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FIRM-LEVEL TECHNOLOGICAL CHANGE IN AN INTERMEDIATE ECONOMY: EVIDENCE FROM PORTUGAL

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Abstract

Esta tese explora como as empresas de um país, que se encontra num nível de capacidade tecnológica intermédio, podem passar para um nível tecnológico superior – seja encontrando formas de entrar em algum aspecto de um mercado internacional já bem povoado por empresas globais, ou recorrendo a recursos locais, humanos e outros, para aumentar o nível tecnológico das suas atividades de produção. A tese é composta por três estudos.

O primeiro estudo, relatado no Capítulo 2, utiliza métodos qualitativos para explorar se e como as empresas portuguesas podem entrar com sucesso na cadeia de abastecimento para o fabrico de interiores de cabines de aeronaves (ACI). Baseamos a nossa análise em 75 entrevistas breves, 41 entrevistas semiestruturadas mais longas, participação em reuniões e exposições da indústria aeronáutica e um estudo documental, incluindo demonstrações financeiras de empresas. Constatamos que, embora Portugal tenha capacidades tecnológicas significativas que foram desenvolvidas em indústrias relacionadas, elas por si só não foram suficientes para garantir uma presença forte e independente na indústria de ACI. Concluímos que Portugal faria bem em se concentrar no fornecimento de componentes de alto valor, em vez de linhas completas de produtos ACI, e em implementar políticas para atrair tecnologias externas e intensificar as atividades de Investigação e Desenvolvimento (I&D).

O segundo e terceiro estudos adotam análises quantitativas usando um conjunto de microdados extremamente rico e único entre empregadores e empregados, os Quadros de Pessoal, que abrange quase todas as empresas privadas portuguesas e seus empregados. Criamos e aplicamos uma medida mais objetiva de avanço tecnológico com base na mudança da atividade económica atual de uma empresa para uma que envolva um maior nível de intensidade tecnológica.

Usando estes dados, o Capítulo 3 examina até que ponto o capital humano dentro de uma empresa está associado ao desenvolvimento de tecnologia. Três fatores foram encontrados para contribuir positivamente e significativamente para o desenvolvimento tecnológico: 1) nível de escolaridade; 2) experiência anterior de trabalho na mesma indústria; e, 3) a combinação de educação em Ciência, Tecnologia, Engenharia e Matemática (STEM) e experiência anterior de

trabalho na mesma indústria. A tese apresenta contribuições de gestão e políticas sobre como aumentar a probabilidade e a rapidez do desenvolvimento tecnológico das empresas.

O Capítulo 4 explora a relação entre o Investimento Estrangeiro Direto (IED) e o desempenho tecnológico das empresas e, nesse contexto, avalia o papel moderador do ensino superior e do ensino STEM. Os resultados empíricos indicam que a propriedade estrangeira através do IED está positivamente correlacionada com o desenvolvimento tecnológico das empresas. O capítulo também explora o efeito dessas variáveis nas vendas das empresas para diferentes intensidades tecnológicas. Os resultados contribuem para a literatura de gestão de tecnologia, sugerindo que o IED está positivamente associado à atualização tecnológica das empresas e que a educação, particularmente nas áreas STEM, é importante para obter maiores benefícios do IED.

This thesis explores issues related to how firms in a country that lies at an intermediate level of technological capability may move to a higher technical level – either by finding ways to enter some aspect of an international market that is already well populated by global firms, or by drawing upon local human and other resources to increase the technical level of its manufacturing activities. The thesis consists of three studies.

The first study, reported in Chapter 2, uses qualitative methods to explore whether and how Portuguese firms might successfully enter the supply chain for the manufacture of aircraft cabin interiors (ACI).

We base our analysis on 75 brief interviews, 41 longer semi-structured interviews, participation in aerospace industry meetings and exhibitions, and a study of archival data, including firm financial statements. We find that although Portugal has significant technological capabilities that have been developed in related industries, these alone have not been sufficent to secure a strong, independent presence in the ACI industry. We conclude that Portugal would be well advised to focus on supplying high value components, rather than full ACI product lines, and to implement policies to attract external technologies and intensify R&D activities.

The second and third studies adopt quantitative analysis using an extremely rich and unique matched employer-employee micro dataset, the Quadros de Pessoal that covers nearly all Portuguese private companies and their employees. We create and apply a more objective measure of technological advancement based on a companies' change from their current economic activity into one that involves a higher level of technological intensity.

Using these data, Chapter 3 examines the extent to which human capital within a firm is associated with technology development. Three factors were found to contribute positively and significantly to technology development: 1) education level; 2) prior work experience in the same industry; and, 3) the combination of Science, Technology, Engineering, and Mathematics (STEM) education and prior work experience in the same industry. We present managerial and policy insights on how to increase the likelihood and the speed of firms' technology development.

Chapter 4 explores the relationship between foreign direct investment (FDI) and firms' technological performance, and in that context assesses the moderating role of higher education

and STEM education. The empirical results indicate that foreign ownership through FDI is positively correlated with the technology development of firms. The chapter also explores the effect of these variables on firm sales for different technological intensity. The results contribute to the technology management literature, suggesting that FDI is positively associated with firms' technological upgrade and that education, particularly in STEM areas, is important to gain larger benefits from FDI.

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Chapter 1 Introduction

This dissertation explores several aspects of the following research question for firms operating in a county that lies at an intermediate level of technical development:

> *How do the strategic actions of firms and governments increase the likelihood and the speed of technology development and advance their own and their nation's national and international competitiveness of firms and the industrial structures in their country?*

The dissertation consists of three studies that focus on understanding the strategic path of an intermediate country that is working to foster high-tech industries, as well as the main drivers of technology development with particular emphasis on the difficulties of entering well established global markets and the effects of STEM education and foreign ownership.

The technological level of a country and its firms is one of the most influential determinants in explaining its global competitiveness and economic growth (Stokey, 2015). Over the last half of the 20th century, a number of nations have attempted to increase their technological capabilities to maintain or improve their global competitiveness or challenge incumbent countries which possess superior technologies (Amsden, 2001). While American, European and Japanese firms have taken technologically leading positions in most industries, emerging Latin American and some Asian countries were behind the leading countries for many years. However, countries such as Taiwan, South Korea and China, have shown rapid technological growth in many technological fields (Miao et al., 2018).

The rapid technological growth of these Asian countries raises questions regarding the mechanisms and factors of technology development, particularly in the context of technological catch-up. The technological catch-up observed in this subset of Asian countries is not commonly found in other laggard countries, such as those in Latin American and Eastern European, despite the fact that those countries have introduced and carried out a variety of policies to foster domestic technology development. Researchers have conducted extensive studies to explain this technological discrepancy among laggard countries by focusing on a large set of national and industry level factors (Miao et al., 2018).

A closely related strand of research related to technology development involves the strategic decisions of laggard countries to advance their industrial structures and compete with incumbent countries. In industrial sectors in which advanced countries dominate, laggard countries have endeavor to find opportunities to increase their presence in the global supply chains and, as a result, make a structural transformation of their economies. Laggard countries that lack in resources and capabilities face significant barriers that impede technological progress in their catch-up process. For example, technologically lagging countries heavily rely on foreign technologies rather than building their own technological capabilities, which situation is sometimes defined as involving a "middle technology trap" (Akçomak and Bürken, 2021). To assist laggard countries to overcome the barriers and compete with frontrunners in global markets, it is important to understand the technological opportunities and the efficacy of alternative strategies that could help to take advantages of those opportunities.

The literature that examines the technology development of laggard countries, countries such as Portugal that lie at an intermediate stage in technological catch-up, is less developed that that for counties that lie at lower stages, this despite the fact that intermediate countries represent a critical step in the emergence process. Fontes and Coombs (2001) have defined a country at an intermediate stage as a country that has considerable technological capabilities but also faces a number of limitations in its capabilities. While scholars have paid particular attention to the technological environments and activities of rising Asian countries (Miao et al., 2018) a country such as Portugal has different socio-economic contexts in terms of infrastructure, human capital and the openness of an economy. This makes it difficult to extrapolate insights from Asian cases of technological catch-up to intermediate countries. Thus, it is important to analyze and understand technological catch-up in the specific circumstance of an intermediate country.

The first study in this thesis investigates whether and how, under a number of limitations with regard to level of resources and presence of technological and non-technological competencies, Portugal might play a new and larger role in the supply chain of a high-tech industry – airline cabin interiors (ACI). The study provides an in-depth qualitative analysis of the Portuguese industry in this and closely related domains. We find and select research participants using snowball sampling, develop and revise a set of questionnaires, and carry out interviews with heterogeneous stakeholders across the industry. By analyzing the collected and coded data, we

identify the entry barriers that Portugal faces with respect to the ACI if it wishes to catch up with incumbents in this well-developed field with well-established supply chains. We identify and discuss opportunities in which it might use its intermediate level of technological capabilities. This study presents a framework and strategy by which an intermediate country might increase its participation in the global supply chain of a high technology product.

Understanding technology development at the firm level has been considered a key to predict the different behaviors and performance of a country. Given that country-level technological growth is mainly driven by firms, the technological abilities of domestic firms are closely linked with the technological level of countries. When country, industry and firm-levels of technological efforts are well aligned and harmonized, the speed and possibility of technology development can increase (Bartnik et al., 2018). For this reason, technological activities of firms attract particular attention from scholars. Many firm-level studies work on the question of why some firms successfully catch up with their leading firms in the industry and become an industrial leader, and other firms are unable to do.

One major stream of firm-level studies focuses on identifying key factors affecting the heterogeneous technological achievement of firms. The academic community has investigated major determinants of technology development mainly in the integrative framework of building technological capabilities (Miao et al., 2018). Technological capabilities present a firm's abilities to use various resources to generate technological outputs (Afuah, 2002). A firm's technological capabilities accumulate over time through the process of collective learning (Figueiredo et al., 2020). Technological learning including codification, communication and internalization of individuals and organizations is influenced by a large number of resources and capacities of firms (Kale and Singh, 2007).

Among various resources owned by firms, previous studies mostly agree about the role played by highly qualified human capital and human resources in technological learning. Highly educated employees create more innovative outcomes based on their educational attainments (Oluwatobi et al., 2016). Cantabene and Grassi (2020) illustrate that a well-educated workforce stimulates the propensity of firms to invest in R&D cooperation with external partners. Similarly, experienced employers with better managerial skills assist firms to focus on clear vision, allocate

R&D resources effectively and pursue more appropriate technological path (Deligianni et al., 2019; Protogerou et al., 2017). In line with the importance of human capital, firms need to develop human capital to promote knowledge acquisition and creation (Armando et al., 2018). Human capital may intensify the organizational learning system and play key to technology development (Laura, 2020).

The second study in this thesis, reported in Chapter 3, provides an analysis of the impacts of different dimensions of human capital on the technology development of manufacturing firms in Portugal. This analysis builds on literature on general and specific human capital, and their influence on technological activities at the firm level. We ask whether and to what extent the key constituents of general and specific human capital are critical for determining the technological performance of firms. To this end, we create and apply an original measure to objectively and comprehensively evaluate the technological change of firms. In addition, this study uses a rich dataset covering most Portuguese firms and employees in the manufacturing sectors to avoid biases that previous analysis giving too much weight on certain types of firms and industries, such as start-ups, may have. This study shows that each dimension of human capital has differentiated effects on the technological performance of firms. It also provides suggestive evidence that technological knowledge, skills and techniques gained through educational attainments in science, technology, engineering and mathematics (STEM) related fields should be complemented by an appropriate level of understanding of firm and industry contexts.

Existing literature illustrates many technological sources for firms to upgrade their technological capabilities and move up in the technological ladder. Foreign direct investment (FDI) is a channel to absorb foreign technologies and approach the global market for laggard firms with scarce technological resources. Foreign investors transfer advanced technologies to host firms and their suppliers by providing technological licensing, consulting and training (Hobday and Rush, 2007). Local firms may have opportunities to learn technological knowledge when observing and interacting with foreign firms, and imitating their products (Salomon, 2006). FDI could be a method to import external technologies from advanced country firms, which would be helpful to develop the internal technological capabilities of laggard firms.

In the third study, reported in Chapter 4, we expand the second study and explore whether FDI is technologically beneficial to subsidiaries in a host country and how human capital plays a role in the relationship between FDI and technology development. We conduct an empirical investigation to evaluate the statistical association between inward FDI and technology development by using the same dataset for the second study. We also try to examine whether tertiary education level and STEM education level moderate this association. Our analysis does not find evidences that FDI is positively associated with technology development while we find the moderating impacts of tertiary education and STEM education. The possibility of technology development depends on the level of tertiary education, particularly in STEM areas. These findings suggest fruitful implications for technology management and innovation policy.

The final chapter provides a brief summary of the work and some conclusions.

Chapter 2 Climbing up a Technology Ladder: Insights from the case of Portugal and aircraft cabin interiors

Abstract

This chapter asks how a country at an intermediate level of technological capability might increase its presence in a high-tech industry so as to upgrade its industrial structure. We focus on the role of Portugal in the supply chain for aircraft cabin interiors. We find that although Portugal has significant technological capabilities developed in related industries, these alone are not enough to secure a strong, independent presence in the ACI industry. Portugal would be advised to focus on supplying high value components, rather than full ACI product lines, and to implement policies to attract external technologies and intensify R&D activities.

2.1. Introduction

Many countries that are at an intermediate level of technological sophistication face the difficulty of developing strategies that will allow them to increase their role in the supply chain of higher technology goods and services. For example, Brazil is struggling to provide products in technologically advanced industries (Fraga, 2019; Stark, 2010) and South Korea wants to expand its supply to the aeronautic industry but it is uncertain whether that can be achieved (Lee, 2018). One possible strategy for doing this is to identify areas in which such countries have already developed significant capabilities in other sectors that overlap the skills and technology needed to participate in the high-technology sector of interest. Such overlap could provide the domestic foundation on which to build when trying to enter and move up the supply chain in other more challenging markets.

An example of this possible dynamic is presented by Portugal in the context of the supply chain for aircraft cabin interiors. Portugal, which today has only a marginal presence in the global ACI industry, has built a number of capabilities in aeronautics, including hosting an Embraer aircraft component assembly facility and developing a significant aircraft maintenance capability. The country also has well-established capabilities in automotive manufacturing,

casting, injection-moulded plastics, and leather and fabrics, all of which involve capabilities that are relevant to ACI manufacturing.

Therefore, we examine whether these current technological capabilities of Portuguese firms might provide a basis for growing a Portuguese presence in the supply chain for aircraft cabin interiors. In Section 2.1 we review and discuss the literature on technological catch-up and justify our choice of Portugal and the ACI industry. Section 2.2 comprises framework development including a review of the literature on related concepts, such as technological trajectories and technological capabilities. Section 2.3 discusses why we believe that Portugal might have a significant potential to become a supplier in the ACI industry. Section 2.4 describes the methods that we adopted to collect and analyze our data. Section 2.5 summarizes the current technical status of Portuguese firms, and assesses the opportunities and barriers that Portugal and its firms will face if they wish to enter the bottom rungs of, and then move up, the ACI industry supply chain. Finally, on the basis of the forgoing, in Section 2.6 we develop more general recommendations about the factors that firms and the government should consider before they try to enter a new high technology sector with the hope of moving up existing or future supply chains.

2.2. Theoretical background

2.2.1. Technological catch up in countries at an intermediate technological level

Researchers have argued that organizational and collective learning is a critical factor to improve technologies (Amsden and Hikino, 1994; Carayannis and Stokes, 1997; Ernst, 1998; Gil et al., 2003; Hansen and Ockwell, 2014; Kim, 1998; Malerba and Nelson, 2011; Mathews and Cho, 1999; Shan and Jolly, 2011). In term of learning process, R&D activities that firms and nations conduct are highlighted as core activities in technological development (Jan and Chen, 2006; Jin and von Zedtwitz, 2008; Shan and Jolly, 2011; Teubal, 1996; Wang et al., 2014; Wang, 1994). To increase the effectiveness and efficiency of R&D activities, the R&D-policy of governments need to be carefully designed and implemented (Chiang, 1990). Some researchers emphasize the importance of networks among R&D institutions including universities (Bodas

Freitas et al., 2013; Dantas and Bell, 2009; Goktepe, 2003; Mazzoleni and Nelson, 2009). Analysis regarding policies is not limited to R&D, but has expanded to the whole industrial plan including the role of a nation's institutions (Amsden and Chu, 2003; Breznitz, 2006; Gulhati and Sekhar, 1982; Haggard, 2004; King and Nowack, 2003; Veloso and Soto, 2001; Westphal, 1990).

As a source of technologies for latecomers which are not able to generate knowledge independently, importing technology assumes a significant role establishing requisite technological capabilities (Fu et al., 2011; Lee, 1996). Inward and outward foreign direct investment (FDI) is a major channel to absorb advanced technologies of foreign firms and foster technological innovation (Amighini and Rabellotti, 2010; Barry et al., 2003; Fu and Gong, 2011; Lorentzen et al., 2003). Multinational companies (MNC) mainly contribute to FDI and affect domestic technological growth ((Amighini and Rabellotti, 2010; Buckley and Hashai, 2014; Narula and Dunning, 2000).

In some industries, each technology has a specific lifespan and technology trends change in a way that provides latecomers with the opportunity to develop a strategy to seize the technological leadership from incumbents which may be stuck with obsolete technologies (Landini et al., 2017; Lee and Ki, 2017; Lee and Malerba, 2017; Park and Lee, 2006).

Most of the literature on catch up for firms and nations with intermediate levels of technological sophistication deals with industries such as semiconductors, automotive and telecommunication industries or with firms located mostly in East Asian and Latin American countries such as South Korea, China, Singapore and Brazil (Cho et al., 1998; Dantas and Bell, 2009; Fan, 2006; Figueiredo, 2014; Gao, 2014; Hitt et al., 2000; Jan and Hsiao, 2004; Lee and Lim, 2001; Mathews and Cho, 1999; Mu and Lee, 2005; Quitzow et al., 2017; Shan and Jolly, 2011; Sohn, Eunhee et al., 2009; Viotti, 2002; Wong, 1999). In contrast, intermediate countries in Europe have attracted less research attention (Fagerberg and Godinho, 2006; Narula and Sadowski, 1998).

The size of the domestic market may shape the possibility of benefitting from economies of scale and the availability of natural resources can partly explain the likelihood of earning foreign exchange (Auty, 2007, 1994). Using the two factors, domestic market and natural resource, countries have been classified into four categories: 1) market-modest and resource poor, such as

Korea, Taiwan and Portugal, 2) market-rich and resource-poor, such as India and China, 3) market and resource-rich, such as Brazil and Mexico, and 4) market-poor and resource-rich, such as Kenya (Auty, 2007, 1994).

In the category 1), East Asian and Latin American countries pursued catch up strategies in a context that was very different from the one faced by late industrializing economy in the European Union in light of significantly different social and cultural backgrounds. South Korea and Taiwan were not true multiparty democracies for most of the time they were catching up to technological leaders, which may have made decisive government action easier to pursue (Stark, 2010). East Asian and Latin American countries were also not part of a close-knit economic and political entity like the EU. The workforce of these countries could not leave easily to work and gain experience in more developed countries.

Portugal is classified as an "intermediate economy" a term that describes countries which possess considerable technological capability but also have constraints that prevent them from developing technologies independently or establishing effective innovation systems at the national level (Fontes, 2001; Fontes and Coombs, 2001; Padua et al., 2002). Workers in Portugal have access across the EU and most younger Portuguese professionals are fluent in English and often also other European languages (AICEP Portugal Global, 2013a; EY, 2017). EU firms are simultaneously potential collaborators, customers, and competitors for Portuguese firms. Portugal can receive support from – but is also constrained by the rules of – both national and EU institutions.

For these reasons, a study of the technological capabilities and catching up strategies of Portugal can provide insights that extend, in varying degrees, to an understanding of the options available to other countries at the intermediate level of technological capabilities. However insights gained are likely to most directly generalize to other EU member countries that are in a similar situation, such as the Eastern European countries.

2.2.2. Theoretical framework for identifying technological catch up and entry barriers in a high tech industry

2.2.2.1. Latecomers, late entrants and late arrivers

The literature argues that the process of shrinking a technological gap between technological leaders and followers is typically continuous and gradual (Abramovitz, 1986; Raz et al., 1983; Sohn, Eunhee et al., 2009). It differentiates two groups that may need to catch up, latecomers and late entrants. Latecomers have limited capabilities in all relevant domains, and thus have no choice but to enter a market late compared to their incumbents because of resource scarcity and limited technical and organizational capabilities. In contrast, later entrants typically have developed significant technical and organizational capabilities in some other area. As Mathews (Mathews, 2002) explains, they choose to delay entry to a market for a variety of strategic reasons, such as reducing the time and money required to search out consumer response. Of course, in many cases there is no sharp distinction between latecomers and late entrants.

