61.00 (0.440)	49.140 (0.348)	61.00 (0.440)	61.00 (0.440)
χ^2_{Normal}	2.635 (0.268)	27.68 (0.000)	7.623 (0.022)	3.692 (0.158)
χ^2_{RESET}	1.560 (0.211)	3.280 (0.030)	0.920 (0.439)	1.080 (0.369)
CUSUM	1.157[b]	0.337 (Stable) [b]	0.937 (Stable) [b]	0.978 (Stable) [b]
Break year(s)	1983-1984[c]	-	-	-

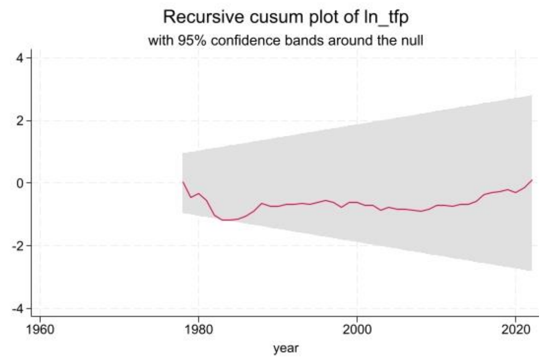
Notes: In brackets, we have the test's p-values. [a] – The critical value for I(0) regressor at 1%=3.41; Criterion: If F< critical value for I(0), we accept H0 of no levels relation → No cointegration. The critical values were obtained from Kripfganz and Schneider (2020). [b] – We reject the null hypothesis of a constant mean/ No structural breaks at the 1% level because the test statistic value of 1.157 exceeds the 1% critical level of 1.143. [c] – Based on the visual inspection of the plot of the recursive cusum process. [d] – Reject H0 of no levels relationship as F > critical value for I(1) regressors (3.99) at 2.5% of significance.
Source: Author's computation using Stata 18.



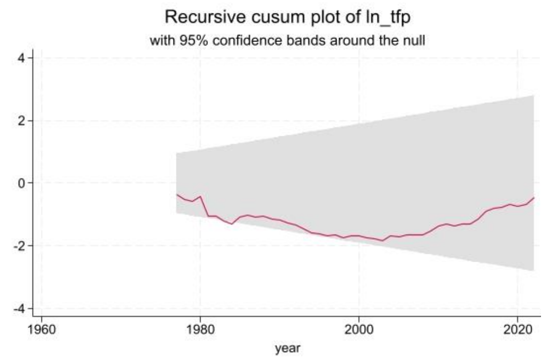
Baseline model without structural breaks



Baseline model with structural break in 1983/84



Model with HC interaction



Model with R&D interaction

Figure 9: Plots of CUSUM statistics for coefficient stability

Note: The dashed lines represent the 5% confidence interval; the straight line stands for CUSUM

Source: Author's computation using STATA 18.

4.2.2. Estimation results and discussion

For analysing the estimated models without interaction terms, that is, the 'Baseline models' (Table 3, the first two columns), we should bear in mind that according to the diagnosis tests, the adequate model is the one that includes a structural break in the years of 1983-1984. This latter period was marked by a recession which reflected a "delayed adjustment of the Portuguese economy to the rise in oil prices, combined with the impact of an IMF--supervised adjustment programme." (Aguiar-Conraria et al., 2024, pp. 13).

The estimation results of Models 1a and 1b do not differ substantially, but Model 1b entails a stable long-run relation between the variables (cf. bounds test in Table 1). The negative and significant coefficient of the lagged dependent variable (TFP) represents the speed of adjustment, that is, how fast the process for TFP reverts to its long-run relationship when this equilibrium is distorted (Kripfganz & Schneider, 2023). As the estimate is negative and lower than one, it reflects a partial adjustment process, where the gap to the equilibrium is gradually closed over time. Specifically, the error correction term coefficient estimate shows that TFP converges to the long-run equilibrium by 16.3% in one period.