Many existing and potential players in the ACI industry have not only the features of latecomers but also that of late entrants. Firms with poor technological capabilities face challenges to maintain the consistent quality level that is essential in the ACI industry (Oliver Wyman, 2015). Due to the diversity of upcoming technologies and increasing R&D expenses, the ACI industry is highly uncertain. This can hinder firms that do not have enough resources and capabilities to enter the industry (Reis et al., 2016). For this reason, in parts of the discussion that follows we use the more neutral and intermediate term “late arrivers”.

2.2.2.2. Technological trajectory of late arrivers

A number of scholars have described the different stages of technological catch-up. These stages are classified by the level and the characteristics of accumulated knowledge (Dutrénit, 2004; Kim, 1980; Lall, 1992; Mathews, 2002). As firms accumulate technological capabilities they move from the initial stage of establishing routine production capability (sometimes termed essential knowledge) to later stages of building basic and intermediate knowledge, and finally develop advanced or more complex knowledge (Dutrénit, 2004). Table 2-1 provides our

synthesis of the overall literature that discusses the catching up stages in technology as well as key strategy and major source of technologies.

To build minimum capabilities and essential knowledge, firms may begin by focusing on assembling final products using imported parts (Lee and Lim, 2001), simply imitating products of incumbents(Kim, 2001) and mostly obtaining manufacturing technologies (Dutrénit, 2007).

In later stages firms may imitate existing products, while upgrading some parts of those products (Kim, 2001; Lee and Lim, 2001). Sohn et al. (2009) and Kim (1999) argue that imitation of advanced technologies is a requisite learning experience to accumulate knowledge that can become the root of further technological capabilities. In these middle stages firms rarely have abilities to create knowledge on their own, and mainly must rely on external sources (Dutrénit, 2004; Li and Kozhikode, 2008; Sohn, Eunhee et al., 2009).

As the technological capabilities of firms increase, they establish a more complex knowledge base and find it increasingly difficult to extract support from incumbents (Lee, 2005). Incumbents may feel threatened by firms entering late as they begin to develop more advanced technological capabilities. Incumbents may hesitate to transfer technologies due to fear of a "boomerang effect" in which their technology buyers become their competitors and take their leading position in the market based on transferred technologies (Lee, 2005). For some latecomers, this situation is perceived as a technological crisis and makes them purse a strategy of independence (Kim, 1998).

The final stage in Table 2-1 involves advanced or complex knowledge. At this stage, simple assimilation of obsolete technologies, which is typically the basis for work in the previous stages, is insufficient and intensified learning activities are critical to catching up to incumbents (Sohn, Eunhee et al., 2009). Firms, which reach this stage, typically must make high R&D investments (Lee, 2005) and have the ability to create new or better products (Lee, 2005; Lee and Lim, 2001). In many cases, firms in this third stage own their brands and announce innovative products (Mathews, 2002).

Table 2-1: Technological catch up stages of late arrivers and key features of each stage. While this table was constructed by the authors, it is informed by the writings of Dutrénit, 2004; Kim, 1980; Lall, 1992; Lee, 2005; Lee and Lim, 2001; Li, 2011; Pavitt, 1984.

	Stage 1	**Stage 2**	**Stage 3**
Technological Level	Low	Medium	High
Catching up Stage	Routine Production Capability or "Minimum Essential Knowledge"	Basic and Intermediate Knowledge	Advanced Knowledge or "Complex Knowledge"
Major Activities	Assembly Operation and Process	Low and High-tech Part Development	New Product Design
Technology Strategy	Technology Import - Production with given design and manuals Increasing Absorptive Capacity	Switch to In-house R&D - R&D consortium - Overseas R&D outposts Increasing Absorptive Capacity	Intense R&D - Co-development - Strategic Alliances - Public R&D
Key Technology	Cost-cutting	Product-design	Cost-cutting and Product-design

This description of incremental catch up is applicable to low-volume, high-tech, and high-value products, such as the components of the aircraft cabin interiors. Kiamehr (2017) observed that the technological catch up model which consists of three different stages is valid for technology intensive products, drawing evidence from the Iranian hydro power industry.

2.2.2.3. Developing technological capabilities of late arrivers

Advancing from one stage in Table 2-1 to the next requires the acquisition of technological capabilities. Technological capabilities, including explicit and tacit knowledge, are a source of a firm's sustainable competitiveness in the market (Lee et al., 2001; Nelson, 1991; Porter, 1985). Many studies have shown that technological capabilities are abilities to understand, duplicate and manipulate technologies (BELL and PAVITT, 1993; Figueiredo, 2008).

External knowledge and absorptive capacity acquired through R&D activities

Developing technology capabilities has been generally understood in terms of learning processes (Hansen and Ockwell, 2014; Kim, 1999). Thus, the R&D activities that firms undertake in order to assimilate and internalize technological knowledge have been seen as a critical factor to create technological capabilities (Helfat, 1997; Nelson, 1981; Sher and Yang, 2005). The proxies which are related to R&D activities include R&D intensity, R&D expenditures, physical infrastructure such as R&D facilities and test centers, and technical personnel who possess skills and abilities to manipulate and improve technologies(Lall, 1992; Lee and Lim, 2001).

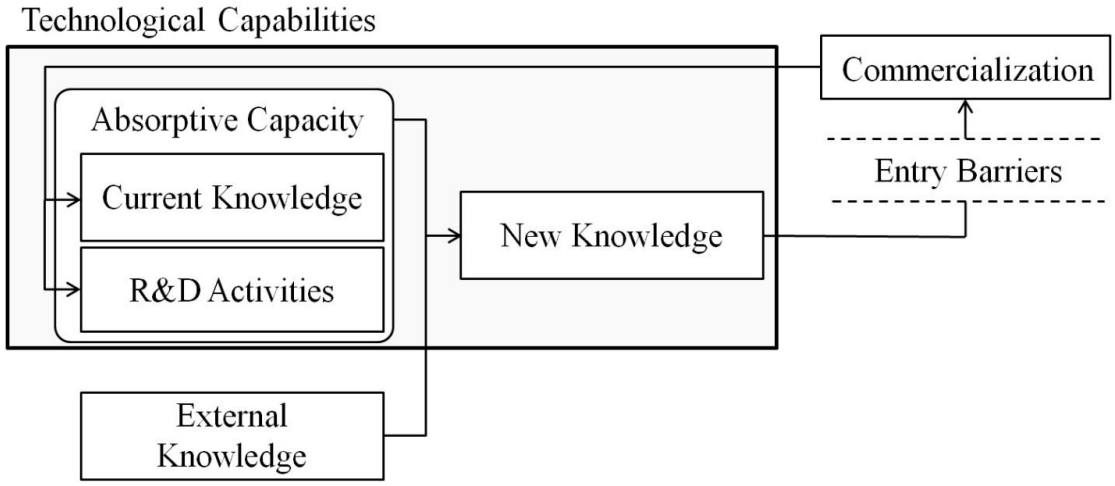


Figure 2-1: Catching up model of technological capabilities (Adapted from the publications of Kim, 1998, and Lee and Lim, 2001)

Latecomers, and to some degree many later arrivers, do not have enough technological capabilities to independently manufacture or design products that can compete against the products of incumbents (Mathews, 2002; Raz et al., 1983). Thus, they require technological support from outside the firm, such as foreign-supplied manuals on production lines or foreign-supplied designs applied to their products, to secure the level of knowledge required at Stage 1 and 2, upon which they can then build to develop more advanced knowledge (Dutrénit, 2004; Lee, 2005; Raz et al., 1983). In much of the literature this support and transfer is reported to come from outside the country.

Wherever transfers come from, when latecomers and later arrivers import technologies, they must possess the ability to understand and assimilate that technology in their organization if they are to make full use of it (Cohen and Levinthal, 1990; Li, 2011; Lichtenthaler and Lichtenthaler, 2010; Shan and Jolly, 2011). This absorptive capacity has been defined as "the ability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128). Many researchers have found that a firm's R&D activities improve its absorptive capacity (Cohen and Levinthal, 1990; Griffith et al., 2003; Lane and Lubatkin, 1998; Leahy and Neary, 2007).

This conception of external knowledge and absorptive capability is pertinent to late arrivers in the ACI industry. New entrants of the ACI industry mainly rely on technologies that are developed elsewhere. Absorptive capacity to identify and assimilate external knowledge is a key capability for these technologically lagged firms in the ACI industry. For example, AVIC, China's largest aircraft manufacturers, has maintained the cooperation relationship with Boeing and merged a series of leading firms to acquire technologies (PRNewswire, 2012; Reals, 2018). The foreign partners of AVIC provide technological support in quality control and operations management (Crane et al., 2014).

Entry barriers to commercialization

Whether a firm is a latecomer, a late entrant, or a late arriver that lies somewhere in between, they typically confront barriers blocking their acquisition or development of technologies and securing customers. Porter (1998) defined barriers as obstacles hindering entry to a specific market.

Firms that enter late typically require considerable expenditure to acquire technologies from incumbents in the initial stage (Perez and Soete, 1988). More advanced products require an even larger investment in knowledge (Howitt, 2005). In addition, these technologies from outside not only involve explicit knowledge but also tacit knowledge, the acquisition of which can require enormous time and energy (Perez and Soete, 1988). Thus, the financial burden of heavy investment for technology acquisition becomes an obstacle for firms that enter late.

After overcoming the technical barriers, the outcome of R&D activities is tested in the market (Lee and Lim, 2001). Successful commercialization of the technological output provides resources for more vigorous R&D activities, which can further strengthen the technological capabilities (Lee and Lim, 2001). In high technology industries, the market oriented knowledge integrates with the current knowledge and significantly increases a chance of successful R&D activities (De Luca et al., 2010; Im and Workman, 2004).

Firms that enter late typically also face non-technical disadvantages and barriers that hamper commercialization of the R&D output. Many studies show that incumbents have a cost advantage and already possess required product certifications (Han et al., 2001; Karakaya, 2002; Pehrsson, 2009). On the other hand, late arrivers typically suffer under financial burdens until they generate enough profits to offset their initial investment which was required to enter the market (Karakaya, 2002). Even after late arriving firms establish a complex knowledge base to design and manufacture competitive products, customers who are used to buying from the incumbents hesitate to change suppliers. This may be due to factors including customer loyalty, brand recognition, and high switching costs (Han et al., 2001; Karakaya, 2002; Krouse, 1984; Lee, 2005).

Entry barriers are one of the distinctive attributes to understand the ACI industry. It is commonly believed that the aeronautic industry has high barriers to entry (Brown-Grossman and Domínguez-Villalobos, 2012; Hernández Chavarria and Carrillo, 2018; Kiamehr, 2017). A series of technical and non-technical barriers limit the opportunity for late arrivers to collaborate with incumbents and expand their involvement in the supply chain of the aeronautic industry (Bediér et al., 2008). The ACI industry seems to share similar barriers to entry while there are growing signs that major players of the ACI industry are more open to find new vendors for more robust and reliable supply in recent years (Foster, 2019; Global Banking & Finance Review, 2019; Walton, 2017).

2.3. Portuguese ACI industry context

2.3.1. The global ACI industry

While reliable numbers are difficult to find, in 2017 the ACI market was certainly smaller than $30 billion per year, although estimates suggest that it might be as small as $12 billion (Frost & Sullivan, 2018; Oliver Wyman, 2015). It is dominated by a handful of companies, such as Zodiac Aerospace, B/E Aerospace, Recaro Aircraft Seating, Jamco and Diehl whose revenues in 2017 are $3 billion, $3 billion, $0.5 billion, $0.6 billion and $ 0.7 billion respectively (Diehl, 2018; Jamco, 2018; Recaro, 2018a; Securities and Exchange Commission, 2017; Zodiac Aerospace, 2017). This suggests that the largest five companies might control up to 65% of the market. This degree of consolidation represents a significant barrier to entry. These companies spend heavily on research, development, and engineering. B/E Aerospace spent $290 million in 2017 or 10% of its revenues; Diehl, the parent company of Diehl Aviation spent $330 million, up from $260 million in 2016.

At the same time it is not clear that the business is particularly profitable. Zodiac Aerospace's interiors business made an operating loss of 5% of revenues in 2017 and Jamco, B/E Aerospace, Thompson Aero Seating recorded 17%, 3%, and 13%. The leading companies have a presence in emerging markets with low labor costs. Zodiac Aerospace has a seat assembly facility in China (Euronext, 2013). China's own companies have started developing and delivering aircraft seats (Qiu and Goh, 2018).

A simplistic calculation illustrates that the industry represents a modest, niche market: in 2017, Airbus and Boeing collectively delivered about 1500 aircraft (Leahy, 2017). At a generous 250 seats per aircraft, this translates to 375,000 seats per year. In contrast, nearly 100 million automobiles were sold in 2017. At four per vehicle, this represents a market of 400 million seats (OICA, 2019).

2.3.2. Portuguese potential in the ACI industry

The Portuguese aeronautic industry, including the space sector, includes 68 firms (AICEP Portugal Global, 2018). Portugal manufactures a wide range of parts, such as materials, electronics, and software (AICEP Portugal Global, 2013a). 87% of the parts which are produced in Portugal are exported (AICEP Portugal Global, 2018).

In 2015, 68 firms of the Portuguese aeronautic industry realized an annual turnover of 1.72 billion Euros and employed 18,500 employees (AICEP Portugal Global, 2018). Another statistics from Banco de Portugal (2018) shows that the combined revenues from the 29 firms in Portugal's "Manufacture of air and spacecraft and related machinery" sector were $160 million in 2017. The sector produced a net operating income of $21 million in 2017, which fell to a loss of $400k once interest and tax were accounted for. Of the 29 firms, 18 had a negative net income. Total cash in hand, as of 2017, was $8 million.

As noted above, Portugal and its firms have a number of skills and technologies similar to those needed in the ACI industry. In the automotive industry Portugal already has strength. The ACI and vehicle interior industries share many components, such as seats, windows, seatbelts, non-flammable textile and fabrics. Global car interior manufacturers, such as Recaro, Mitsubishi Chemical and Toray, supply their products to both industries (Mitsubishi Chemical Corporation, 2018; Recaro, 2018b; Toray, 2018). Toray in Japan develops advanced materials for both industries at one R&D center (Toray, 2018). Boeing, the leading aircraft manufacturer, works to develop aircraft seats with Adient, the car seating provider (Boeing, 2018).

Portugal's automotive industry, including car interiors, has achieved a competitive position in the global market. Portugal was ranked 32nd in car manufacturing in 2016. A number of global leading firms, Toyota, Mitsubishi, Isuzu, PSA and Volkswagen, own manufacturing facilities in Portugal and have increased their manufacturing capacity (AICEP Portugal Global, 2017; OICA, 2019). Global and Portuguese components firms supply products to car manufacturers in and outside of Portugal. In 2018, more than 200 automotive components suppliers in Portugal recorded an annual turnover of 10 billion Euros and employed 50,000 employees (AFIA - Associação de Fabricantes para a Indústria Automóvel, 2019).

Portugal also has a strong industrial base in plastic moulding, metal work, leather and fabrics, all industries that are relevant to the ACI industry. These industries are key manufacturing sectors in Portugal and have secured international competitiveness (Portuguese Chamber Of Commerce, 2019). Automotive components firms mainly manufacture and supply metal, plastic, rubber and textile parts of cars (AFIA - Associação de Fabricantes para a Indústria Automóvel, 2019). Plastic moulding firms in Portugal have innovated, targeting the global market and becoming leading firms in the industry (Beira et al., 2005). Portugal ranked in 14th out of 27 EU member countries by export volume in metal work and has increased its share in the global market (Arnold, 2015; ECORYS SCS Group, 2009).

2.4. Method

As discussed in Section 2, researchers have so far paid scant attention to the process by which countries at intermediate levels of technical sophistication enter supply chains of the aeronautic industry that require capabilities that overlap with their existing industrial base. Qualitative research is suitable to understand phenomena that are theoretically immature or controversial (Edmondson and Mcmanus, 2007; Gibson, 2006). Therefore, this study applies qualitative methods to our study of Portugal's prospects as a late arriver to the ACI industry.

Case studies allow researchers to understand complicated social phenomena in a holistic and cohesive manner (Starman, 2013; Yin, 2009). This study adopts a single case study approach. Our unit of analysis is the Portuguese ACI industry, including both Portuguese companies that are already in this industry and the ones that might potentially participate in the future (Yin, 2009). We believe that studying this case will yield insights for other countries with intermediate technological capabilities, which are attempting to foster high-tech industries in the countries (Seawright and Gerring, 2008).

To collect data, we conducted semi-structured interviews with open-ended questions. These induced rich, detailed response from interviewees (Jackson et al., 2007). The results from these interviews have helped reveal key opportunities and barriers for Portuguese industry to enter the ACI supply chain (Edmondson and Mcmanus, 2007). The data collection is composed of two

phases of interviews: the first phase consists of exploratory interviews and the second phase of three rounds of in-depth interviews (DiCicco-Bloom and Crabtree, 2006; Krosnick, 1999).

During the first phase of interviews, we begin to scope out the topic, by conducting exploratory interviews at the Aircraft Interior Expo held in Hamburg, Germany, in April 2017. These exploratory interviews were designed to help us to understand the overall ACI supply chain, key success factors, entry barriers, major components, and major players across the ACI industry. This Expo is the industry's leading event, involving more than 550 exhibitors covering wide range participants in the ACI industry from materials suppliers to full-system integrators. It attracts more than 18,000 visitors (Aircraft Interiors Expo, 2019). We interviewed ACI exhibitors who we identified as potential competitors or customers of Portuguese firms because they are active in those product categories that Portugal might consider entering: seating, flooring, material, plastic moulding, overhead storage, galley, window shades and blinds, and soft furnishing, upholstery and textiles (see section 3). We did not interview in categories in which Portuguese industry has lower competitive capabilities, such as in-flight entertainment and communication (IFEC) and IT solutions. Seventy five exhibitors agreed to respond among a total 396 firms in the product categories we targeted. The exploratory interviews were conducted through one-on-one meetings of 10-20 minutes. Relying partially on an informal protocol, we asked respondents to provide information regarding trends, business norms, and the structure of the ACI industry. If interviewees requested, we provided them with a print copy of the protocol to help them to easily understand our questions and prepare answers. In this case, as with our interviews, interviewees were allowed to provide their opinions without constraints and interviewers asked additional questions if necessary.

In the second phase of the study, in order to delve more deeply into what we found through these exploratory interviews, we collected data from relevant and well-developed industries in and out of Portugal, such as textile, leather, plastic moulds, metalwork, and automobile. The rationale for the selection of these industries is explained in Section 3. In this second phase, we conducted a total of 41 detailed semi-structured interviews with individuals who work in each of the relevant industries, or with the governments. Interviews lasted between 15 and 60 minutes and were conducted between December 2016 and November 2018. The interview protocol was composed by questions that covered the concepts of Section 2.2.3: market and technological

barriers to entry in the ACI industry, strategies and policies to support firms entering the ACI industry, technological capabilities, R&D strategies, and required management resources. The questions were adapted for the different interviewees' profiles: (1) managers of companies already supplying components to aircraft interiors industry (27 interviews), (2) managers of companies with the capabilities to supply ACI industry (9 interviews), (3) participants of R&D projects about aircraft interiors (3 interviews among 9 interviews with (2)), and (4) industrial associations and government agencies (5 interviews).

We recruited respondents by snowball sampling (Noy, 2008). Portuguese industry with involvement in ACI is small and integrated with the aeronautic or relevant industries. Hence it is difficult to identify individual firms and stakeholders. In this case snowball sampling had the advantage of efficiently finding relevant people to participate in the study (Sadler et al., 2010).

A total forty-one interviews with Portuguese and non-Portuguese stakeholders were conducted in three rounds. The process started with four preliminary interviews to refine the interview protocol and identify potential interview participants. Each interviewee in the first round provided one to three links to other potentially key players in this industry that helped us to recruit other respondents. We refined the interview protocol and applied it to a further eight interviews in the second round. To cross validate what we found through the two rounds of interviews, in a third round we conducted 29 interviews with five Portuguese stakeholders and 24 non-Portuguese stakeholders, such as officers of a foreign government and, potential customers and competitors.

While the number of respondents may seem modest, for two reasons we believe it is sufficient and appropriate to understand the Portuguese ACI industry. First, the respondents include all significant players involve with the ACI industry in Portugal as listed in the Portuguese aeronautic firm lists of PEMAS, the Portuguese aerospace industry association, and AICEP, Portuguese trade and investment agency (AED Portugal, 2019; AICEP Portugal Global, 2018). Second, as we completed the third-round interviews, we found respondents were no longer identifying new firms or organizations relevant to the ACI industry or providing new information or insights. Hence we believe that our data pool reached saturation with respect to useful responses.