The results suggest that in the period of analysis (1960-2022) and accounting for a structural break in 1983-1984, albeit human capital and R&D Indigenous efforts failed to emerge as significant determinants of the Portuguese TFP, the six-year lagged acquisition of external licenses and royalties (LIC), i.e., the lagged foreign knowledge acquisition, impacts positively and significantly (at less than 10% significance) on TFP. In concrete, a 1% increase in licenses leads, on average, all the remaining factors being held constant to a 20.4% increase in TFP. The results also evidence the critical importance of acquiring foreign technology via machinery and other equipment imports for Portugal's TFP. Indeed, as a technology-laggard country, Portugal seems to benefit highly from the foreign, more advanced technology embodied in machinery and other equipment: a variation in the imports of machinery and other equipment (ΔMach) leads to a statistically significant variation in the same direction of TFP.

Thus, the results from the 'baseline model' validate H1c (*The acquisitions of licenses tend to increase long-term TFP*) and H1e (*The acquisition of foreign machinery and other equipment, is likely to boost long-term TFP*), but not enough evidence exists to validate H1a (*The accumulation of HC enhances long term TFP*), H1b (*The Indigenous R&D efforts tend to promote long-term TFP*), and H1d (*FDI tends to promote long-term TFP*).

These results are, in part, not aligned with the findings of Teixeira & Fortuna (2010), who have found a statistically significant direct and positive impact of human capital and R&D on Portuguese TFP growth. It is important to recall that the analysis of Teixeira & Fortuna (2010) covers a shorter time span, 1960-2001, which misses the long stagnation and decline of TFP over the period between 2001 and 2019, in spite of that, we continue to assist an improvement in the overall formal education of Portuguese adult population and business R&D efforts. The more recent period was thus characterized by a sequence of serious crises (e.g., the World Financial Crisis, in 2008-2009, and the Portuguese longest crisis since the 1980s, from 2010 until 2014, that included the 2011 bailout request and the subsequent restrictive policy package associated with the Troika Program), which imposed acute credit constraints to firms and other economic agents located in Portugal leading to a string fall in private and public investment with adverse consequences in terms of knowledge and technology acquisitions by firms, and their productivity.

Table 3: Determinants of the evolution of Total Factor Productivity (TFP): ARDL/ EC models estimation, Portugal, 1960-2022

	Model 1a: Baseline model (BM)	**Model 1b: BM with structural breaks**	**Model 2: BM with HC interaction**	**Model 3: BM with R&D interaction**
	No cointegration ARDL (2,0,0,2,0,2)	Cointegration ECM - ARDL (1,0,0,0,0,2,0)	No cointegration ARDL (2,0,0,2,0,2,0,0,1)	No cointegration ARDL (2,0,0,2,0,0,0,0,2)
TFP				
t-1	1.039*** (0.000)	-0.163*** (0.006)	1.002*** (0.000)	1.004*** (0.000)
t-2	-0.204 (0.122)		-0.241* (0.071)	-0.246* (0.052)
HC				
t	-0.032 (0.353)	-0.183 (0.411)	-0.211 (0.358)	-0.030 (0.472)
R&D				
t	-0.0003 (0.974)	-0.003 (0.963)	-0.005 (0.689)	0.044 (0.633)
LIC				
t	0.042** (0.027)	0.204* (0.090)	0.057 (0.215)	0102 (0.279)
t-1	-0.027 (0.164)		-0.027 (0.164)	-0.030 (0.114)
t-2	0.027* (0.097)		0.033* (0.097)	0.028** (0.067)
FDI				
t	-0.001 (0.923)	-0.006 (0.847)	0.052* (0.092)	0.061* (0.056)
MACH (with a time lag of 6 years)				
t	-0.059 (0.162)	-0.169 (0.379)	-0.057 (0.668)	-0.095 (0.546)
t-1	0.146*** (0.013)		0.257*** (0.004)	
t-2	-0.118*** (0.010)		0.096** (0.037)	
D_1983/84		-0.296** (0.045)		
ΔMach				
t		-0.021 (0.586)		
t-1		0.085** (0.023)		
HC/RD*LIC				
t			-0.011 (0.694)	0.008 (0.580)
HC/RD*FDI				
t			0.028* (0.091)	0.010* (0.054)
HC/RD*Mach				
t			-0.001 (0.991)	-0.005 (0.828)
t-1			-0.064 (0.160)	0.024*** (0.002)
t-2				0.016*** (0.005)
Trend			0.0002 (0.929)	0.0005 (0.855)
Constant	1.014*** (0.003)	0.945*** (0.002)	1.288 (0.813)	0.546 (0.924)
F-stat	34.68 (0.000)	-	27.28 (0.000)	30.25 (0.000)
Adj. R2	0.861	0.322	0.868	0.872