The 41 interviews in the second round were conducted in person at the interviewee's office or in three cases via Skype video conferencing. After obtaining the interviewee's informed consent, 40 of the interviews were recorded. In the one case in which the interviewee asked not to be recorded the two interviewers took extensive notes.

Interview responses were analyzed in stages. First, all the transcripts of the interviews were read carefully several times. They were then analyzed with an open coding scheme to capture key aspects of the data (Leavy and Saldaña, 2014). The codes were classified and grouped according to subject. This process was iterated to refine the codes into broader categories. The categories were refined until they provided a balanced and comprehensive representation of the interview data. The list of categories was modified according to the discussion of a faculty committee. This approach provided a systematic overview of the data, making it possible to find themes in the data that are not immediately apparent (Ritchie et al., 2014). Transcripts of the interviews were analyzed using the MaxQDA software.

Table 2-2: Multiple data sources were used to enhance trustworthiness and credibility.

Category	**Sources**
Official Documents	Governments, International Organizations
Datasets	Portuguese Central Bank, Industrial Associations
Market Reports	Consulting Firms, Market Research Firms, Major Players' Reports, Industrial Associations
Site Visits	Embraer, Mecachrome, Lauak, OGMA
Industry Fairs	AED Days (Portugal), The ACI Expo (Germany), The Istanbul Air Show (Turkey)
Regulations	FAA, EASA
Press Releases	News Papers, Magazines
Journal Articles	Academic Journals
Others	Catalogs, Brochures, Homepages

To enhance trustworthiness and credibility, triangulation was used. Triangulation is a strategy "to collect data using multiple methods and look at the research question from multiple data points" (Leavy and Saldaña, 2014, p. 551). The interview responses were triangulated against

data from resources that included journal articles, newspapers, national and international statistical data, market reports, regulations, and official documents from governments and the EU. When ambiguities arose we requested interviewees to clarify their meanings and our interpretations.

2.5. Assessment of the Portuguese ACI industry in the context of technological catch up

2.5.1. Portugal in the technological trajectory of late arrivers

Potential suppliers focus primarily on simple manufacturing and are mainly at Stage 1 (Table 2-1). These firms are experienced in 1) the other sectors of the aeronautic industry, such as maintenance, reimbursement and operation (MRO), or 2) the automotive industry, which shares similar technologies and regulations with the ACI industry and other relevant industries such as plastic and metalworking. Product designs mainly rely on sources that lie outside of Portuguese firms. In the automotive industry, for example, because of its low labor cost, Portugal plays a role as a manufacturing base rather than as a R&D center (AICEP Portugal Global, 2017).

Evidence from interviews shows that many Portuguese firms have the technical potential and capability to become suppliers and some of them own significant capabilities to compete with incumbents in the ACI industry. For example, the metal moulding industry in Portugal generates approximately $1 billion a year in revenue, an operating profit of 16%, and $60 million cash in hand in 2017 (Banco de Portugal, 2018). However, respondents suggested that technologies and skills accumulated in other industries will need further adjustment if they are to be applied in the ACI industry.

Some Portuguese firms are already supplying services and products in the ACI industry. These include Alma Design, Couro Azul and AUNDE (formerly Karmann Ghia). Alma Design is a Portuguese design company which specializes in the interiors of transportation vehicles (Almadesign, 2018). However, while they have done conceptual ACI designs, as best we could determine Alma Design appears not to have undertaken any engineering or certification work. That said, the “Specialized design activities” sector, into which Alma Design falls, had a turnover of $270 million in 2017, and turned operating and net profits of $27 million (a 10%

operating margin) and $13 million, respectively (Banco de Portugal, 2018). This suggests that the sector might have the financial resources to mount a marketing campaign targeted at selling into the aerospace industry.

Couro Azul also has provided leather products for private jets, as well as for to all the Airbus A330 neo aircraft that TAP has purchased (APLF, 2016). The leather industry generated $3 billion in revenue, on which they earned operating and net profits of $174 (5% operating margin) and $46 million respectively. AUNDE produces textiles used in the automotive and aeronautic industries (AUNDE, 2017).

Table 2-3: Portuguese existing suppliers mainly remain at Stage 2 for ACI industry.

	The features of Stage 2	**Portuguese existing ACI suppliers**
Technological Level	Medium	• Own manufacturing and operational skills, but still lack design skills
Catching up Stage	Basic and Intermediate Knowledge	• Supply products to majors players in the ACI industry • Need to technological support from leading firms • Can not conduct testing and examination independently • Do not have or partly have certifications
Major Activities	Low and High-tech Part Development	• Develop technologically simple parts: leather, synthetic leather, fabric, etc. • Upgrade the products: - Increase product duration - Apply environmentally friendly manufacturing process - Add colours or patterns in the product assortment • Undertake the interior refurbishment project for TAP
Technology Strategy	Switch to In-house R&D - R&D consortium - Overseas R&D outposts Increasing Absorptive Capacity	• Establish consortiums for co-R&D projects • Intensify the domestic network through the industrial association • Understand technical guidance from outside and imply them to the products
Key Technology	Product-design	• Adjust and improve the product designs

The products of Portuguese existing suppliers in the ACI industry are similar and partially upgraded in terms of quality and price compared to those that their competitors supply, which means, rather being innovative or entirely new.

A few Portuguese firms have made attempts to move to Stage 3 in which firms secure independent abilities to develop innovative products that can differentiate companies from its competitors or create new markets. For example, Alma Design participated in the R&D project and the futuristic concept of aircraft cabin interior as the result of that project received the international 'Crystal Cabin Award' in 2012 (Crystal Cabin Award, 2019). However, there is no evidence that these efforts have led to commercial products or given rise to commercial success by Portuguese firms in the ACI industry.

2.5.2. Technological capabilities of Portugal

2.5.2.1. Absorptive capacity acquired through R&D activities

In the ACI industry, it is essential to conduct intensive R&D activities and extensive product testing to demonstrate quality and achieve certification before a product can be sold. Portuguese firms also have conducted some independent R&D activities to move forward to the further stage in the technology development trajectory. The Portuguese government sponsored a series of ACI design projects called 'FACE', 'New FACE', 'LIFE' and 'Flexcraft'. These projects were conducted by consortiums which consisted of Portuguese suppliers, R&D institutions and the aircraft manufacturer and aimed to create the new configuration of the cabin (Flexcraft, 2019; LIFE, 2011; NEWFACE, 2015). Through these R&D projects, eight Portuguese firms including Amorim and Frontwave, which specialize in materials, obtained technologies and skills necessary to manufacture and design ACI components and figured out what technologies and skills are missing currently.

Besides four projects solely focusing on ACI designs, Portugal has conducted 132 R&D projects aimed at enhancing the skills and technologies that would be required in the aeronautic industry since 2005 (Barros et al., 2019). Two third of the projects were undertaken by international consortiums that leading firms, such as Dassault, Safran and Zodiac in France and

Rolls-Royce in the UK participated in. A total of 68 Portuguese firms, research institutes and universities involved in these projects covering aerostructures, testing and materials.

Portugal operates product and material testing facilities: for example, CEiiA, which is a center testing materials and full-scale structures for high-tech industries such as aeronautics (CEiiA, 2016). CEiiA conducts and analyses the results from material strength and fatigue tests to help aeronautic product development (CEiiA, 2016). ISQ, which is a firm conducting technology related services in many sectors, also provides testing services for the aeronautic industry. Based on its experiences regarding the aerospace sector mainly accumulated at the European Space Center in French Guiana, this company conducts various testing services for major players such as Thales (ISQ Group International, 2019)

Some Portuguese firms including TAP Maintenance and Engineering, Alma Design and Couro Azul have completed a refurbishment project of the interiors of Airbus A330-200s that TAP is operating (Kjelgaard, 2017). These Portuguese firms demonstrated their absorptive capacity if appropriate technological support is given, which in this case came from Airbus.

2.5.2.2. Entry barriers

It is well known that significant barriers exist for entry into the market for large commercial aircraft (Nolan, 2012). For example, Klepper (1990) argued that entering the aircraft industry is an expensive and time-consuming endeavor. Particularly, it takes approximately five to ten years to develop new products (Niosi and Zhegu, 2010). Economies of scale and learning are another entry barriers distinguished by Braddorn and Hartley (2007).

Respondents suggested that Portuguese firms encounter difficulties in finding customers in the ACI industry since customers in this industry seldom change suppliers. The interviewees suggested that this conservatism is mainly due to concerns about safety, which also drives stringent regulatory certification. Aircraft manufacturers tend to give approvals to relatively few ACI suppliers for their aircraft. Because R&D in the industry takes a long time and a single disruption of a supplier can result in the failure of an entire supply chain, customers prefer long-term relationships with their suppliers (EY, 2018a; Haillette and Plandé, 2015; Results Today, 2013).

Respondents stated that the ACI industry requires firms to make long-term investments, which are major entry barriers, to become suppliers. The aeronautic industry requires a significant amount of investment at the market entry stage which entails long lead time and financial risk (EY, 2018a; Results Today, 2013).

Corporations which operate within aviation do so under the auspices of a regulator like the Federal Aviation Administration (FAA) to ensure passenger safety. The FAA oversees all aircraft production and maintenance procedures (Waikar and Nichols, 1997). For example, according to FAA Regulation Part 25, all aircraft seats should endure stresses of sixteen times the force of gravity and all materials used for the ACI have to meet strict fire-safety requirements in the various environments that the materials might experience during their service lifetime (Federal Aviation Administration, 2018). Suppliers who provide products directly to aircraft manufacturers should receive certifications from authorities for the installation. Manufacturers who do not supply parts to aircraft manufacturers directly may also obtain a Part Manufacturers Approval (PMA), which "is a combined design and production approval for modification and replacement articles." (Federal Aviation Administration, 2016). Aircraft manufactures require suppliers to conform to their own quality system requirements, which may include obtaining certification from third parties (e.g., AS9100C) (Supplier Quality Integration Team, 2017). As such, being a supplier to the ACI industry requires certification from some combination of the aircraft manufacturers, the regulator, and third parties.

Many respondents highlighted that the certification process is costly and time-consuming. Confirming this, a study investigating the case of the Mexican aeronautic industry suggested that certification span facilities and equipment inspections, which takes around four years, and in that case cost between $4,000-40,000 (Brown-Grossman and Domínguez-Villalobos, 2012). The entry barriers identified in our interviews correspond to the descriptions provided by Pehrsson (2009) and Karakaya (2002) (Table 2-4).

Table 2-4: Summary of entry barriers in the ACI industry.

Pehrsson (2009)	Karakaya (2002)	This study	Illustrative Quote from Stage 2 Interviews
● Customers' switching costs	● Customer loyalty advantage held by incumbents ● Customers' costs associated with switching from one supplier to another	● Stable supply chain relationships	*'Aeronautic industry is very conservative. And so they do not change very quickly and they are always concerned about changes, so they do very small steps at a time'. (Interview 4)*
● Need for capital for the establishment	● Capital requirements to enter markets ● Capital intensity of the market ● Amount of sunk cost involved in entering a market ● R&D expense involved in entering a market	● Long-term and high investment	*'We are fighting in an area called aeronautics where investments are huge to get small steps of increasing production and supply chain'. (Interview 5)* *'A lot of time and money should be invested to meet all technological requirements'. (Interview 12)*
● Government policy	● Government licensing requirements	● Certification	*'I would say that probably it's difficult to have all of these certifications that are required, it's necessary to have a big investment'. (Interview 10)*
● Access to distribution channels	● Access to distribution channels	● Not identified	-
● Number of competitors	● Number of firms in a market		
● Seller concentration	● Amount of selling expense involved in marketing a product		

2.6. Discussion

2.6.1. Implication for building a market entry strategy

The match of the technological capabilities of a country with those that are needed to enter an industry and the analysis of the entry barriers of that industry are the key determinants of which catch-up stage of Table 2-1 a country should consider targeting. The findings of this analysis for our case study suggest that it would be unwise for Portuguese firms to try to become major suppliers or to develop entire new products lines related to aircraft cabin interiors. It is also not clear that if they could do these things that it would be particularly lucrative. On the other hand, Portuguese firms could use their skills in materials, plastic and sheet metal working and assembly, tool manufacturing, and industrial design to supply components and sub-assemblies to the aircraft interior industry. Each of these industries is profitable and already earns a considerable portion of its revenues through export (Banco de Portugal, 2018; Portuguese Chamber Of Commerce, 2019). Therefore, perhaps with some government assistance for things like training, it is likely that firms have the resources to develop both the products and necessary relationships to supply the ACI industry. This suggests that Portugal should seek to continue to deploy and burnish these strengths to participate in the supply chain for aircraft interiors: it should supply high-value machinery and materials such as metal moulds and specialized leather; selected components and sub-assemblies, and high value services such as interior design.

To generalize, late entrants, latecomers and late arrivers which attempt to enter or expand their presence in the supply chain of the high tech industry need to comprehend the industrial dynamics including the market power of legacy firms, entry barriers, market size and profitability. On the base of this understanding, firms may find niche opportunity that their potential rivals are not willing to target, and gain a foothold to build market knowledge and insight.

2.6.2. Implication for developing technological capabilities

2.6.2.1. Using external knowledge and absorptive capacity

To transform knowledge accumulated in the relevant industries to the manufacture of ACI components and move to the Stage 2, Portuguese firms, which mainly remain at Stage 1, will need sources of technologies that have programs to help potential and existing suppliers technologically. Based on technological support from existing suppliers accompanied by the highly developed absorptive capacity of Portuguese firms, Portuguese firms could achieve the required technologies and skills to move to Stage 2.

Aircraft manufacturers and their major suppliers have expanded their manufacturing bases to new countries in order to cut costs. Airbus and Bombardier operate final assembly lines in China and their Tier 1 suppliers, such as Safran, Thales, and Zodiac, have come to Asian countries and Mexico (Hernández Chavarria and Carrillo, 2018; Oliver Wyman, 2015).

Airbus has a training day to educate and inform its suppliers, and supplied service bulletins, supported engineering designs and provided methodologies, which are needed to the interior refurbishment project, to Portuguese suppliers (Kjelgaard, 2017). Embraer opened the meetings and invited Portuguese firms that may have potential to become its suppliers. Mecachrome has started to make business relationships with Portuguese suppliers that provide materials and components after settling down in Portugal.

In addition to growing their own, Portugal has strengths to attract existing ACI suppliers to the country, such as lower labor costs and well-developed human resources (AICEP Portugal Global, 2018; EY, 2018b). According to the survey conducted by EY (EY, 2018b), investors ranked Portugal first in attractiveness and international trade among the EU countries. Despite its several strengths, some aspects of Portugal are still less than attractive. For example, taxation and incentives are less attractive and make investors hesitate to invest in Portugal (EY, 2018b). According to the World Bank's report on 190 countries (2019), it is relatively difficult to set up a new business in Portugal and the country is not always able to adequately protect legal rights.

2.6.2.2. Intensifying R&D activities

R&D projects with well-trained engineers from incumbent firms could transfer a high level of technologies about product designs to Portuguese suppliers (Liefner et al., 2019). Currently while Portugal has been able to attract the manufacturing facilities of existing suppliers those firms conduct few R&D activities in the country (AICEP Portugal Global, 2013b). To improve this situation the Portuguese government could emphasize and increase the current R&D incentives targeting R&D organizations or the R&D functions of existing suppliers, or conduct international co-R&D projects with existing suppliers. In this vein, Israel attracted the R&D centers of US firms by providing upfront R&D grants that are recouped as royalties from successful products (Breznitz, 2006).

Existing suppliers in and out of Portugal may be concerned that Portuguese suppliers could become their competitors and thus reduce technological support. Independent and intensified R&D activities have proven an effective tool in many cases to overcome this problem (Breznitz, 2006; Fan, 2006; Lee, 2005). The Portuguese ACI industry needs to build a national R&D network including universities which currently do not actively participate in such work, and expand the industrial organizations or R&D authorities, such as the AED cluster established in 2016 (Harbi et al., 2009; Laranja, 2009; Lee, 2004; Ratinho and Henriques, 2010).

2.6.2.3. Overcoming entry barriers

By accumulating good reputations and track records by applying their skill in smaller or niche markets, Portuguese firms could expand their customer bases to foreign countries. For example, Turkish Airlines procured seats which were newly developed by Turkish Technic and Turkish Technic was then able to expand its business to Russia based on the domestic market success (Harbison, 2017a). Currently, Turkish Technic and its joint ventures are manufacturing seats and galleys for Boeing and Airbus (Harbison, 2017b). TAP, the Portuguese state-owned airline, has the potential to launch an offset program supplying Portuguese components to Airbus. TAP has maintained a close and long-term relationship with Airbus (Kjelgaard, 2017). The Portuguese Government, a member country of the EU, might be able to approach Airbus, which is controlled by the French, German and Spanish Governments, to develop such a relationship. The Portuguese government could attract other airlines which operate fleets or own bases in Portugal

to discover Portuguese suppliers, such as Netjets, EasyJet and Ryanair and share the knowledge that the Portuguese Air Force owns. Etihad, the airline of the United Arab Emirates, and Air China have localized their procurement (Air China, 2013; Tyler, 2017). In addition, efforts to induce more airlines, which are potential customers of Portuguese suppliers, to Portugal should be coordinated. For example, experts point out that it is critical to develop new routes connecting cities which have moderate travel demands, present analytics and data to airlines to ensure the profitability, and do co-marketing with airlines to increase demand (Finavia, 2017; Global LCC Summit, 2019).

To relieve the financial burden, the Portuguese government may develop programs providing financial support that are compliant with EU and WTO rules for certification process which accounts for the major part of the burden. For example, the Turkish government implements policies to refund all or a part of expenses which Turkish suppliers spend for certifications. In company with these programs, the Portuguese government selects R&D projects and deputizes firms to develop technologies in a certain period of time (da Silva, 2014). The Portuguese government may expand a series of these commissioned R&D projects which remain less common than the EU average to support Portuguese firms (European Commission, 2016).

The Portuguese government might initiate strategies that support a public organization, which is responsible for training and consulting related to certification. For example, the Government of South Korea established the Korea Aerospace Quality Group (KAQG) in 2016 to provide quality control consulting and training, and issue certification, such as AS9100 which is the international quality management standard for aircraft (ASQ, 2019; KAQG, 2019). The government of the Philippines provides quality control training to assist Philippines firms to receive certifications (Frost & Sullivan, 2015). In this sense, the Portuguese government or the aeronautic industry association might establish a testing center to offer essential testing and relevant consultation programs required in the ACI industry. Alternatively, TAP Maintenance and OGMA might try to receive approvals for their testing facilities and enable Portuguese suppliers to access those facilities

2.7. Implications for Portugal and Other Countries

Late arriving firms and countries that want to become players in high tech industries would be well advised to look for industries that overlap their existing technological capabilities. In doing so they should look for opportunities that involve modest entry barriers. These barriers should be examined to see whether and how they can be easily overcome. Such countries would also be well advised to avoid fields in which supply chains are dominated by a few legacy firms that are highly entrenched. Governments should diagnose where their firms are located in the stages of technological trajectory and whether they have appropriate absorptive capacity. On the basis of these estimations, a government can work with its local industries to facilitate knowledge learning and transfer, and develop policies supporting firms to foster the high tech industry strategically in the country.

Our research has found that the aircraft cabin interiors industry is highly concentrated and not particularly profitable as compared with margins in Portugal's other industries. Entering the aircraft interiors business in a major way would involve investing a great deal of effort to enter a relatively small market dominated by a few very powerful firms. This suggests that Portugal would be wise to increase the supply of high-value equipment, materials, and possibly components and sub-assemblies rather than becoming a system integrator or try to develop whole new product lines. In order to accomplish this, we recommend conducting an intense R&D and collaboration among firms in and out of the country.

What we found through the analysis regarding Portugal in the ACI industry is probably difficult to replicate directly in other countries as policy decisions tend to be contingent on specific conditions. Conclusions will and should be different depending on the industrial and political context that each country faces. Nevertheless it is expected that this Portuguese ACI case opens a new door to investigate the potential of technologically intermediate countries in a high technology sector and develop the strategies to upgrade their industrial structure. It seems evident that existing and potential late arrivers require different strategies to improve their technological capabilities depending on which stage they are in the technological trajectory of late arrivers and what overlapping capabilities they have already developed. There are some industrial dynamics which are important to shape the strategies to enter or move up the supply

chains of the high tech industry, namely legacy firms dominating the industry and high entry barriers. These meaningful ramifications gained by illuminating Portuguese ACI industry can probably best be generalized to other intermediate European countries, particularly Eastern European countries, such as Poland and Hungary, and Southern European countries, such as Greece, which have significant but relatively low technological capabilities in the EU (Paci and Usai, 2000; Radošević and Kutlača, 1999).

Chapter 3 How Is General and Specific Human Capital Related to Technology Development in Firms?