Notes: *** (**) [*] statistically significant at 1% (5%) [10%]. In brackets, we have the p-values.
Source: Author's computation using Stata 18.

It is also important to note that the positive evolution of the average years of schooling and the improvements in R&D intensity in Portugal may bring positive and significant impacts on Portugal's economic growth, as several studies suggested or demonstrated (Teixeira, 1999; Teixeira, 2005; Teixeira & Fortuna, 2004; Teixeira & Queirós, 2016), but they may be insufficient to boost (total factor) productivity. This latter may require more selected, specific human capital and R&D efforts as Acemoglu et al. (2006) and Vandenbussche et al. (2006) suggested.

Despite the idea found in the literature regarding the long-term positive impact of FDI on productivity growth (Ghosh & Parab, 2021), we should point out that Portugal's inward FDI has been in some periods targeting mainly lower-income industries (1960s-1980s) or services (2010s-2020s), where significant productivity impacts may be more difficult to materialize.

Results in the Baseline model with a structural break further show that the 1983-84 crisis had a negative and significant impact on TFP (-29.6%), which confirms the contend that crises are harmful to TFP dynamics, often due to the scarcity of capital (Ouyang, 2009; Aghion et al., 2012).

In a nutshell, the Baseline Model (BM) essentially conveys that the key determinants of Portugal's TFP between 1960 and 2022 are related to the acquisition of advanced knowledge (through licenses) and technology (embodied in machinery and equipment) from abroad.

Concerning the BM with HC and R&D interactions with international trade related-factors (Table 4, columns 3 and 4) that take into consideration not only the direct impacts but also the indirect impacts of the selected determinants on TFP, we found enough statistical evidence to support H2 (*Internal absorption capabilities (i.e., HC and R&D indigenous efforts), are likely to boost the impact of international trade, most notably, the imports of machinery and other equipment, on long term TFP*).

The estimated direct effects of HC, R&D, and Licenses align with those obtained in the BM without interactions. But, in the extended model, FDI, in addition to the lagged Licenses, emerges as a critical booster of TFP. Specifically, a 1% increase in the ratio of FDI to GDP yields, on average, *ceteris paribus*, a 5.2% (6.1%) increase in TPF when considering HC (R&D) interactions. For the lagged acquisitions of foreign knowledge (i.e., Licenses), the corresponding impact is 3.3% (2.8%). Interestingly, in the case of the model with HC interactions, the direct impact of machinery imports is very strong in statistical significance and magnitude. A 1% increase in the 7 (8) years lagged ratio of machinery imports tends to generate, on average, a 25.7% (9.6%) increase in TFP.

Thus, the BM with interactions validate the hypotheses validate H1c (*The acquisitions of licenses tend to increase long-term TFP*), H1e (*The acquisition of foreign machinery and other equipment is likely to boost long-term TFP*) (in the case of the model with HC interactions), and H1d (*FDI tends to promote long-term TFP*).

Focusing now on the estimates associated with the interaction terms, results suggest that human capital and R&D Indigenous efforts are crucial to enhance the productivity impact of FDI, with the magnitude of the estimated effect being larger in the case of human capital. Moreover, higher R&D intensity will likely significantly boost TFP via the advanced technology embodied in foreign-acquired machinery and equipment.

In the literature, several studies (e.g., Grossman & Helpman, 1991; Hermes & Lensink, 2003; Batten & Vo, 2009) evidence that FDI is an important vehicle for modernizing the economy, contributing to economic growth and, ultimately, aggregate productivity in developing and/or technology laggard host countries. The extant literature has also shown that FDI boosts countries' economic performance through technology transfer and diffusion (Wang & Blomstrom, 1992), productivity increase, and introduction of new processes, management skills, and know-how in host countries (Girma, 2005). Increased flows of FDI in Portugal also have been found to be associated with less unequal income distribution and lower poverty rates (Teixeira & Loureiro, 2019).

The results are clear evidence that foreign trade has been a productivity enhancer for the Portuguese economy by introducing more advanced knowledge and technology into domestic production (Coe & Helpman, 1995; Coe et al., 1997). Moreover, formal education and, to a larger extent, internal R&D efforts by companies emerge as critical to assimilating/absorbing FDI flows and embodied advanced technology from machinery imports.

Our results are aligned with recent cross-country evidence analyzed by Afonso (2024, pp. 975) who focused on the 27 EU countries over the last two decades (2000-2019) and concluded that the "… openness to international trade, imports of machinery and transport equipment, and domestic investment in R&D [are] facilitators of the process of technology absorption and knowledge diffusion from FDI.".

5. Conclusions

The main aim of the present dissertation was to investigate whether the technological absorption hypothesis is valid for Portugal, a technological laggard economy, over a long period, 1960-2022, which includes post-2001 economic and financial crises and shocks. Additionally, it sook to scrutinize the direct effects of HC, internal R&D, and foreign trade (via Licenses, FDI, and machinery imports) on Total Factor Productivity.

To address these aims, we resorted to the Autoregressive Distributed Lag (ARDL) bounds testing methodology to study the long-run relationship between the selected variables.

Two main results are worth highlighting: 1) In the period of 1960-2022, the most important direct booster of the Portuguese TFP growth was the acquisition of foreign new knowledge and advanced technology through licenses/royalties and imports of machinery and other equipment, respectively; and 2) in spite of being considered a developed, high-income economy, Portugal is still a technological laggard economy where (total factor) productivity increases are obtained mainly through the absorption of foreign practices (FDI), knowledge (Licenses) and technology (imports of machinery).

Portugal is still at an intermediate level of development in terms of technology, depending crucially on international trade for innovation that significantly affects total factor productivity. Although general human capital (formal education) and internal business R&D efforts failed to emerge as significant direct boosters of TFP, they are critical for absorbing external practices, knowledge, and technology from abroad via FDI or the imports of machinery and equipment.

This study has contributed to the relevant literature at the theoretical, methodological, and empirical levels. At the theoretical level, the present study contributes to the very scarce literature on single countries' technological absorption capabilities clarifying through which channels TFP growth can be promoted. At the methodological level, the study employs the recent developments in time series analyses (see Kripfganz, & Schneider, 2023) and resorts Autoregressive Distributed Lag (ARDL) model estimations, which in contrast to more conventional cointegration approaches, allow to consider the structural breaks in the data and addresses the matters of endogeneity and serial correlation that characterizes time series data. At the empirical level, this study offers a rigorous and robust account of technology laggard contexts, where regardless of the level of a country's development, absorptive capabilities and international trade are fundamental for overcoming the prevalent and nerve-wracking productivity slowdown.

Our results have important policy implications. First, they seem to suggest that distinct, more ambitious education and innovation policies should be implemented to guarantee that the country has the 'right' type of human capital and R&D which are aligned with companies' needs for achieving higher levels of competitiveness and productivity. Secondly, given the importance of international trade for promoting TFP, a more efficient financial market and trade liberalization policies are in demand, which permit companies to access adequate and timely funding to acquire knowledge and technology from abroad. Finally, a good design and selective FDI attraction policies may be of surmount importance in stimulating aggregate TFP and ultimately putting Portugal converging, in a sustained way, to more developed economies.