Abstract

This chapter examines directly the extent to which human capital within a firm is associated with technology development. We create and apply a more objective measure of technological advancement based on a companies' change from their current economic activity into one that involves a higher level of technological intensity. We do this using an extremely rich and unique matched employer-employee micro dataset, the Quadros de Pessoal that covers nearly all Portuguese private companies and their employees. Three factors are found to contribute positively and significantly to technology development: 1) education level; 2) prior work experience in the same industry; and, 3) the combination of Science, Technology, Engineering, and Mathematics (STEM) education and prior work experience in the same industry. We explore managerial and policy insight of our findings on how to increase the likelihood and the speed of firms' technology development.

3.1. Introduction

Firms must continue to innovate in order to retain their position in global markets. (Apak and Atay, 2015). Accordingly, both governments and firms consider technology to be a critical factor in improving firm performance and accelerating industrial development (Acemoglu, 2012; Acemoglu and Autor, 2012; Bjornali et al., 2016; Lee and Grewal, 2004; Tsai and Wang, 2008). The literature has focused on a variety of roles that human capital plays in shaping and influencing technological development. A number of authors find that mobility of engineers and scientists facilitates technology transfer and enables firms to absorb foreign technologies (Faggian and McCann, 2008; Mu and Lee, 2005; Simonen and McCann, 2008). Higher education has long been discussed as a precondition for technological development in the sense that education is the key process of facilitating learning and the acquisition of knowledge (Drine, 2012; Lee et al., 2010; Romijn and Albaladejo, 2002). Much of the literature analyses the

influence of the education and experience of firm founders and top management teams on technology development. Kato et al. (2015) highlight that a highly educated and experienced founder is more likely to encourage R&D activities and boost innovative outcomes. Alexieve et al. (2010) and Talke et al. (2011) show that diversified educational background and experience of managers provide heterogeneous perspectives that are beneficial to innovation.

Although theoretically we know that human capital is important to technology development (Crown et al., 2020; Martin-Rojas et al., 2019; Solheim et al., 2020), there is limited consensus about which specific dimensions of human capital influence the technological improvement of firms (De Winne and Sels, 2010). For example, researchers provide inconsistent empirical evidence on the relationship between educated workforce and technological development (Capozza and Divella, 2019; McGuirk et al., 2015). The impact of education on technological development varies between articles, depending on the degree levels of education, the stages of country development and the types of technology development, mainly distinguished as product and process innovation.

Some of this confusion may result from the fact that the data that previous studies have collected and analyzed may be biased. First, the existing measures for technology development rely on indirect and subjective evaluation of technological input and output, such as R&D intensity and self-evaluation. Second, specific types of firms and industries have received considerable attention from scholars. Technology based firms, small and medium enterprises, and start-ups have been analyzed (Drine, 2012; Fu et al., 2011; Gimmon and Levie, 2010; Honjo, 2021) since they are believed to be primary sources introducing technological innovation (Acs, 2004; Wong et al., 2005). For the reason that high-tech industries put more emphasis on technologies and conduct more R&D activities (Wolf and Terrell, 2016), researchers chiefly build on new knowledge based on evidence from high-tech industries (Cosar, 2011; Frantzen, 2000; Simonen and McCann, 2008; Wright et al., 2007), thus neglecting other technological intensity levels (low, medium-low and medium-high).

In summary, current understanding of the role played by human capital (a key explanatory variable) on technology development (the phenomenon to be explained) is still limited by fragmented approaches, a dependence on indirect or subjective measures, and by the absence of

any comprehensive analysis that controls for different industries, regions, types of firms, and types of human capital.

This chapter makes several contributions to advance our understanding of the link between human capital and technology development in multiple ways. First, we create and employ an original and more objective measure of technological development based on companies' transition from their current economic activity into a new one involving one with a higher or lower level of technological intensity. Second, we adopt a conceptual framework that directly links human capital with technological development and devote attention to the combined impact of different types of human capital. Third, to test our research hypotheses empirically, we use an extremely rich and unique longitudinal matched employer-employee microdata set – Quadros de Pessoal – that covers nearly all Portuguese private companies and their employees over a span of approximately 30 years. These provide a more precise and original approach that is more responsive to the whole gamut of forms of human capital and its impact on firms' technology activities.

The results of our empirical analysis show that: 1) Education is an important form of general human capital which associates positively and significantly to technology development; 2) Industry experience is an important form of specific human capital which associates positively and significantly to technology development; and, 3) STEM education is a type of specific human capital that, by itself, does not suffice to explain technology development, but when combined with industry experience becomes important and associates positively and significantly with technology development.

In the following section, we review the literature regarding human capital and technological development and introduce five hypotheses. Section 3.3 explains the dataset used and the methodology. Section 3.4 presents the findings resulting from the analysis. Finally, based on the findings, Section 3.5 discusses policy implications and recommendations for firms and governments.

3.2. Conceptual background and research hypotheses

3.2.1. A new measurement of technology development

This study develops and applies an original technology development measurement by tracking companies' change of activity and technological development over time through the Nomenclature of Economic Activities (NACE) . We apply an OECD's typology which draws on the NACE, to classify firms into Low, Medium-low, Medium-high and High-tech levels (Eurostat, 2020; OECD, 2003) and assess whether a firm's new activity has a higher (or lower) technological intensity.

The existing literature has measured the technological achievements of firms by using: firm survival (Gimmon and Levie, 2010; Kato and Honjo, 2015); number of employees (Colombo and Grilli, 2005); firm sales (Grilli et al., 2020); size of funding (Hsu, 2007; Patzelt, 2010); number of patents (Valenti and Horner, 2019), R&D intensity (Cao and Im, 2018; Fassio et al., 2019; Guo et al., 2020; Valenti and Horner, 2019); entrepreneurs' self-evaluation (De Winne and Sels, 2010; Deligianni et al., 2019; van Uden et al., 2017; Vyas and Vyas, 2019); or technical performance improvement (Coccia and Watts, 2020). These measures evaluate technological inputs and outputs indirectly. Thus, they have difficulty in clarifying whether the characteristics and efforts made by workers and managers' have actually been associated with firms' technological advancement. There have also been limitations in the measures used to assess the overall technological level of firms. Finally, some previous findings may be biased by the fact that they are based on responses to surveys in which subjective judgment may have played a major role (Armando et al., 2018) and may fail to cover important types of innovative activities (Dakhli and De Clercq, 2004; Nordli, 2017).

By tracking and empirically studying changes in the NACE codes, we directly examine which (and to what extent) human capital and other technological inputs within the firm are associated with moving to higher technological intensity levels, thus generating technological progress. Within the timeframe of the present analysis, Portuguese companies were legally obliged to register with only one key NACE code. A change in a firm's NACE code is not a frequent event as it implies that the company has made a substantial change in its production outputs and/or industry. Moreover, making such a change requires an official procedure and validation from the

National Statistics Office (INE), the Tax Authority (AT) and the Institute of Registries and Notaries (RN). Hence, through the use of this new measure we can assess a real change in a company's technological knowledge and output that is both scientifically robust and accepted in the market. This allows us to track, distinguish and understand the development of technology within firms in a more structural and dynamic way.

3.2.2. Human capital and technology development

The development of technological capability within firms occurs in part through the accumulation of human capital – employees who develop and accumulate stocks of technological knowledge (Romer, 1990). Several researchers have found that human capital, embodied in employees who engage in technological learning, is a primary factor in the ability of firms to achieve economic growth by absorbing and creating new technologies (Dakhli and De Clercq, 2004; Fox and Smeets, 2011; Galindo-Rueda and Haskel, 2005; Lebedinski and Vandenberghe, 2014; Vandenbussche et al., 2006). For this reason, investing in various strategies to strengthen human capital, which mainly has been studied through human resources management (HRM), shows a positive impact on firms' technological performance (Laursen and Foss, 2000; Lei et al., 2021; Lin and Sanders, 2017).

One stream in the literature addresses the relationship between human capital and technological development focusing on the concept of innovation. The results of these studies on innovation present mixed evidence, due to the existence of contextual differences among countries (Edsand, 2019; Kaasa and Vadi, 2010; Zanello et al., 2016) and, eventually, because of the lack of a comprehensive conceptual understanding of how different human capital related internal and external factors affect, directly or indirectly, on firms' technological trajectories (De Winne and Sels, 2010).

It is useful here to divide the concept of human capital into two major categories: general and human capital that is specific to technology development (Becker, 1975; Stucki, 2016). General human capital is knowledge and skills that are transferable across jobs and industries whereas specific human capital is those that are most applicable within the specific contexts. This classification creates a more comprehensive nexus between the level of education, working experience, type of education, and industry experience among the firms' workforce.

3.2.3. General human capital and technology development

General human capital can be operationalized through measures of the level of formal education as well as labor market experience among workforce (Bilan et al., 2017; Domurath and Patzelt, 2019; Schulz et al., 2013). Previous literature has stressed the role of the educational attainment of employers on knowledge creation (Krueger and Lindahl, 2001; Lebedinski and Vandenberghe, 2014; Sianesi and Reenen, 2003).

Better educated individuals may have project management skills such as setting better goals, a greater ability to motivate co-workers, and better communication skills (Hatch and Dyer, 2004; Rauch et al., 2005). Educational attainments and their interaction with varying expertise of employees lead to more dynamic communication, proactive knowledge integration, original and valuable idea creation (Smith et al., 2005). Education contributes to improving the productivity of firms, which allows firms to devote more resources to technology development (Lebedinski and Vandenberghe, 2014; Madsen, 2014). For example, higher levels of education can result in a higher probability of adopting a new technology that enhances a firm's productivity. This effect of education is found to remain for an extended period of time after graduation (Kämpfen and Maurer, 2018). Firms with more educated workforce are more likely to be funded by investors, because this is seen as signalling that firms have more entrepreneurial and technological capabilities (Hsu, 2007; Patzelt, 2010). Based on the empirical examination with technology ventures, Marvel and Lumpkin (2007) show that education is positively influential to the likelihood of firms to enhance their innovative activities. Thus, firms which hire a large share of well-educated workers are likely to accelerate technology development. This leads us to advance:

> *Hypothesis 1a*: The educational level of a firm's workforce is positively associated with the firm's transition to a higher level of technological intensity.

Individuals and teams with work experiences are found to have a positive impact on the technological performance of firms (Crook et al., 2011; de los Dolores González and Husted, 2011; Lafuente and Rabetino, 2011; Schneider et al., 2010). Workers who perform various functions across the firm may develop expanded understanding of technologies and build a more balanced view that incorporates different elements relating to technology development (Kato et al., 2015; Lee and Walsh, 2016). Prior work experiences may give workers more opportunities to accumulate knowledge about effective approaches to technology development through learning based on their prior successful and failed trials (Robson et al., 2012).

Work experience enhances managerial capabilities that are required to lead a group of employees or co-work with other entities. It can also enhance entrepreneurial abilities to recognize commercial opportunity (Ganotakis, 2012). Although technological knowledge obtained through education and experience is highly critical for a firm's technological efforts, this technological knowledge can be linked to the performance of firms only when appropriate managerial and entrepreneurial skills are supported (Ganotakis, 2012; Oakey, 2003). Otherwise, firms may excessively focus on technical dimension and make myopic decisions without thorough and comprehensive consideration about all feasible alternatives (Oakey, 2003). With evidence from a comparative case study of two R&D projects conducted by a firm in the lighting industry, Ravasi and Turati (2005) note that experienced workers who tend to operate under serious resource scarcity are typically under considerable and constant pressure to enhance decision-making skills about what actions are worth pursuing to maximize expected outcomes, coordinate and integrates heterogeneous knowledge, skills and know-how. Furthermore, these potential strengths of technological and managerial expertise embedded in experienced workers have positive influence on financial support from external investors which is essential to increase R&D intensity (Colombo and Grilli, 2005; Gimmon and Levie, 2010; Henning et al., 2003; Patzelt, 2010). With this in mind, we advance the following hypothesis:

> *Hypothesis 1*b: The work experience level of a firm's workforce is positively associated with the firm's transition to a higher technological intensity level.

3.2.4. Specific human capital and technology development

Much literature has accepted the definition of specific human capital as an individual's capabilities that are particularly relevant to the business or job concerned (Colombo et al., 2004; Gimeno et al., 1997; Henning et al., 2003; Kato et al., 2015). Within the context of a firm's transition to a higher technological intensity level, and following Henning et al. (2003) and Stucki (2016) categorization, this chapter conceptualizes specific human capital as the specific education and experience closely related to and demanded for technology development in firms.

Employees who have academic degrees related to engineering and science fields are likely to have a higher level of understanding of the technologies that firms are applying or attempting to develop. It is not surprising that the employees with such expertise help firms to create more technologically advanced products. The level of STEM education contributes to technological development through two mechanisms: increased ability to recognize and value external technologies; and the facilitation of internal technology integration and generation (Bianchi and Giorcelli, 2020). These two mechanisms are aligned with the concept of absorptive capacity which is comprehensively conceptualized and elaborated by Cohen and Levinthal (1990). Jiménez-Barrionuevo et al. (2011) define absorptive capacity as "the organization's relative ability to develop a set of organizational routines and strategic processes through which it acquires, assimilates, transforms and exploits knowledge acquired from outside the organization in order to create value". The empirical literature on technology-based firms reports a positive impact of the technical and scientific education on technological performance of firms (Colombo and Delmastro, 2002; Colombo and Grilli, 2005; Ganotakis, 2012; Romijn and Albaladejo, 2002; Valenti and Horner, 2019). Therefore, we advance the following hypothesis:

> *Hypothesis 2a*: The STEM education level of a firm's workforce is positively associated with the firm's transition to a higher technological intensity level.

It is likely that employees who have gained a significant stock of knowledge, skills and techniques in the same industry play an important role in a firm's undertake technology development (Romijn and Albaladejo, 2002). Training programs in the workplace enhance manufacturing workers, engineers and managers to do specific jobs in a better way (Agénor and Dinh, 2013; Bell and Figueiredo, 2012; Hobday, 2003). Individuals who have work experience

in the same sector have a better understanding about industry-related technologies and are more likely to discover technological opportunities, search for required resources, and participate actively to set up and shape a firm's knowledge strategy (Shane, 2000). Moreover, empirical studies investigating international labor migration imply that workers who develop a stock of knowledge in the same industry are likely to be able to contribute to technology spillover between firms (Hatch and Dyer, 2004; Kwark and Shyn, 2006; Lin and Rasiah, 2014). In line with these findings, we expect that firms having employees with more industry specific experience are likely to make more technological progress and move to technologically advanced industry. Hence, we put forward the following hypothesis:

> *Hypothesis 2b*: Specific industry experience of a firm's workforce is positively associated with the firm's transition to a higher technological intensity level.

Individuals may obtain prerequisite technological knowledge and skills through a STEM curriculum that provides basic competency for conducting activities within a firm. Although the improvement in human capital through education and its importance in technology development is well-acknowledged, there are studies documenting that educational attainment is not directly linked to undertaking given tasks and taking lead roles in firms' technology development (Borah et al., 2019; De Grande et al., 2014; Enders, 2004; Hancock and Walsh, 2016; Hayter and Parker, 2019). According to Hayter and Parker (2019), many fresh STEM degree holders have considerable difficulties in understanding how the real world works and applying their knowledge and skills in support of technological activities of firms. There is often a mismatch between skills that students learn in their scientific education and training, and those required to pursue job responsibilities (De Grande et al., 2014; Salminen-Karlsson and Wallgren, 2008; Stenard and Sauermann, 2016). In particular, when individuals with specialties outside the scope of the firms' current technological outlook are hired, this mismatch is more common and apparent (Buenstorf and Heinisch, 2020). Thus, graduates often lack the required skills to transfer their scientific and engineering knowledge into engineering model and practices in the context of commercial opportunity (Hancock and Walsh, 2016; Hayter and Parker, 2019). Furthermore, much STEM education tends to underestimate the importance of social and communication skills such as presentation and interaction with diverse workers (De Grande et al., 2014).

Experience in the same industry helps workers develop educated expertise on real-world projects (Box, 2009). The involvement in executing tasks to develop technologies in a firm offers practical knowledge and skills that educational institutions pay less attention to (Borah et al., 2019). Furthermore, it provides the latest technologies in the industries to workers (Kim et al., 2004; Lee, 2005). On the job training leads to impart firm-specific knowledge that can be applied in the specific environment of firms and increase the productivity of workers (Hatch and Dyer, 2004). Findings in this literature suggest the following hypothesis:

> *Hypothesis 3*: The existence of individuals endowed both with STEM education and specific industry experience within a firm's workforce positively associates with the firm's transition to a higher technological intensity level.

In summary, Figure 3-1 shows the hypotheses tested in this study.

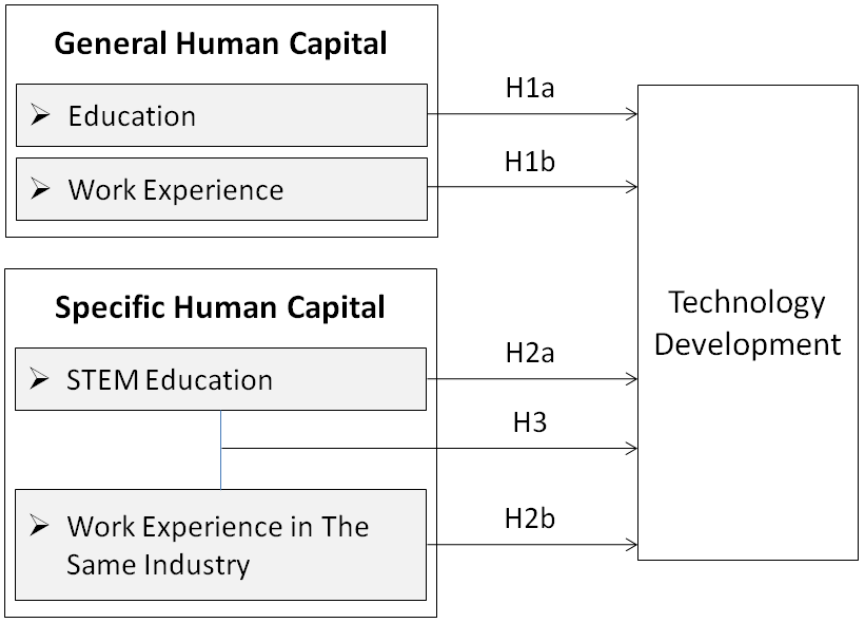


Figure 3-1: Research model showing the positive effect of general and specific human capital, and the combined impact of STEM education and industry experience, on firms' technological development.

3.3. Dataset and methods

3.3.1. Dataset

Our empirical investigation draws on an extremely rich and unique matched employer-employee microdata set – Quadros de Pessoal (QP). The QP covers a span of roughly 30 years (1985-2015). With the exception of public administration, nearly all public/private companies which hired at least one employee/wage-earner in either Continental Portugal or in Autonomous Regions (islands), together with their employees, are included in these data.

The QP survey is conducted by the Portuguese Ministry of Social Security and Labour and participation is mandatory for all employer firms (reporting is not a legal obligation for sole traders). This guarantees coverage of all relevant incorporated businesses in our data.

The fact that Quadros de Pessoal allows for tracking nearly all firms, industries, intensity levels and firm's workforce in the country over the course of a long period, makes it the ideal source of data for investigating the relationship between human capital and technological development of firms. There are around 200,000 firms and over 2.5-million workers in each annual survey. The longitudinal matched employer-employee data include extensive information on the mobility of firms, paid employees and business owners. Individuals and firms are fully linked and can be tracked over time using a unique identification number. Variables cover (at the firm level) demography of firms, industry, financial indicators, type of ownership, performance, firm location and (at the worker level): demographics, occupational status, pecuniary factors, working hours and human capital.

The first and second version of CAE/NACE codes which were used during 1985~2008 are not detailed and are substantially different from subsequent versions. This hampers the harmonization of all the information over the time covered by the dataset. Therefore, we filtered out previous years and focused on data from 2009 to 2015 (CAE Rev.3). This time is the period that the Portuguese economy was forced to adopt austerity measures after the economic recession hit in 2008 (Carneiro et al., 2014). As a result of the bail-out programs that Portugal set up with the IMF and the EU in 2011, the Portuguese government cut on state spending and increased tax (Murillo and Rocha, 2018). Due to the job destruction by closing firms, the

unemployment rate soared to 17.7% in 2013 which tripled the average rate of unemployment before the economic crisis (Carneiro et al., 2014).

The present analysis focuses on the concept of technology intensity, which connects with firms operating exclusively in manufacturing industries. Accordingly, this empirical research considers firms with their first 2-digits CAE/NACE codes starting from 10 (food and beverages manufacturing) to 33 (Others manufacturing). The number of firms in manufacturing industries accounts for, approximately, 10% of all the observations in 2009-2015. This proportion is aligned with the report from Instituto Nacional de Estatística (the National Institution of Statistics) of Portugal and the rest of the data mainly consists of the service providers of various sectors including commerce (23%), construction (19%), accommodation and restaurant (10%), transportation (5%), and others (26%) (Instituto Nacional de Estatística, 2021a) . Excluding firms due to missing data, we ended up with a dataset of 80,995 observations.

3.3.2. Variables

Dependent variable

The technology development of firms is measured via the change of the reported technology intensity level of each firm. Portuguese firms which respond to the survey mark their CAE code depending on the specificity of their main economic activity. Economic activity covers a range of resource input, production process, and product output within the firm. We classified the CAE codes into four technology intensity levels following the definition by the OECD (2003) and Eurostat (2020); low-tech, medium low-tech, medium high-tech and high-tech industries. For example, the pharmaceutical industry is classified as a high-tech industry whereas rubber and plastic manufacturing is in medium low-tech industry. By tracking firms' transitions between CAE codes according to the four technology intensity levels, the technology development of firms can be identified, evaluated and tracked. The dependent variable is a dummy variable which takes the value '1' if a firm moves to an industrial activity with higher technology intensity level. A transition into a higher technological level is path dependent and it is usually the lagged outcome of an assortment of organizational inputs, resources, strategies and behaviors available/established in previous years (Nesta and Saviotti, 2005). Therefore, we investigate the effect that a set of independent variables at a given year t produces on the firm technology

development at year t + 2. A two-year time lag model is suitable to the phenomenon under analysis and widely accepted in the literature (Zhou et al., 2011; Zoghi et al., 2010).

Independent variables

The first group of variables of interest is used to investigate the role of the general human capital of firms and consists of education level and work experience. Overall education of employees is measured in terms of 8 levels based on the number of schooling years: 1) Primary education (6 years of education) or less; 2) Lower secondary education (3 years of education); 3) Upper secondary education (3 years of education in the academic and practical courses); 4) Post-secondary education (professional training mainly required for nurses and elementary school teachers); 5) Bachelor; 6) Post-graduate degree (specific education mainly for bachelor's degree holders; 7) Master; 8) Ph.D. Work experience measures the number of working years of workers. The average of each of these two variables (workforce education and work experience) within each firm is used for the analysis.

The second group refers to the specific human capital in firms. This group includes STEM education and work experience in the same industry. STEM education is measured by a ratio of workers having STEM related educational background. Work experience in the same industry is included as the average number of years that workers experienced in the same industry (where he/she works presently) before being enrolled in their current firm. To investigate the synergetic gains between these two specific human capital variables, an interaction variable combining STEM education and industry work experience was developed. The combination variable of STEM education and work experience in the same industry is a ratio of workers with STEM education and work experience in the same industry. This variable is set equal to 1 if a worker has both a STEM degree and same industry work experience, otherwise it is set equal to 0.

Control variables

Drawing on prior studies, we employ several control variables in our empirical analyses. First, we include foreign ownership, as it may impact a firm's preference for human capital (Lorentzen et al., 2003; Teixeira and Tavares-Lehmann, 2014). This variable is measured as the percentage of the foreign owned capital in the firm. Second, we control for initial capital (in euros) as, for

example, according to Honjo (2021), laborers with technological capabilities are closely related to the size of initial capital and initial financing size has an impact on firm performance (Agarwal and Audretsch, 2001; Honjo and Kato, 2019). Third, the type of ownership, such as private and public ownership, may affect technology development activities (Guo et al., 2020; Yi et al., 2017). Hence, each firms' ownership type is included as a control and measured as the ratio of private capital to total assets in a firm. Fourth, we include information on firm sales as this may influence the amount and span of a firm's resources that are available to be invested for technology development (Chakrabarti and Halperin, 1990). Fifth, we control for firm size because the number of workers can be closely linked with the firms' ability to search, absorb and employ external technologies that are critical for new product development (Stock et al., 2001). Firm size can also affect a firms' productivity (Lenaerts and Merlevede, 2015). Measure of firm sales and size are operationalized using ten quantiles to address the skewed nature of the distribution. Finally, this study introduces region, municipality, firm size and firm age dummies for the additional analysis. The region dummies, which consist of Norte, Lisbon Metropolitan Area, and Algarve regions of Portugal, are equal to 1 if a firm is located in the corresponding region. The municipality dummies take the value of 1 if a firm is located in the biggest city of each region that is Porto, Lisbon, and Faro respectively. The firm size dummies are variables categorizing the firm size following the EU's classification of firms (Lenaerts and Merlevede, 2015; The Commission of the European Community, 2003). They include micro (less than 10 employees), small (less than 50 employees), medium (less than 250 employees) and large sizes. The firm age dummy is equal to 1 if a firm is older than 6 years (García-Quevedo et al., 2014; Testa and Szkuta, 2018).

3.3.3. Estimation method

A logistic regression model was estimated to test our hypotheses. The logistic regression model is appropriate to the purpose of this study to understand the relative likelihood of a firm ascending the ladder of technology intensity levels. This statistical technique is appropriate to the data under study since the dependent variable has binary responses and the independent variables are continuous.

Table 3-1: Variables and descriptive statistics.

Variables	All firms (N = 80,995)				Transitioned firms (N = 202)				Non-transitioned firms (N = 80,793)			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Independent Variables												
General Human Capital												
Education level	2.473	0.826	1	8	2.735	1.077	2	7	2.473	0.825	1	8
Work experience	2.251	0.959	1	12	2.221	1.024	1	9	2.252	0.959	1	12
Specific Human Capital												
STEM education	0.024	0.100	0	1	0.033	0.104	0	0.833	0.024	0.100	0	1
Work experience in the same industry	3.158	2.114	1	15	3.738	2.480	1	10	3.157	2.112	1	15
STEM education and Work experience in the same industry	0.131	0.337	0	1	0.173	0.379	0	1	0.131	0.337	0	1
Control Variables												
Foreign capital	2.025	13.666	0	100	0.495	7.036	0	100	2.029	13.679	0	100
Initial capital	0.48M	14.7M	0	2,000M	210,211	987,515	0	11.1M	482,080	14.7M	0	2,000M
Private capital	80.529	39.436	0	100	85.644	35.152	0	100	80.516	39.445	0	100
Firm sales	6.205	2.845	1	10	6.149	3.048	1	10	6.205	2.844	1	10
Number of workers	6.182	3.109	1	10	5.871	3.091	1	10	6.183	3.109	1	10

Table 3-2: Correlation matrix of the independents and control variables shows low risk of multicollinearity.

	Variables	1	2	3	4	5	6	7	8	9	10
1	Education level	1.00									
2	Work experience	-0.03***	1.00								
3	STEM education	0.48***	0.00	1.00							
4	Work experience in the same industry	0.11***	-0.08***	0.02***	1.00						
5	STEM education and Work experience in the same industry	0.33***	0.02***	0.61***	0.00	1.00					
6	Foreign capital	0.12***	0.03***	0.11***	-0.00	0.23***	1.00				
7	Initial capital	0.04***	-0.00	0.02***	0.00	0.06***	0.05***	1.00			
8	Private capital	0.06***	0.09***	0.03***	0.03***	0.06***	-0.28***	-0.01*	1.00		
9	Firm sales	0.08***	0.07***	0.09***	-0.02***	0.35***	0.15***	0.04***	0.30***	1.00	
10	Number of workers	-0.01	0.11***	0.05***	-0.10***	0.34***	0.13***	0.04***	0.31***	0.74***	1.00

*** p<0.001, ** p<0.01, * p<0.05

We report the coefficients indicating the probability of the firm climbing the ladder of technology development among 'low-tech', 'medium low-tech', 'medium high-tech' and 'high-tech' industries. To make it easier to interpret the outcomes of the logistic regression we also report marginal effects, which give us a measure of the effect that each independent variable has on the probability. The marginal effect is the probability that the respective category of the dependent variable changes when the independent variable increases by 1 unit, fixing all the other variables at the mean values (Norton et al., 2019).

The descriptive statistics are reported in Table 3-1. Notably, during the period 2009-2015 only 0.25% (i.e. 202 firms) of the Portuguese firms moved to the industry with higher technology intensity level. This implies, and confirms, that a firms' structural technology development (implying a transition to a higher technological intensity level) is a very complex, arduous and rare event. The descriptive statistics show the distribution of the firm sales and number of workers is highly skewed to the right. This highlights that the average size of the Portuguese firms is, on average, fairly small. In Table 3-2, we provide the correlation matrix of the variables. Most correlation values among the variables are relatively small, thereby suggesting that the risk of multicollinearity is low. The Variance Inflation Factor (VIF) test was also run and shows the absence of collinearity among the variables.

3.4. Results

3.4.1. Estimation results

Our five hypotheses, developed from the literature in Section 2, were tested using logistic regression models. The results are presented in Table 3-3. Model 1 with four independent variables served as the baseline and Model 2 added the interaction term between STEM education and work experience in the same industry. All the models controlled for firms' characteristics, such as firm size and capital structure, and included the constant term. The constant term is not reported in the table of results.

Table 3-3: Logistic regression analysis predicting firms' technology development (N=80,995 engaged in manufacturing) shows that education level, the same industry work experience and the combination of STEM education and the same industry work experience are statistically significant.

Variables	Model 1		Model 2	
	Coef.	*Std.Err.*	Coef.	*Std.Err.*
Independent Variables				
General Human Capital				
Education level	0.258***	0.071	0.251***	0.071
Work experience	-0.002	0.075	0.000	0.075
Specific Human Capital				
STEM education	-0.226	0.587	-1.231	0.817
Work experience in the same industry	0.093**	0.030	0.092**	0.030
STEM education and Work experience in the same industry			0.600*	0.276
Control Variables				
Foreign capital	-0.014	0.011	-0.015	0.011
Initial capital	0.000	0.000	0.000	0.000
Private capital	0.003	0.002	0.003	0.002
Firm sales	0.019	0.038	0.009	0.038
Number of workers	-0.035	0.035	-0.051	0.036
Model summary				
Pseudo R^2	0.012		0.014	

*** p<0.001, ** p<0.01, * p<0.05

The first set of the hypotheses (Hypothesis 1a and 1b) state that general human capital of workers in a firm increases the possibility of technology development, stressing the importance of education level and work experience. Our results show higher possibility of technology development when firms possess more educated workers on average (b=0.258, p<0.001), thereby supporting Hypothesis 1a. The marginal effect analysis indicates that a one standard deviation

increase in the average level of education (0.826) results in a 0.054 percentage point (pp) increase in the likelihood of firms moving up in the ladder of the technology intensities. Although this increase may seem very small, it is substantial in light of the fairly low rate at which Portuguese firms move to a higher technology intensity level (0.25%). This finding aligns with the literature highlighting that workers with more education may have better technological and managerial capabilities to engage in more effective and efficient technology-related activities, such as product development, problem solving, communication and opportunity detection within the firm.

The coefficient between general work experience and technology development is not statistically significant; therefore, we do not confirm Hypothesis 1b that the work experience level of a firm's workforce alone is positively associated with the firm's technological development.

With regard of specific human capital, the analysis does not support Hypothesis 2a, which posit that STEM education leads to greater likelihood of technology development for firms. The results show that, by itself, a workforce endowed with STEM education is not significant in stimulating a firms' technology development.

However, Hypothesis 2b, which expected a positive impact of work experience in the same industry on technology development, is confirmed. The coefficient of industry experience is positive and significant as proxied by number of studies ($b=0.093$, $p<0.01$). A one standard deviation increase in the average years of work experience of workers the same industry (2.114) is associated with a 0.049 pp increase in the probability of technology upgrade. This magnitude is approximately 20% of the predicted possibility of technology development.

We previously discussed the conceptual and empirical importance of combining STEM education with industry experience on technology development. According to Hypothesis 3, the existence of individuals endowed both with STEM education and specific industry experience within a firm's workforce positively associates with the firm's technological development. The coefficient of the variable interacting STEM education and Industry experience in Model 2 is positive and significant ($b=0.600$, $p<0.05$). Consequently, Hypothesis 3 is supported, underlining the importance of this mediating effect on firms' propensity to move to the higher technology

intensity level. Holding other variables at their mean, a 1% increase in the percentage of workers with STEM education and industry experience leads to a 0.0015 pp increase of the likelihood of technology development. In other words, the probability to move up to a technologically more intensive industry category increases by 0.05 pp given a one standard deviation increase in the rate of workers who have STEM education and the prior work experience in the same industry occurs. This change is nearly 22% of the average probability of a firm climbing up in the technology intensity ladder.

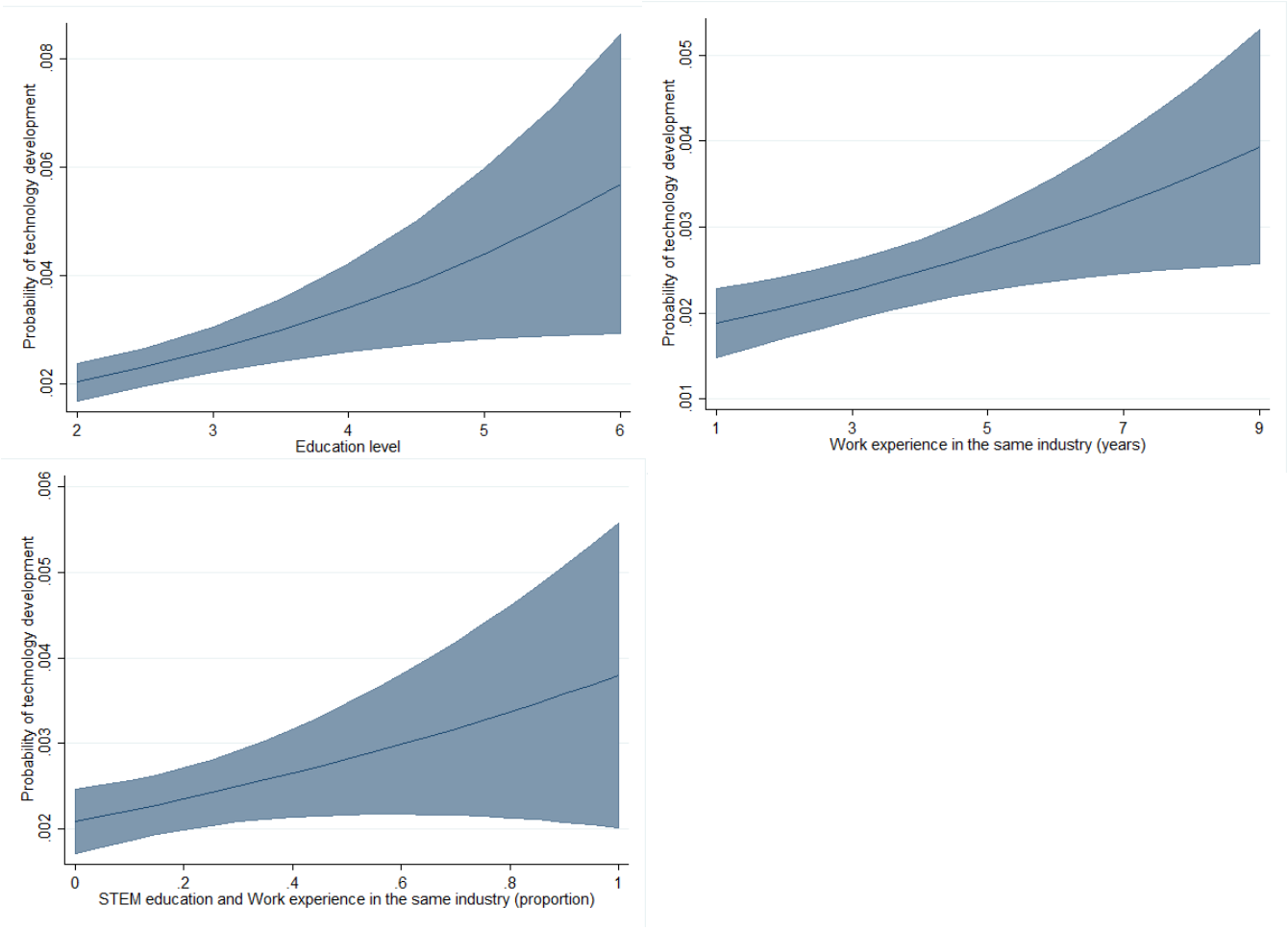


Figure 3-2: Predictive margins of general and specific human capital on technology development with 95% confidence intervals.

Figure 3-2 maps the predictive margins of education, industry experience and the combination of STEM education and industry experience on technology development based on the regression

coefficient from the analysis. The graphs clearly show that all three variables are statistically significant and positive across the distribution of each variable as predicted in Table 3-3.

In summary, the following main outcomes can be emphasized: 1) Education is an important form of general human capital which associates positively and significantly to technology development; 2) Industry experience is an important form of specific human capital which associates positively and significantly to technology development; and, 3) STEM education is a type of specific human capital that, by itself, is not suffice to explain technology development but when combined with industry experience becomes important and associates positively and significantly to technology development.

The R-squared values of the models are small. First, this indicates that there could be a number of relevant factors that were not observed or considered, or there could be considerable heterogeneity in the firms in the data set. Scholars suggest that a low R-squared value in some fields like social science is inevitable and common since there are inherently unexplainable dimensions in human behavior (Kashyap and Swastik, 2021; Wooldridge, 2015). Indeed, it is not surprising since there are likely many variables that directly and indirectly influence technology development. Candidates in the context of this study include individual characteristics, such as self-efficacy and autonomy, firm characteristics, such as gender diversity, top management team's diversity, and R&D efforts, and socio-economic factors, such as income, population and infrastructure. Second, the rare occurrences of the transition among different technology intensities (0.25%) could bias the estimation and possibly lower the R-squared value of our models (King and Zeng, 2001). Furthermore, this study analyses the whole population covering most of firms and employees in Portugal. Thus, our R-squared values are not estimates from samples that are likely to be biased by many external factors, but the R-squared value of the population, which is meaningful to understand the influence of human capital on technology development.

Table 3-4: Logistic regression results with region and municipality dummy variables

Variables	Model 3		Model 4		Model 5		Model 6	
	Coef.	*Std.Err.*	Coef.	*Std.Err.*	Coef.	*Std.Err.*	Coef.	*Std.Err.*
Independent Variables								
General Human Capital								
Education level	0.263***	0.071	0.255***	0.072	0.248***	0.072	0.241***	0.072
Work experience	-0.004	0.075	-0.002	0.075	-0.010	0.075	-0.009	0.075
Specific Human Capital								
STEM education	-0.228	0.588	-1.232	0.817	-0.198	0.592	-1.130	0.817
Work experience in the same industry	0.090**	0.030	0.089**	0.030	0.071*	0.030	0.071*	0.030
STEM education and Work experience in the same industry			0.598*	0.276			0.553*	0.276
Control Variables								
Foreign capital	-0.014	0.011	-0.015	0.011	-0.014	0.011	-0.015	0.011
Initial capital	-0.000	0.000	0.000	0.000	-0.000	0.000	-0.000	0.000
Private capital	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002
Firm sales	0.019	0.038	0.009	0.038	0.008	0.038	-0.001	0.038
Number of workers	-0.036	0.035	-0.052	0.036	-0.025	0.035	-0.040	0.036
Municipality – Baseline 'Others'								
Porto	-0.567	1.005	-0.568	1.005				
Lisbon	-0.373	0.715	-0.368	0.715				
Faro	-		-					
Region – Baseline 'Others'								
Norte					-0.682**	0.242	-0.662**	0.242
Greater Lisbon					-0.234	0.304	-0.226	0.304
Algarve					-		-	
Pseudo R^2	0.013		0.014		0.015		0.017	
Observations	80,866		80,866		80,021		80,021	

*** p<0.001, ** p<0.01, * p<0.05

3.4.2. Additional analysis

As additional analysis, we tested whether the differences among the human capital factors that may influence technology development are related to municipality and regional engagement. This study assessed the regional activities of Norte, Lisbon Metropolitan Area, and Algarve regions among all the eight regions of Portugal categorized by the Nomenclature of Territorial Units for Statistics 2 (NUTS2) of European Statistical Office (Eurostat). Five other regions served as reference category. Norte and Lisbon Metropolitan Area regions have been the most industrialized regions in the history of Portugal whereas the Algarve region has gained more recent attention from investors based on its digital industry (Ernst & Young, 2020, 2019). These three regions hold 68.2% of the total number of firms and 73% of employees in Portugal in 2019 (Instituto Nacional de Estatística, 2021b, 2021c, 2021d). Porto, Lisbon and Faro are the largest cities of these regions functioning as the centers of the regional economies.