Despite the novelty and contributions of the present study, there are limitations that may constitute interesting avenues for further research. In line with extant research, we considered human capital, and R&D in the aggregate, that is, without distinguishing their types. Distinct types of human capital (e.g., basic vs. high education degrees; Science and Technology vs. Social related higher education degrees) or R&D (basic vs. applied) may lead to different impacts on TFP. Moreover, we did not consider any variable related to the country's economic specialization evolution. Industry structure is likely to interact with the selected variables and influence the evolution of TFP (see Doré & Teixeira, 2023).

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Annex

Table A 1: Relevant time series

year	tfp	hc	rd	mach	fdi	lic
1960	80.4	1.36	0.0007	0.0291	0.0059	0.0004
1961	83.2	1.45	0.0006	0.0311	0.0059	0.0004
1962	86.0	1.56	0.0006	0.0327	0.0060	0.0003
1963	88.3	1.68	0.0005	0.0355	0.0060	0.0003
1964	90.3	1.84	0.0005	0.0331	0.0060	0.0004
1965	93.7	2.01	0.0004	0.0305	0.0060	0.0003
1966	94.2	2.13	0.0003	0.0320	0.0060	0.0004
1967	98.7	2.25	0.0003	0.0418	0.0050	0.0009
1968	109.0	2.33	0.0003	0.0340	0.0050	0.0007
1969	110.0	2.53	0.0004	0.0362	0.0040	0.0007
1970	112.9	2.74	0.0005	0.0400	0.0036	0.0007
1971	113.3	2.88	0.0006	0.0405	0.0061	0.0006
1972	116.8	2.98	0.0007	0.0418	0.0065	0.0005
1973	124.2	3.12	0.0006	0.0404	0.0063	0.0006
1974	115.7	3.23	0.0005	0.0417	0.0061	0.0007
1975	105.7	3.34	0.0006	0.0421	0.0060	0.0006
1976	109.0	3.38	0.0004	0.0452	0.0031	0.0007
1977	110.2	3.47	0.0004	0.0454	0.0027	0.0008
1978	109.3	3.55	0.0003	0.0449	0.0028	0.0010
1979	111.2	3.72	0.0005	0.0478	0.0029	0.0010
1980	110.9	3.91	0.0007	0.0611	0.0048	0.0011
1981	108.9	4.24	0.0008	0.0453	0.0055	0.0004
1982	108.0	4.41	0.0008	0.0439	0.0047	0.0009
1983	102.5	4.59	0.0008	0.0484	0.0054	0.0011
1984	99.5	4.74	0.0009	0.0472	0.0079	0.0009
1985	101.4	4.69	0.0009	0.0545	0.0101	0.0010
1986	103.9	4.9	0.0009	0.0600	0.0061	0.0010
1987	105.5	4.96	0.0009	0.0657	0.0097	0.0012
1988	109.3	5.1	0.0009	0.0657	0.0164	0.0015
1989	110.6	4.91	0.0011	0.0609	0.0287	0.0015
1990	110.3	5.15	0.0012	0.0630	0.0332	0.0012
1991	112.4	5.41	0.0012	0.0588	0.0274	0.0014
1992	110.5	5.46	0.0012	0.0515	0.0174	0.0015
1993	107.4	5.62	0.0012	0.0586	0.0161	0.0020
1994	106.2	5.8	0.0011	0.0646	0.0127	0.0016
1995	107.2	5.9	0.0011	0.0643	0.0058	0.0013
1996	106.9	6.53	0.0012	0.0636	0.0128	0.0016
1997	106.8	6.67	0.0013	0.0599	0.0232	0.0014
1998	105.9	6.66	0.0014	0.0559	0.0490	0.0016
1999	105.4	6.71	0.0015	0.0537	0.0058	0.0021
2000	104.5	6.79	0.0019	0.0561	0.0615	0.0023