We included the municipality dummies in Model 3 and 4 and the regional dummies in Model 5 and 6. Table 3-4 presents the estimation results of those models. The results reconfirm the positive relationship of education, industry experience and the combination of those two human capitals on technology development. The differences in the marginal effects between the models that include municipality dummies, and the original models, are trivial. However, the marginal effects for the statistically significant variables become weaker by 3%, 22%, and 7% respectively when we add the region dummies. In addition, we find differences in the possibility of technology development among the regions. Firms in the Norte region show a considerably lower likelihood of moving to higher technology intensity levels (approximately 67% lower than a reference category). One potential reason for observing fewer transitions of firms in the Norte region may be that this region is the home of traditional industries such as the textile, apparel, footwear, food and furniture industries. The industrial clusters of the fashion industry contribute 11% of the gross value added (GVA) created in Norte region (Ernst & Young, 2019) whereas the proportion of the GVA from technology-based products is less than 1% that is substantially lower than the average of Portugal (Ernst & Young, 2020).

In order to examine whether the impact of human capital was associated with the different size groups of firms, we used firm size dummies consisting of micro (less than 10 employees), small

(less than 50 employees), medium (less than 250 employees) and large sizes. Results of Model 7 and 8 reported in Table 3-5 are stable and similar to the previous analysis with the approximately 3% increased marginal effects. In addition, the results on large sized firms are positive and significant. It indicates that large firms are more likely to develop technologies and expand their business to technologically more intensified one. The results demonstrate that technology development relies on different resources and organizational processes, which might be limited and affected by firm size. This is in line with the recent studies which found that larger firms are better positioned to access resources, overcome managerial constraints, efficiently conduct technological activities and succeed in technology development (Chun et al., 2015; Fang et al., 2021; Li et al., 2020).

Firm age may affect the probability of technological growth of firms. Many scholars have focused on the relationship between firm age and technological output (Coad et al., 2018, 2016; García-Quevedo et al., 2014; Wöhrl et al., 2009). To explore whether our results are linked to the effect of firm age, the original estimation was repeated with the firm age dummies. The results shown in Model 9 and 10 of Table 3-5 are similar to previous ones, although the marginal effect of the industry experience becomes smaller by approximately 4%. There is no evidence of a positive or negative association between firm age groups and technology development. Mature firms, which are older than 6 years, show positive coefficients, however, they are not statistically significant. This suggests that technological advancement including R&D output and commercialization is arduous regardless of firm age. Moreover, compared to the previous analysis of firm size, our results imply that firm-level resources including R&D capabilities and managerial skills that are critical in technology development are more likely to be influenced by firm size rather than firm age.

Table 3-5: Logistic regression results with firm size and firm age dummy variables

Variables	Model 7		Model 8		Model 9		Model 10	
	Coef.	*Std.Err.*	Coef.	*Std.Err.*	Coef.	*Std.Err.*	Coef.	*Std.Err.*
Independent Variables								
General Human Capital								
Education level	0.267***	0.071	0.261***	0.071	0.261***	0.071	0.253***	0.071
Work experience	-0.006	0.075	-0.004	0.075	0.006	0.075	0.007	0.075
Specific Human Capital								
STEM education	-0.236	0.594	-1.166	0.845	-0.219	0.588	-1.220	0.817
Work experience in the same industry	0.096**	0.030	0.095**	0.030	0.088**	0.030	0.088**	0.030
STEM education and Work experience in the same industry			0.557	0.300			0.596*	0.276
Control Variables								
Foreign capital	-0.017	0.011	-0.018	0.011	-0.014	0.011	-0.015	0.011
Initial capital	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000
Private capital	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002
Firm sales	-0.004	0.032	-0.013	0.033	0.015	0.038	0.005	0.039
Firm size – Baseline 'Micro'								
Small	-0.062	0.204	-0.153	0.212				
Medium	-0.128	0.400	-0.398	0.431				
Large	1.791**	0.616	1.450*	0.645				
Firm age – Baseline 'Young'								
Mature					0.169	0.260	0.158	0.260
Pseudo R^2	0.014		0.016		0.012		0.014	
Observations	80,995		80,995		80,995		80,995	

*** p<0.001, ** p<0.01, * p<0.05

Table 3-6: Robustness check with rare events logistic regression models ('relogit' and 'firthlogit' in STATA)

Variables	relogit				firthlogit			
	Model 11		Model 12		Model 13		Model 14	
	Coef.	*Std.Err.*	Coef.	*Std.Err.*	Coef.	*Std.Err.*	Coef.	*Std.Err.*
Independent Variables								
General Human Capital								
Education level	0.262***	0.072	0.256***	0.073	0.262***	0.070	0.254***	0.071
Work experience	0.003	0.080	0.005	0.080	0.002	0.074	0.004	0.074
Specific Human Capital								
STEM education	-0.149	0.474	-1.052	0.662	-0.154	0.571	-1.033	0.781
Work experience in the same industry	0.093**	0.031	0.093**	0.031	0.093**	0.030	0.092**	0.030
STEM education and Work experience in the same industry			0.562*	0.262			0.541*	0.269
Control Variables								
Foreign capital	-0.010	0.012	-0.011	0.012	-0.010	0.009	-0.012	0.009
Initial capital	0.000	0.000	0.000	0.000	0.000*	0.000	0.000*	0.000
Private capital	0.003	0.002	0.003	0.002	0.003	0.002	0.0028	0.002
Firm sales	0.017	0.041	0.008	0.041	0.017	0.038	0.008	0.038
Number of workers	-0.038	0.035	-0.052	0.037	-0.037	0.035	-0.052	0.036
Degrees of freedom	9		10		9		10	
Penalized log likelihood					-1345.00		-1341.80	
χ^2					45.05***		48.20***	
Observations	80,995		80,995		80,995		80,995	

*** p<0.001, ** p<0.01, * p<0.05

3.4.3. Robustness checks

We complemented the analysis with additional tests to evaluate the robustness of the results. Our data show that the transition of firms within the different levels of technology intensity, which is the dependent variable of this study, is a relatively rare event. According to King and Zeng (2001), logistic regression with rare events data can be biased towards the majority cases and underestimate the probability of rare events. To consider the concerns about potential biases caused by the rareness of these events, we adopted the Rare Events Logistic Regression and Firth Logistic Regression . The Rare Events Logistic Regression applies a bias corrected estimator and hence generates a lower mean square error for coefficient and possibilities (King and Zeng, 2001) whereas the Firth Logistic Regression uses a penalized maximum likelihood estimation method to minimize bias known as "rare event bias" or "small sample bias" (Firth, 1993; Laplume et al., 2015; Thies et al., 2019). The consistent results represented in Table 3-6 support the robustness of our models. In addition, the Chi-squared values and the penalized log likelihood of the Firth Logistic Regression show that the model change is statistically significant and the model fit is improved by adding the independent variable. To check the robustness of our findings in the additional analysis, we ran the same regression with the sliced data following the criterion mentioned in the previous section. The results obtained stay generally consistent with those displayed and discussed herein.

3.5. Discussion and conclusions

Prior research about human capital and technology development assessed technology development of firms through potentially biased measures, originating from subjective self-reported surveys, or indirect evaluation, such as R&D intensity. For example, the usefulness of R&D intensity, one of the most widely used indicators to explain technological capability, is of limited value since it is not possible to reflect non-R&D factors that are a critical element to enhance technological capabilities (Archibugi et al., 2009). This study proposes an original measure that can more adequately capture the overall (static) technological level of firms at a given moment in time and firms' (dynamic) structural change based on a transition from their current business into a new one that involves a higher technological intensity level.

Our results advance the knowledge about human capital by reinforcing the finding that education level is positively related to firm performance, particularly in terms of technology development. On the other hand, although workers' general experience in the labor market can be considered a form of human capital, it does not necessarily translate into firms' technology development.

In the realm of specific human capital, this study elucidates the positive impact of prior same-industry work experience on technology development. This finding suggests that work experience accumulated in the same industry provides workers with a more sophisticated understanding of relevant technologies and more opportunities to search for external resources required for problem solving, both of which may help to develop and upgrade the technological knowledge of firms. By having more workers who have considerable same-industry work experience, firms may foster technology development. This finding is in line with those from previous studies (Colombo and Grilli, 2005; Ganotakis, 2012; Valenti and Horner, 2019).

Interestingly, our results find that STEM education is positively linked to technology development only when it is complemented by work experience in the same industry. Technological and scientific expertise acquired in educational institutions has limited impact on firms' efforts to develop technologies. This implies that STEM education courses may be most likely to impact a firms' technology development if workers are endowed also with appropriate industry-specific and firm-specific knowledge by attending on the job training or conducting real tasks within a firm over time. This finding suggests the need for further research about the job training design and collaboration between university and industry towards technology development.

In addition to insights for the related literature stream, results from this work have implications for effective technology development in a strategic context. Many firms, particularly in the knowledge-intensive industries (services), attempt to hire STEM workers including Ph.D. students who have just received their degree. Our results indicate that STEM educated employees are not always advantageous to firms that engage in technology development. Given the findings that the benefit of STEM education can arise from same-industry work experience, it is imperative that firms pay attention to how they build the composition of their workforce with

employees who received degrees in STEM related majors and have work experience in the same industry as well. Otherwise, firms may have to invest in internal programs that complement and balance these workers' specific education with specific practical technological and operational skills.

Moreover, the empirical results imply that firms need to elevate the overall education level of employees. Well-educated workers may shape a more supportive work environment for technology development by engaging in effective communication and leadership. Firm managers should be cautious about entertaining equilibrium among these three major indicators of human capital – general education level, STEM education and the same-industry work experience – to drive strategic outcomes of technological activities. In other words, our results suggest that technology-based firms may lose an advantage in delicately balanced human capital if they lean disproportionately towards general education, STEM education, or work experience in the same-industry when composing the workforce needed for technological development.

The findings of this study carry also practical implications for policy makers and government administrators, particularly with respect to higher educational and industrial policies. The results suggest that policy makers should focus on interventions that enhance STEM education that includes emphasis on practical knowledge and skills. Such policy initiatives may include placing a high priority on improving the quality of the STEM education curriculum and instruction in collaboration with industry and introducing more internship programs. Governments need to consider incentives to encourage students and teachers to be involved in more active domain-specific learning in engineering and science fields. Developing STEM learning programs and providing career advice are likely to also be important to supporting firm's transition to a higher level of technological intensity.

Our study has limitations. First, the data of this study was collected in Portugal. Future research could extend this study by investigating the role of human capital in other locations or economies that might have different socio-economic contexts. Particularly, future research could adopt comparative perspective and examine how the effects of human capital vary in the different stages of technological catch-up. Second, human capital management philosophies, policies, and practices may vary among firms and industries, which carries different consequences of

technological achievement for firms with the similar level of human capital. For instance, start-ups often have fewer hierarchies and an open culture to facilitate more communication and interaction among workers. Unfortunately, this study was unable to test these issues more carefully because our data does not include information on the human capital management of firms. A more extensive analysis of these issues could shed light on our comprehension of the human capital and technology development link. Lastly, our new measure is less likely to capture certain types of technology development. For example, it does not track technological growth within the same technology intensity level. Furthermore, among the firms remaining at the same level of technology intensity, the new measure does not distinguish firms that intentionally choose to stay in the same technology intensity level from firms that fail to move into a higher technology intensity level. In addition, it does not fully capture firms' transition among different technology intensities in the area where the technology intensities of lower and higher-tech industries are overlapped. Future studies could expand this study to directly assess technological advancement within and across heterogeneous technology intensities, and provide a holistic understanding of how human capital influences technological activities.

Chapter 4 Foreign Direct Investment and Host Firms' Technology Development: The moderating role of overall and STEM education

Abstract

This chapter explores the relationship between foreign direct investment (FDI) and firms' technological performance, and in that context assesses the moderating role of higher education and STEM education. The empirical results indicate that foreign ownership through FDI is not correlated with the technology development of firms. The chapter also explores the effect of these variables on firm sales for different technological intensities. The results contribute to the technology management literature, suggesting that overall education, particularly in STEM areas, is important to gain larger benefits from FDI.

4.1. Introduction

Technology development through internal research and outsourcing has been considered to be a core activity of manufacturing firms since technology has been identified as one of the major drivers to firm performance and to fostering economic growth (Acemoglu, 2012; Tsai and Wang, 2008). In order to strengthen technology development capability, and decrease the technological gap with those that are more technologically advanced, firms have paid careful attention to foreign direct investment (FDI) as a mean for technological learning. There is ongoing debate in the strategic management literature regarding whether FDI offers benefits to firms in host countries (Ali et al., 2016; Hu, 2021; Jin et al., 2019; Matthias Arnold and Javorcik, 2009). The previous literature suggests that FDI can be either beneficial or deleterious to technology development of firms (Ali et al., 2016; Matthias Arnold and Javorcik, 2009). In addition, the influence of FDI may differ depending on internal and external factors such as R&D expenditure and the technology intensity of the industry in which the firm operates (Fu and Gong, 2011; García et al., 2013; Hu, 2021; Jin et al., 2019). This prompts important questions about the relationship between FDI and technology development, and the moderating factors that strengthen or weaken the relationship.

This chapter investigates the relationship between FDI and technology upgrading of firms and examines how different levels and types of educational attainments of workers in a firm are associated with this relationship. We argue that both general tertiary education and science, technology, engineering and mathematics (STEM) education of workers are associated with the moderating role of qualified workers.

While previous research has focused on the impact of FDI on technology development (García et al., 2013; Singh, 2017), it remains unclear whether and how FDI is associated with the short and long term technological performance of the host firms. Although researchers argue that the relationship between FDI and technology development is influenced by the human capital of the firms, the detailed dimensions of human capital are rarely investigated. Particularly, compared to other dimensions of human capital, such as schooling years or work experience (Ali et al., 2016; Lee and Walsh, 2016), the STEM related educational background of workers has been highlighted relatively less in discussion on FDI.

This study advances the literature on FDI and technology development in at least two ways. First, it contributes to the existing literature by providing extensive empirical evidence about the relationship among FDI, education and technology development. For that, we use a rich dataset covering various types of firms and industries. Moreover, this study adopts a measure based on substantive and comprehensive progress of technology development of firms (Shin et al., n.d.). Second, this study generates theoretical and empirical contributions by adding STEM education of workers as a new determinant moderating the linkage between FDI and technology development. If it becomes possible to understand the influence of FDI on technology development and its moderating factors more clearly, firm managers and policy makers would have important managerial and policy implications.

The balance of the chapter is structured as follows: Section 4.2 provides a brief overview of the literature regarding FDI, education and technological development. It is followed by the formulation of hypotheses. Section 4.3 discusses the details of the dataset and the methodology used in this study. Section 4.4 and 4.5 analyze the empirical results which are discussed in Section 4.6. Section 4.7 concludes the chapter.

4.2. Theoretical review and hypotheses development

4.2.1. Technology development measure

This study uses a measure to assess the technology development of firms that is based on the change of the industry classification codes of firms (Shin et al., n.d.)]. Researchers have adopted a variety of approaches to measure technological progress. For example, previous studies apply self-evaluation of workers, number of patents, citation counts of patents or publication, R&D intensity, technical performance improvement, firm survival, size of funding, number of employees and firm sales as summarized in Table 4-1. However, these approaches, on which much of the academic debate about technology development has relied, are likely to be imperfect and biased because they omit important dimensions of technological input and output, or they are based on subjective assessment. Self-evaluation of a firm's technology level involve the risk that responders are affected by personal opinions, feelings, beliefs and desires. Using patents or publication has limitation considering many of them are not used or not connected to firms' products. Furthermore, counting the number of patents or publication does not provide inside about the quality of new technologies while counting citation of them fails to assess the quantity aspect of technological capabilities. The measurement of R&D intensity ignores non-R&D technology development, such as licensing. Quantifying technical performance is less likely to capture technological achievement related to processing, such as cost cutting technologies. A set of indirect measures which are firm survival, size of funding and number of employees can be met skepticism since it is unclear that those measures result in or from technological progress. To address these measurement problems, we apply a more comprehensive measure.

This study captures the technology development of firms by tracking the change of CAE code. The CAE code is the Portuguese classification of of a firm according to its main economic activity. The main economic activity is determined by comparing the amount of the added value of each activity. This study divides the CAE codes of manufacturing industries to four technology intensity levels: low-tech, medium low-tech, medium high-tech and high-tech industries. The division of manufacturing industries follows the industry classification of the OECD and Eurostat (Eurostat, 2020; OECD, 2003). For example, if the technology intensity level where a firm's CAE code transitions from medium low-tech industry to high-tech industry,

we can identify that the main activity of the firm changed to an industry involving a higher level of technologies. This is interpreted as the technological advancement of the firm.

The upgrade of the main activity requires the overall improvement of a whole range of manufacturing process including resource input and product output, and reflects its commercial appeal to the market. The CAE typology and technology intensity levels are based on official and validated information. Therefore, the measurement based on the firms' transitions between CAE codes consequently leads to more direct, accurate and robust assessment of technology development.

Table 4-1: Most representative measurements for technology development

Measurements used	**Authors**
a. Self-evaluation of innovative output	De Winne and Sels, 2010; Deligianni et al., 2019; van Uden et al., 2017; Vyas and Vyas, 2019
b. Number of patents	Liu and Qiu, 2016; Valenti and Horner, 2019
c. Citation counts of patents or publication	Guarascio and Tamagni, 2019; Schultz et al., 2013; Van Roy et al., 2018
d. R&D intensity	Cao and Im, 2018; Fassio et al., 2019; Guo et al., 2020; Valenti and Horner, 2019
e. Technical performance improvement	Coccia and Watts, 2020
f. Firm survival during certain years	Gimmon and Levie, 2010; Kato and Honjo, 2015
g. Size of funding	Hsu, 2007; Patzelt, 2010
h. Number of employees	Colombo and Grilli, 2005
i. Firm sales	Grilli et al., 2020

4.2.2. FDI, education and technology development

A broad literature has shown mixed findings with respect to the impact of FDI on technology development. Scholars suggest that competition from foreign entrants can have serious negative impacts upon a domestic innovation system. Foreign entrants often possess more efficient production methods and provide higher quality products to the market (Matthias Arnold and Javorcik, 2009). This can increase the level of competition within the domestic market and raise wage and other resource costs (Matthias Arnold and Javorcik, 2009). FDI consequently can put enormous pressure on domestic competitors to operate in less profitable markets or even exit the market (García et al., 2013).

Another stream of the literature suggests that there are beneficial impacts of FDI. Researchers focus on technology transfer or spillover from foreign entrants to host firms. FDI acts as a conduit for technologies from foreign firms that are mainly technologically superior (Ali et al., 2016). Such transfer of technologies from foreign firms can result in the more efficient use of resources and hence increase the productivity of a host firm (Girma, 2005; Liang, 2017). The resulting improved productivity may result in the firm increasing its level of resources applied to support technological innovation (Liang, 2017; Singh, 2017).

While there is a possibility that foreign entrants may hamper the dynamics of the domestic market in the long term, FDI often brings host firms advanced technologies and provides them opportunities to upgrade their technological knowledge. Accordingly we hypothesize:

> *Hypothesis 1*: At least in the short run, FDI is positively associated with technology development of host firms.

The presence of highly educated employees within the firm is an important factor for the positive impact of FDI. Scholars argue that technological outcome of firms is never achieved from FDI automatically (Javorcik, 2010). Educational attainment may become a foundation upon which to understand complex specialized knowledge and improve internal intellectual capital (Protogerou et al., 2017). Moreover, a well-educated workforce is more likely to invest in R&D cooperation with external partners (Cantabene and Grassi, 2020). That is, education can play a central role in a firm's ability to absorb and internalize external technologies (Das and Drine,

2020). Among different levels of education (i.e. primary, secondary and tertiary education), tertiary education plays a more important role on technology development (Ang et al., 2011; Zhang and Zhuang, 2011). The following hypothesis is hence generated:

> *Hypothesis 2*: Tertiary education positively moderates the positive relationship between FDI and technology development of host firms.

Scientific and engineering education can have a higher potential to spur and shape the technological growth of FDI recipients. Workers with STEM education are more likely to be actively involved in a firm's process of technology development and use their knowledge and skills in that context (van Wetten et al., 2020). STEM degree holders are trained to apply their problem solving skills to the technology development processes of firms through their education (Walsh et al., 2013). Empirical evidence shows the positive effects of STEM education on technology development (Bianchi and Giorcelli, 2020). Therefore, we propose:

> *Hypothesis 3*: STEM education positively moderates the positive relationship between FDI and technology development of host firms.

Based on the aforementioned literature, our research model is depicted in Figure 4-1.