year	tfp	hc	rd	mach	fdi	lic
2001	104.3	6.88	0.0024	0.0586	0.0503	0.0022
2002	103.8	6.96	0.0023	0.0618	0.0044	0.0015
2003	102.8	7.15	0.0023	0.0662	0.0627	0.0016
2004	103.8	7.39	0.0026	0.0734	0.0131	0.0018
2005	103.7	7.49	0.0029	0.0730	0.0171	0.0018
2006	103.7	7.62	0.0041	0.0772	0.0642	0.0017
2007	103.7	7.67	0.0058	0.0739	0.0250	0.0015
2008	102.3	7.78	0.0072	0.0655	0.0297	0.0018
2009	99.5	7.93	0.0075	0.0628	0.0228	0.0014
2010	100.7	8.06	0.0071	0.0670	0.0377	0.0015
2011	100.4	8.28	0.0069	0.0658	0.0401	0.0013
2012	99.0	8.5	0.0069	0.0671	0.0990	0.0014
2013	99.2	8.66	0.0063	0.0684	0.0695	0.0014
2014	98.5	8.87	0.0060	0.0701	0.0524	0.0014
2015	98.7	8.99	0.0058	0.0562	0.0064	0.0016
2016	99.0	9.11	0.0062	0.0555	0.0356	0.0017
2017	100.0	9.22	0.0067	0.0520	0.0483	0.0017
2018	100.7	9.14	0.0069	0.0492	0.0324	0.0016
2019	101.5	9.33	0.0073	0.0495	0.0430	0.0014
2020	99.5	9.58	0.0092	0.0526	0.0174	0.0018
2021	101.1	9.70	0.0100	0.0538	0.0307	0.0022
2022	106.6	9.83	0.0106	0.0554	0.0357	0.0025

Legend: tfp: Total factor productivity at constant national prices for Portugal, Index 2017=100, annual, not seasonally adjusted; hc: Education attainment for population aged 15-64, Total population, Portugal; rd: Ratio of business R&D to GDP, Portugal; mach: Ratio of machinery and equipment imports to GDP in t-6, Portugal; fdi: Ratio of inward FDI to GDP, Portugal; lic: Ratio of licenses and royalties to GDP in t-6, Portugal.

Sources: tfp: FRED (https://fred.stlouisfed.org/series/RTFPNAPTA632NRUG), 2020-2022 missing values filled assuming the growth rate of TFP conveyed by the OECD data; hc: 1960-1997 Teixeira & Fortuna (2010),1998-2020 UNESCO, 2020-2022 missing values filled assuming the average growth rate 2015-2020; rd: For FDI expenditures at current prices, for 1964-1972: JNICT ("Junta Nacional de Investigação Científica e Tecnológica") (1986), "Indicadores de Ciência e Tecnologia Portugal 1964-1982", for 1976-1990: INE, "Anuário Estatístico do INE 1976-1993, for 1992: JNICT (1995), "Potencial Científico e Tecnológico Nacional, 1992. Série Folha Informativa (Pré-publicação), Missing values filled using the author's linear interpellation. For nacional business expenditures of R&D at current prices, the data source used was DGEEC/ME-MCTES – "Inquérito ao Potencial Científico e Tecnológico nacioanl (IPCTN) – and source PORDATA última atualização: 2023-12-22. Finally, for the data on GDP at current prices the source used was INE – "Contas Nacionais Anuais (base 2016) – última atualização: 2024-02-29"; mach: Banco de Portugal, "Séries Longas" (1954-1995) and INE (1996-2020); fdi: Teixeira & Fortuna (2010) (1965-1969) and World Bank (1970-2022), missing values filled assuming the average growth rate 1965-1971 (1960-1964); lic: Teixeira & Fortuna (2010) (1960-2001), Banco de Portugal ("Balança de pagamentos tecnológica") and INE – "Contas Nacionais Anuais (Base 2016)" in PORDATA (2002-2022).