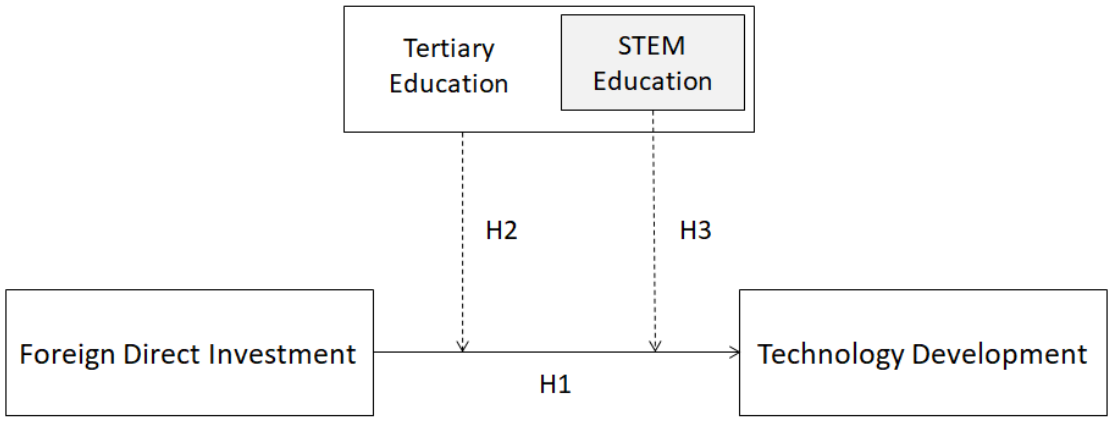


Figure 4-1: The conceptual model used to evaluate the hypotheses assessed in this study.

4.3. Methods

4.3.1. Dataset

The data employed in this study, which focuses on firms in manufacturing industries, were generated from a uniquely rich data set - Quadros de Pessoal (hereafter termed QP) that was used for the study in Chapter 3. QP is a Portuguese matched employer-employee database from the legally mandatory annual survey conducted by the Portuguese Ministry of Labor, Solidarity, and Social Security. They cover nearly the entire population of companies that have had at least one employee within Continental Portugal and Autonomous Regions since 1982.

As such, the use of QP yields distinct benefits in investigating the relationship among FDI, education and technological development of firms. QP contains extensive information on firms and individuals. Firm variables cover firm characteristics, such as industry, performance, size, type of ownership, location, firm founding and mortality, and individual variables include demographic attributes, occupational details and human capital. Firms and individuals (paid workers and business owners) are assigned unique identification numbers, so they can be matched and tracked over years. The longitudinal and highly inclusive nature of the extremely large survey provides a high degree of representativeness and informativeness making it possible to answer research questions where comprehensive analysis concerning heterogeneous factors is required.

To make use of the full benefits of its abundant and rich data on firms and individuals, we needed to clean and filter the data. Portuguese industry classification codes that are included in the QP have been updated four times during the observation period. The first, second and third versions that were adopted for the survey during 1982~2007 have insufficiently detailed categories of industries and lack the continuity with subsequent versions. This significantly impedes the process of harmonizing and integrating all the information collected through the years. For that reason, in this study we restricted the analysis to the period of 2009~2015. After data cleaning and filtering, we ended up with a dataset of around fourteen thousand observations.

4.3.2. Variables

Since the aim of this chapter is to investigate the linkage among FDI, education, and technology development of firms, it is necessary to adopt a new measure as described in Section 4.2. This variable is a dummy variable that corresponds to whether a firm transitions to a higher tech intensity level.

FDI is a dummy variable that equals 1 when the foreign-owned equity of a firm exceeds 50% and 0 otherwise. The 50% threshold of foreign ownership has been widely accepted in other studies since the majority of the ownership is a simple and clear method to judge whether a certain type of investor owns and run a firm (Bellak, 2004; Teixeira and Tavares-Lehmann, 2014).

The tertiary education level of workers is denoted by the ratio of the workers who have bachelor, master and doctorate degrees to the total number of employed people. STEM educated workers is a continuous variable measured by a ratio of workers who have completed bachelor or higher degrees in STEM related fields. For example, a worker with a bachelor degree in electrical engineering or a master degree in physics is counted as a STEM educated worker.

A large set of control variables that may influence technology development are included in the models. In detail, this study controls for working experience, the same industry working experience, gender diversity, workers' age, firm age, firm size, years and regions. Working experience enhances technological and managerial expertise of workers (Ravasi and Turati, 2005). It is measured as the average number of working years. The same industry working experience helps workers to understand industry specific technologies and find better technological opportunities that are well aligned with the technological trend of the industry (Shane, 2000). Work experience in the same industry is measured as the average number of years in the same industry where workers are employed presently. Gender diversity among team members provides various perspectives, which is beneficial for firm performance (Triana et al., 2019). Gender diversity is calculated by using the formula, $(1-\sum Pi2)$, where Pi is the proportion of each gender (Xie et al., 2020). When workers grow older, their knowledge may become outdated, but they may have better communication and organizational skills (Schubert and Andersson, 2015). Workers' age accounts for the average age of firm workers. Young and

mature firms may have different levels of risk taking and different capabilities (Coad et al., 2016). This study controls for the effects of firm age by adding a dummy variable which is equal to 1 if the aged of the firm is greater than or equal to 10 years. Firm size measured as the logged number of workers is controlled since it is closely associated with firms' technological capabilities (Stock et al., 2001).

4.3.3. Estimation method

In order to test whether FDI is associated with technology development and whether education moderates its impact, the data were analyzed through the use of logistic regression. A logistic regression model is appropriate to estimate the likelihood of binary possible outcomes of dependent variables. The dependent variable in this study has a dichotomous value indicating whether a firm climbs up from the industry with a lower technology intensity level to another with a higher technology intensity level. Thus, the logistic regression model is fitted to analyze the data and examine the linkage among FDI, overall and STEM tertiary education, and technology development.

This study calculates and reports the coefficients from the logistic regression models. These coefficients show the probability that the firm develops technologies, applies them to their products, and, as a result, ascends in the ladder of technology intensity levels consisting of four categories: 'low-tech', 'medium low-tech', 'medium high-tech' and 'high-tech'. To enhance the interpretation of the coefficients, the marginal effects corresponding to the independent variables are also computed and presented. The marginal effects reflect the impact of a one-unit change of the independent variables on the probability belonging to the outcomes of the dependent variable when holding other variables at the means (Norton et al., 2019).

4.4. Findings

Technology development involves a long and arduous marathon in which a handful of firms are able to attain their technological goal. During the period from 2009 to 2015, 0.21% of all manufacturing firms (i.e. 404 firms) experienced moving up in the ladder of technology intensity. The data reveal that technology development generally entails complicated processes and access to considerable resources, which most firms cannot afford. The descriptive statistics show that the distribution of the number of workers is highly skewed to the right. This highlights the fairly small average size of the Portuguese firms. Table 4-2 illustrates the descriptive statistics including the mean, standard deviation, minimum and maximum values.

We found no evidence of multicollinearity. To confirm the absence of multicollinearity, the variance inflation factor (VIF) test was run. All of the values were below 10, which is the widely used permissible limit, indicating the collinearity among variables is not an issue (Cohen, 2003). Table 4-3 shows the correlation matrix.

Table 4-2: Descriptive statistics of variables

Variables	***Mean***	***S.D.***	***Min***	***Max***
FDI	0.02	0.15	0.00	1.00
Tertiary Education	0.05	0.14	0.00	1.00
STEM education	0.02	0.08	0.00	1.00
Working experience	2.27	0.91	1.00	11.00
Same industry working experience	4.73	1.88	1.00	9.00
Workers' age	27.86	8.13	16.00	69.00
Gender diversity	0.22	0.21	0.00	0.50
Firm age	0.74	0.44	0.00	1.00
Firm size (logged)	1.95	1.26	0.00	8.18

Table 4-3: Correlation matrix shows low risk of multicollinearity.

Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. FDI	1.000								
2. Tertiary Education	0.149***	1.000							
3. STEM education	0.125***	0.594***	1.000						
4. Working experience	0.020***	-0.025***	0.003	1.000					
5. Same industry working experience	0.006*	-0.055***	-0.036***	-0.053***	1.000				
6. Workers' age	0.071***	0.104***	0.053***	-0.016***	0.007**	1.000			
7. Gender diversity	-0.050***	-0.058***	-0.044***	-0.139***	-0.227***	-0.043***	1.000		
8. Firm age	0.019***	-0.010***	-0.000	-0.291***	0.272***	0.093***	-0.034***	1.000	
9. Firm size (logged)	0.225***	0.113***	0.119***	0.106***	0.005*	0.418***	-0.178***	0.142***	1.000
VIF	1.08	1.59	1.56	1.19	3.05	1.18	1.24	1.23	1.38

*** p<0.001, ** p<0.01, * p<0.05

Table 4-4: Estimates of logistic models on the relationship between FDI and technology development and its moderating factors factorsshow that education, particularly in STEM fields, has moderating impacts.

Variables	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	0.171	(0.275)	0.168	(0.277)	-0.640	(0.423)	0.110	(0.275)	-0.251	(0.343)
Education			0.015	(0.259)	-0.207	(0.284)				
FDI×Education					2.717**	(0.866)				
STEM education							1.055**	(0.340)	0.839*	(0.370)
FDI×STEM Education									2.267*	(1.029)
Working experience	-0.300***	(0.061)	-0.301***	(0.061)	-0.305***	(0.061)	-0.296***	(0.061)	-0.299***	(0.061)
Same industry working experience	-2.473***	(0.077)	-2.473***	(0.077)	-2.476***	(0.077)	-2.471***	(0.077)	-2.472***	(0.077)
Gender diversity	0.689*	(0.291)	0.684*	(0.292)	0.673*	(0.292)	0.696*	(0.292)	0.690*	(0.292)
Workers' age	-0.005	(0.006)	-0.005	(0.006)	-0.004	(0.006)	-0.004	(0.006)	-0.004	(0.006)
Firm age	0.743***	(0.126)	0.740***	(0.126)	0.739***	(0.126)	0.751***	(0.126)	0.747***	(0.126)
Firm size (logged)	0.545***	(0.047)	0.545***	(0.047)	0.557***	(0.047)	0.535***	(0.047)	0.539***	(0.047)
Year dummies	yes		yes		yes		yes		yes	
Region dummies	yes		yes		yes		yes		yes	
Pseudo R^2	0.393		0.394		0.395		0.395		0.396	
Observations	195,350		195,230		195,230		195,230		195,230	

*** p<0.001, ** p<0.01, * p<0.05

We test our hypotheses described in Section 4.2 by using logistic regression. The results of our regression analysis are summarized in Table 4-4, which Report results from 5 models. We began by estimating a baseline model to evaluate the relationship between FDI and technology development as shown in Model1. Models 2,3,4 and 5 provide the results of the full models with the moderating effects of overall and STEM tertiary education. Model 3 contains the interaction term of FDI and tertiary education to explore whether the tertiary education level of workers moderates the relationship between FDI and technology development. Model 5 includes the interaction term that combines FDI with STEM tertiary education.

The first hypothesis of this study (Hypothesis 1) suggested that FDI is positively associated with technology development. Model1 shows no support for the contention that foreign ownership would matter for the technological upgrade of host firms, at least in the short run. Thus, this study does not support the debate, reviewed in Section 4.2., that FDI is conducive to technological improvement.

Our second hypothesis (Hypothesis 2) proposed that the tertiary education level of workers strengthens the positive relationship between FDI and technology development. This hypothesis is supported by our data in Model 3. The interaction term of FDI and tertiary education is positive and statistically significant with $p<0.01$. When workers of firms have the award of undergraduate degree or postgraduate degree in average, FDI is more likely to be associated with technology development than when firm workers attain educational degrees below bachelors.

Finally, the third hypothesis (Hypothesis 3) argued that STEM education positively moderates the linkage between FDI and technology development. This hypothesis is supported by Model 5. STEM education has a significant positive interaction effect ($p<0.05$) with the relationship between FDI and technology development. This result indicates that the positive relationship between FDI and technology development varies with the portion of science and engineering related degree holders within a firm.

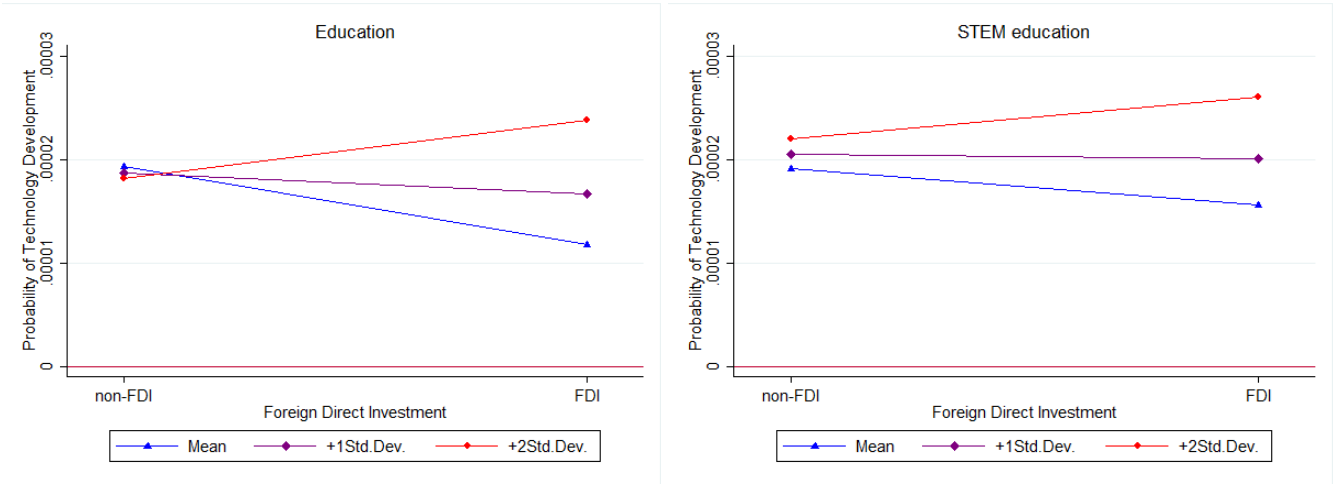


Figure 4-2: Moderating effects of tertiary education and STEM education

Figure 4-2 depicts graphically the significant interaction effects of overall education and STEM education on technology development. The margin plots show the moderating impacts of the overall and STEM tertiary education respectively when overall and STEM tertiary education are at different levels. The values used in these plots are at the mean, a 1 standard deviation higher level, and a 2 standard deviation higher level.

When a firm is domestically owned, the possibility of technology development remains similar across the different levels of tertiary education. On the other hand, foreign-owned firms with a higher rate of tertiary-educated workers are more likely to improve their technologies. Similarly, the level of STEM educated workers is of minor importance in domestically owned firms since it does not function well as a proxy for technology development. STEM education increases the likelihood of technology development when a firm is owned by foreign capital. Thus, we observe positive effects in these interaction plots supporting the hypotheses that higher levels of tertiary education and STEM education are in a better position to gain more technological benefits from FDI. These results support Hypothesis 2 and 3.

Among control variables, we find the significant coefficients for working experience, the same industry working experience, gender diversity, firm age and firm size. Gender diversity, firm age and firm size become more important for the technological performance of foreign invested firms while general working experience and the same industry working experience come to be more critical drivers in domestically owned firms.

4.5. Additional analysis

In an extensive set of additional analysis reported in Table 4-6, 4-7 and 4-8, the impact of FDI on firm performance is tested. We also explore to what extent the impact of FDI is driven by the heterogeneous levels of overall and STEM tertiary education. This additional analysis adopts three measures of firm performance: firm sales; firm size (number of workers); and firm sales per worker. We use 1 year lagged values for all these three measures. Each model is estimated and compared across two different technology intensity settings that are low and medium low-tech, and medium high and high-tech. The results of the additional analysis are summarized in Table 4-5.

Table 4-5: Summary of the additional analysis

Dep.Var.	**1. Firm sales**			**2. Firm size**			**3. Firm sales per worker**		
	a. Low& Med-Low	**b. Med-High &High**	***Coef.***	**a. Low& Med-Low**	**b. Med-High &High**	***Coef.***	**a. Low& Med-Low**	**b. Med-High &High**	***Coef.***
FDI	+, Sig.	+, Sig.	a<b	+, Sig.	+, Sig.	a<b	+, Sig.	+, Sig.	a<b
Tertiary education	+, Insig.	–, Sig.	-	–, Sig.	–, Sig.	a>b	+, Sig.	+, Sig.	a<b
STEM education	+, Insig.	–, Insig.	-	–, Sig.	–, Sig.	a>b	+, Sig.	–, Sig.	a>b

First, we investigate whether FDI has an impact on firm sales and its impact depends on education. Table 4-6 shows that firm sales heavily depend on ownership. Foreign owned firms are more likely to have larger firm sales compared with domestically owned firms. This pattern is amplified when firms are in the medium high and high-tech industry. We do not find any indication that differences in the level of tertiary education and STEM education determine the impacts of FDI on firm sales in the low and medium low-tech industry. In the medium high and high-tech industry, tertiary education has a negative moderating effect whileas the moderating role of STEM education is insignificant.

Second, we examine the impact of FDI on firm size measured as the number of workers. In addition, the moderation effects of tertiary and STEM education are analyzed. Table 4-7 indicates that foreign ownership contributes to the size of firms, particularly in the higher level of

technology intensity. While most Portuguese firms are moderate in size, a larger number of employees is found in foreign owned firms than in domestically owned firms, and in firms in the medium high and high-tech industry than those in the low and medium low-tech industry. Furthermore, we find evidence that tertiary education and STEM education negatively moderate the positive impact of FDI on firm size. These moderating effects are reinforced in the low and medium low-tech industry.

Third, combining the first and second analysis, we estimate whether firm sales per worker depends on foreign ownership. The interaction effects between FDI and the level of tertiary and STEM education are also explored. Table 4-8 reveals that firms owned by foreign investors are significantly more likely to bring larger firm sales per workers than domestically owned firms. We note that technology intensity is positively associated with the impact of FDI on firm sales per worker. That is, the coefficients of FDI for firm sales per worker increase across the heterogenous technology intensities. Given the technology intensity levels, we observe the positive moderating effect of tertiary education on the impact on firm sales per worker. This moderating effect is strengthened in the medium high and high-tech industry. STEM education functions as a positive moderator in the low and medium low-tech industry while it weakens the positive relationship between FDI and firm sales per worker in the medium high and high-tech industry.

We ran the same analysis using 2 year lagged values in order to check the robustness of our findings. This gave rise to results that are qualitatively similar to those reported and discussed above.

Table 4-6: The impact of FDI on firm sales and its moderating factors in different technology intensities

A. Low&Medium Low Tech Industries	**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 10**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	9.383***	(1.906)	7.969***	(1.915)	4.973	(2.557)	8.386***	(1.911)	7.028**	(2.245)
Education			15.940***	(2.060)	15.260***	(2.095)				
FDI×Education					20.030	(11.330)				
STEM education							26.170***	(3.499)	25.380***	(3.565)
FDI×STEM Education									21.320	(18.500)
Working experience	-1.095***	(0.304)	-0.968**	(0.305)	-0.974**	(0.305)	-1.052***	(0.304)	-1.049***	(0.304)
Same industry working experience	0.128	(0.198)	0.311	(0.200)	0.309	(0.200)	0.229	(0.199)	0.228	(0.199)
Gender diversity	-7.971***	(1.335)	-8.580***	(1.337)	-8.636***	(1.337)	-7.965***	(1.335)	-7.983***	(1.335)
Workers' age	0.084	(0.044)	0.083	(0.044)	0.083	(0.044)	0.081	(0.044)	0.081	(0.044)
Firm age	-0.839	(0.678)	-0.765	(0.678)	-0.751	(0.678)	-0.792	(0.678)	-0.781	(0.678)
Firm size (logged)	5.671***	(0.231)	5.556***	(0.231)	5.576***	(0.231)	5.531***	(0.231)	5.536***	(0.231)
R^2	0.011		0.012		0.012		0.012		0.012	
Observations	66,824		66,795		66,795		66,795		66,795	

B. Medium High&High Tech Industries	**Model 11**		**Model 12**		**Model 13**		**Model 14**		**Model 15**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	22.880***	(2.009)	22.420***	(2.033)	28.920***	(2.909)	22.920***	(2.018)	24.540***	(2.459)
Education			3.809	(2.574)	6.782*	(2.743)				
FDI×Education					-24.480**	(7.844)				
STEM education							-0.804	(3.931)	1.214	(4.302)
FDI×STEM Education									-12.550	(10.870)
Working experience	-1.079	(0.754)	-0.949	(0.759)	-0.769	(0.760)	-1.084	(0.754)	-1.055	(0.754)
Same industry working experience	0.705	(0.407)	0.791	(0.412)	0.802	(0.411)	0.698	(0.409)	0.715	(0.409)
Gender diversity	-21.420***	(3.167)	-21.910***	(3.184)	-21.960***	(3.182)	-21.410***	(3.168)	-21.510***	(3.169)
Workers' age	0.186	(0.114)	0.188	(0.114)	0.184	(0.114)	0.186	(0.114)	0.187	(0.114)
Firm age	-4.326**	(1.633)	-3.924*	(1.655)	-3.610*	(1.657)	-4.356**	(1.640)	-4.251**	(1.642)
Firm size (logged)	12.500***	(0.464)	12.510***	(0.464)	12.270***	(0.470)	12.510***	(0.466)	12.450***	(0.469)
R^2	0.165		0.165		0.167		0.165		0.165	
Observations	6,642		6,642		6,642		6,642		6,642	

*** p<0.001, ** p<0.01, * p<0.05 / Year and Region dummies are included / All numbers are in million

Table 4-7: The impact of FDI on firm size and its moderating factors in different technology intensities

A. Low&Medium Low Tech Industries	**Model 16**		**Model 17**		**Model 18**		**Model 19**		**Model 20**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	90.35***	(1.102)	87.78***	(1.107)	104.4***	(1.483)	88.19***	(1.105)	93.19***	(1.294)
Education			25.18***	(1.150)	28.64***	(1.167)				
FDI×Education					-107.9***	(6.418)				
STEM education							44.56***	(1.953)	47.45***	(1.991)
FDI×STEM Education									-74.64***	(10.07)
Working experience	2.198***	(0.166)	2.360***	(0.166)	2.366***	(0.166)	2.219***	(0.166)	2.207***	(0.165)
Same industry working experience	0.182	(0.138)	0.486***	(0.139)	0.491***	(0.139)	0.366**	(0.139)	0.369**	(0.138)
Gender diversity	32.85***	(0.679)	31.45***	(0.681)	31.45***	(0.681)	32.29***	(0.679)	32.29***	(0.678)
Workers' age	-0.426***	(0.0191)	-0.401***	(0.0191)	-0.400***	(0.0191)	-0.409***	(0.0191)	-0.409***	(0.0191)
Firm age	10.21***	(0.344)	10.27***	(0.344)	10.19***	(0.344)	10.16***	(0.344)	10.13***	(0.344)
R^2	0.074		0.077		0.079		0.077		0.078	
Observations	145,894		145,801		145,801		145,801		145,801	

B. Medium High&High Tech Industries	**Model 21**		**Model 22**		**Model 23**		**Model 24**		**Model 25**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	147.9***	(3.634)	149.0***	(3.674)	208.0***	(5.237)	147.1***	(3.661)	168.6***	(4.527)
Education			-9.780*	(4.688)	14.68**	(4.903)				
FDI×Education					-231.6***	(14.77)				
STEM education							13.09	(7.085)	34.69***	(7.563)
FDI×STEM Education									-171.0***	(21.27)
Working experience	1.033	(1.371)	0.719	(1.380)	1.643	(1.369)	1.106	(1.373)	1.262	(1.370)
Same industry working experience	1.103	(0.924)	0.860	(0.932)	0.815	(0.924)	1.246	(0.928)	1.410	(0.926)
Gender diversity	53.84***	(5.411)	54.99***	(5.440)	51.26***	(5.399)	53.36***	(5.424)	51.07***	(5.419)
Workers' age	-1.308***	(0.155)	-1.342***	(0.156)	-1.278***	(0.155)	-1.288***	(0.156)	-1.262***	(0.155)
Firm age	27.16***	(2.681)	26.33***	(2.713)	26.66***	(2.690)	27.48***	(2.689)	27.83***	(2.683)
R^2	0.137		0.137		0.152		0.137		0.141	
Observations	14,201		14,191		14,191		14,191		14,191	

*** p<0.001, ** p<0.01, * p<0.05 / Year and Region dummies are included

Table 4-8: The impact of FDI on firm sales per worker and its moderating factors in different technology intensities

A. Low&Medium Low Tech Industries	**Model 26**		**Model 27**		**Model 28**		**Model 29**		**Model 30**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	0.112***	(0.005)	0.096***	(0.005)	0.054***	(0.006)	0.103***	(0.005)	0.092***	(0.006)
Education			0.176***	(0.005)	0.167***	(0.005)				
FDI×Education					0.280***	(0.028)				
STEM education							0.217***	(0.009)	0.210***	(0.009)
FDI×STEM Education									0.177***	(0.046)
Working experience	0.002**	(0.001)	0.004***	(0.001)	0.004***	(0.001)	0.003***	(0.001)	0.003***	(0.001)
Same industry working experience	-0.006***	(0.000)	-0.004***	(0.000)	-0.004***	(0.000)	-0.005***	(0.000)	-0.005***	(0.000)
Gender diversity	0.011***	(0.003)	0.004	(0.003)	0.004	(0.003)	0.011***	(0.003)	0.011***	(0.003)
Workers' age	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)
Firm age	0.003	(0.002)	0.004*	(0.002)	0.004*	(0.002)	0.004*	(0.002)	0.004*	(0.002)
Firm size (logged)	0.010***	(0.001)	0.009***	(0.001)	0.009***	(0.001)	0.009***	(0.001)	0.009***	(0.001)
R^2	0.024		0.041		0.042		0.033		0.033	
Observations	66,686		66,657		66,657		66,657		66,657	

B. Medium High&High Tech Industries	**Model 31**		**Model 32**		**Model 33**		**Model 34**		**Model 35**	
	Coef.	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***	***Coef.***	***Std.Err.***
FDI	0.185***	(0.017)	0.154***	(0.017)	-0.044	(0.024)	0.174***	(0.017)	0.200***	(0.021)
Education			0.256***	(0.022)	0.166***	(0.023)				
FDI×Education					0.745***	(0.065)				
STEM education							0.224***	(0.033)	0.256***	(0.036)
FDI×STEM Education									-0.198*	(0.092)
Working experience	0.020**	(0.006)	0.028***	(0.006)	0.023***	(0.006)	0.021**	(0.006)	0.021***	(0.006)
Same industry working experience	-0.006	(0.003)	0.000	(0.003)	-0.001	(0.003)	-0.004	(0.003)	-0.004	(0.003)
Gender diversity	0.015	(0.027)	-0.018	(0.027)	-0.016	(0.026)	0.012	(0.027)	0.010	(0.027)
Workers' age	-0.001	(0.001)	-0.001	(0.001)	-0.001	(0.001)	-0.001	(0.001)	-0.001	(0.001)
Firm age	-0.012	(0.014)	0.015	(0.014)	0.005	(0.014)	-0.004	(0.014)	-0.002	(0.014)
Firm size (logged)	0.013**	(0.004)	0.013***	(0.004)	0.020***	(0.004)	0.010**	(0.004)	0.009*	(0.004)
R^2	0.034		0.055		0.073		0.041		0.042	
Observations	6,637		6,637		6,637		6,637		6,637	

*** p<0.001, ** p<0.01, * p<0.05 / Year and Region dummies are included / All numbers are in million

4.6. Discussion

In this chapter, we take on the challenge of investigating how FDI influences technology development and firm performance. We heed the call for more research regarding the moderating roles of overall and STEM tertiary education. We develop the hypotheses and conduct empirical analysis adopting a more objective measure and a rich dataset.

This study finds no evidence for our first hypotheses that FDI is positively related to technology development. Our results provide indications that tertiary education and STEM education are conditional factors that reinforce the positive association of FDI and technology development.

The insignificant correlation between FDI and technology development implies that technology transfer from parent firms to host firms does not happen automatically. If host firms lack the prerequisite foundation for technology absorption, such as technological infrastructure and human capital, it appears that host firms are not able to internalize imported technologies. In the context of technological catch-up, latecomers largely rely on foreign investors to introduce new technologies and upgrade their technological capabilities. However, our analysis suggests that attracting inward FDI might not be always effective for latecomers to facilitate technology accumulation. This finding complements the studies on the role of FDI by adding empirical evidences that give more weight to the precondition of technology spillover (Fadhil and Almsafir, 2015), rather than the efficacy of FDI (Shan and Jolly, 2011). Furthermore, our results based on the analysis of Portuguese data expand our horizon on FDI and technology development that mainly has been built on the cases of developing countries.

Our second key finding involves the importance of tertiary education in obtaining the full benefit of FDI with regard to technology advancement. The moderating effect of tertiary education is observed with the heterogeneous ratio of workers who own bachelor's and higher degree attainment. This means that firms with more educated workers will have more benefits from knowledge coming through FDI. This result is similar to those of previous studies that show that the absorptive capacity of firms plays a key role in technological receptivity. Absorptive capacity is defined as the ability of a recipient organization to acquire and assimilate external knowledge after realizing its benefits (Cohen and Levinthal, 1990). In the formation of

absorptive capacity, effective technological learning focusing on mastering and maneuvering the acquired technologies is fundamental and crucial (Gebauer et al., 2012). In this regard, absorptive capacity building relies on the average quality of workers who conduct technological learning (Pradana et al., 2020). Thus, higher level of tertiary education has been attributed to technology development of a host firm.

Our third important result highlights an interesting distinction between the moderating effects of overall tertiary education and STEM related tertiary education. As described, incremental improvement in the level of tertiary education appears to be important for increasing technological value extraction from FDI. We argue that STEM education is a key element in understanding how tertiary education leads host firms to gain technological knowledge from external sources. That is, the extent to which host firms successfully generate technological benefits from FDI is contingent on workers with STEM related degrees.

Moreover, the moderating effects of overall tertiary education and STEM related tertiary education lead us to an important theoretical implication. According to human capital theory, the dimensions of human capital can be classified into two categories, general human capital and specific human capital (Becker, 1975). General human capital is knowledge and techniques that are generally applicable across jobs and industries while specific human capital is valuable or transferable only in the specific contexts. Following the conceptual categorization that overall tertiary education is general human capital and STEM related tertiary education is specific human capital (Kato and Honjo, 2015), the results from this research imply that both types of human capital help firms to be technologically advanced. The actual potential to capture the benefits of FDI on technology development depends heavily on the educational attainments in non-STEM and STEM fields, and its combination. It confirms the results of some previous studies (Ganotakis, 2012; Marvel and Lumpkin, 2007), and contrasts with those of other studies (Capozza and Divella, 2019; McGuirk et al., 2015).

Our additional analysis examines the impact of FDI on firm performance with the backdrop of measuring firm sales, firm size and firm sales per worker. Firm performance is closely related with the potential ability of firms to conduct intensified R&D activities and technology commercialization. Firms with better performance are more likely to invest technological and

managerial resources in the technological activities of firms and, hence, increase the possibility of technology development. Our results argue that these firm performance factors, which function as an important predictors of potential technology development, are also related to different types of ownership. The finding on the impact of FDI on firm performance helps us recognize that foreign owned firms, particularly in the medium-high and high-tech industry, enhance their availability and affordability to foster future technological upgrade.

Our research also suggests that this positive influence of FDI can be strengthened or weakened by tertiary education and STEM education. First, highly educated workers positively moderate the benefits of FDI on firms' sales per worker. This implies that workers who attain knowledge, communication skills, leadership and project management skills through tertiary education play a role in improving firm performance. Specifically, we find that this educational qualification is more important in the industries with higher technological intensity. It suggests that technological and managerial knowledge is more valuable in circumstances that require more sophisticated levels of intellectual foundation. In contrast with tertiary education, STEM education shows heterogeneous moderating effects across the different levels of technology intensity. A higher ratio of STEM educated workers strengthens the beneficial effect of FDI on firm sales per worker in the lower levels of technology intensity. However, STEM education appears to hamper the positive relationship between FDI and firm sales per worker in the higher technology intensity. Considering that firms in the lower technology intensity put less emphasis on hiring engineers and technicians, a marginal increase in the proportion of STEM educated workers leads firms to quickly internalize foreign technologies, which is linked to the upgrade of the existing product lines. Conversely, firms which operate business in the higher technology intensity mainly have considerable size of R&D department and numbers of STEM-degreed workers. Therefore, overinvestment in STEM education may degrade the managerial capabilities of firms in the higher technology intensity and hinder those firms from obtaining the advantages of FDI.

From a managerial point of view, this study points out the importance of foreign ownership as a strategy to improve technology development of host firms when combined with appropriate human capital. Firms, particularly latecomer firms, usually lack resources and capabilities to independently develop and commercialize new and original technologies (Mathews, 2002). As

our finding posits, foreign direct investment could be one vehicle to facilitate technological progress. For that, firms might need to hire workers who own bachelors or higher degrees. STEM educated workers can be catalysts to boost the technology acquisition, assimilation and transformation of firms. In addition, when taking into account the diverse moderation effects of the different education types on technology development and firm performance, it is wise to seek a balance between overall tertiary education and STEM education to maximize the technological merits of FDI. In turn, firms could attain higher technological competence by enhancing indigenous abilities to utilize technological inflow from parent firms.

Assuming this is true, it is important for policy makers to focus on improving higher education system with particular emphasis on STEM related fields. Strengthening the regional and national levels of education provides a sound business circumstance to promote technological activities of host firms. Carefully designed education curriculum may serve to increase the technological output of FDI recipients.

We note that our models result in low R-squared values. Existing literature argues that a low R-squared value is common in areas of social science in which many unobservable human behavior factors are connected together (Kashyap and Swastik, 2021). In addition, our R-squared values are not estimates, but parameters from the analysis of the whole population. Thus, notwithstanding low R-squared value, our analysis offers valuable insights and understanding of technology development.

4.7. Conclusion

This research extends prior studies by improving our knowledge regarding the formation of technological knowledge through FDI and educational investment. The contribution of the present study is threefold:

First, the study has shed light on integrative approaches to the complex relationships among FDI, education and technology development. A handful of earlier studies on FDI and technology development focus on the role of STEM education on firms' innovative performance. The chapter mitigates some of the ambiguity of the existing literature, which in general does not

explore how different types of education foster or hinder technological progress of FDI host firms.

Second, we believe our empirical approach, using the changes in the CAE code of firms, yields a more objective and systematic method to track firms' technological trajectories and development. It is also a more encompassing approach as changing from one economic activity into another one with higher technology intensity often implies structural changes in firms' activities, such as: production inputs and outputs, strategic management, human resources' policies, investment, partnerships or marketing approaches.

Finally, it is important to highlight that overall research in this field often focus on limited categories of industries, such as the high-tech industry, and certain types or classes of firms, such as starts ups, neglecting other types of firms in different industries. The very rich and unique longitudinal matched employer-employee microdata-set that we have used, allowed us to perform an integrated analysis across a broad range of manufacturing industries and firms and to offer a comprehensive understanding about the linkage among FDI, education, and technology development analyzing nearly the whole population of firms in one country, i.e. Portugal.

Chapter 5 Summary and Conclusions

This dissertation has sought to deepen our knowledge of how the strategic movement of a firm, and in some cases a government, improves the possibility and the speed of technological upgrade of a firm and, as consequence, advances the industrial structure of a country. To that end the thesis has explored three problems by adopting both in-depth qualitative analyses of interview data, and a quantitative analysis based on a wide range of firm and individual-level database.

The first study explored the challenges for an intermediate country in a high-tech industry and outlined a possible strategy to overcome those challenges and gain access to at least a part of a well-established global supply chain of the high-tech industry. This study collected and analyzed qualitative data regarding the role of Portugal and its firms in the supply chain of the aircraft cabin interior industry. Seventy-five exploratory interviews and forty-one in-depth interviews were conducted across multiple rounds to understand the key success factors, entry barriers, major components, major players, and Portuguese current and potential suppliers to that industry. The study concludes that Portugal has accumulated considerable technological capabilities in its aeronautic and relevant industries. In detail, Portuguese firms have technological competitiveness in tooling, assembly, and materials. However, considering high entry barriers, such as strict certification standards that all the products and manufacturing processes must meet due to the safety concerns, the current level of technological capabilities of Portugal is not enough to establish an independent role in the ACI industry. Instead, if it wishes to increase its role in this sector, Portugal would be wise to focus more on providing high-value components to this industry rather than striving to develop full product lines which would require it to compete against legacy firms. In addition, it would be important to intensify in-house R&D activities supplemented with external technologies in order to build its innovation capability.

The second and third studies of this dissertation apply quantitative methods to investigate which factors are associated with firms' success in technology development. Previous empirical studies have been hampered by inaccurate measures and a lack of comprehensive data. We overcome these shortcomings using two ways. First, we created and applied an original measure to assess the technology development of firms based on the tracking record of their transition in the industrial codes. This offers us a holistic approach covering a variety of dimensions of

technology development. Second, we analyzed a rich dataset including most heterogeneous firms and industries in Portugal which we believe eliminates a sample selection bias potentially affecting previous estimates.

The study reported in Chapter 3 examined the extent to which different aspects of human capital are associated with firms' technological improvement. It found that three factors contribute positively and significantly to technology development. First, an overall education level has an impact on technology development. Education allows workers to ameliorate essential skills that are important to help and conduct technological activities of firms. For example, highly educated workers have better project management skills, communication skills, self-motivation, and leadership. Second, the same industry work experience is beneficial to technological upgrades. While working in the industry, workers can acquire tacit knowledge of industrial contexts, such as the latest technology trend and market dynamics. Furthermore, work experience in the same industry provides opportunities to build social relationships with different stakeholders in the industry. Lastly, the combination of STEM education and the same industry work experience increases the likelihood that a firm moves up to a higher technology intensity level. Technological knowledge gained through the curriculum of STEM education is a somewhat disconnected and incoherent assortment of theories and skills, which is unable to be directly utilized in a real workplace. Task completion in a real-world situation integrates and recombines those theories and skills, and hence increases practical problem-solving abilities. Thus, STEM education needs to be supplemented with a certain level of the same industry work experience to contribute to technology development. This research does not find empirical confirmation of the effects of overall and STEM education.

The study reported in Chapter 4 examined the effects of FDI and the moderating role of education on technological performance. It finds no evidence that a FDI host firm is positively associated with technological advancement. However, the positive association between FDI and technological advancement is found when a firm has a higher percentage of tertiary-schooled employees, particularly in STEM related fields. These findings imply that FDI is an important channel for technology diffusion from foreign advanced firms to host firms in a laggard country. In the process of technology diffusion, the higher level of knowledge and skillsets of employers enables external technology acquisition, internal assimilation and manipulation of a host firm.

Therefore, FDI recipients require various efforts and investments to enhance their human capital. This study expands the findings of in Chapter 3 by indicating that human capital is important in explaining technology development and contributes to adding theoretical and empirical insights to the firm's technological learning related to FDI and human capital.

In addition to contributing to theoretical insights, the in-depth analysis of this thesis carriage practical implications for managerial staff and policymakers. To sum up prior research, an intermediate and laggard country needs to find external technological sources to upgrade its technological ability in niche markets for more sophisticated products which current technological competencies can be utilized. Attracting FDI can be an effective way of introducing external technologies to firms in laggard countries with substantial limitations of resources and capabilities. Technological knowledge diffusion embedded in FDI can drive technological upgrading in those countries. Achieving such technological upgrading is not an automated process, but an arduous task that firms need to invest substantial time and effort. Practitioners should replace human capital at the top of the investment list to gain all necessary technologies and build technological capabilities. From a managerial standpoint, hiring employers with the appropriate level and balance of knowledge, skills and techniques can play a pivotal role for firms to work effectively and efficiently in immediate and potential technology development. Overall education, STEM education and work experience in the same industry can be suitable proxies to evaluate the current knowledge level of an individual that potentially contributes to a firm's technological growth. Our results suggested it is worthwhile for firms to invest in and develop an adequate system of education and training. Policymakers should review STEM education programs of higher education institutions and strengthen the linkage between curriculum and real-world applications.

There is still much scope for further exploration on these and related topics. Although the first study sheds some light on the market and technological source that intermediate and laggard firms should focus on, the question remains as to which strategies are more appropriate in catching up with incumbents in the niche market of the high-tech industry. That is, laggard firms can follow the previous path of advanced firms or create their own path by introducing innovative products (Lee and Lim, 2001). The appropriate strategy needs further clarification considering the constraints of business operation in a high-tech industry. In the second and third

studies, we identify human capital factors related to technology development at the firm level. However, due to the lack of proper measures and data, it is difficult to compare and rank these factors. Nor is it possible to move beyond finding highly suggestive statistical associations to actual demonstration of causal effects. Balanced panel data and/or additional data, covering a more extended time-frame and containing potential instrumental variables to assess the impact of independent variables on firms' technological development, would contribute to bring additional and richer insight to the fore. Future research is, also needed to to strengthen the theoretical foundations of firms' technology development.

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Appendix: Interview Protocol

The Portuguese role in the global aircraft interior industry

Interview Protocol

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Introduction

The objective of our research is to identify and explore opportunities for Portuguese companies to become competitive players in supplying parts, or entire systems, for aircraft interiors. As a first step, this exploratory field study will identify the technological capabilities developed in the country for the design, production and delivery of aircraft cabin interiors, identify barriers, and analyse how Portuguese firms are positioned in the global aircraft interiors industry. The idea that Portugal may play a significant role in this industry is based on three facts: (1) the competitiveness of relevant sectors, such as textile, cork, leather, and plastics in the country, (2) the long-term experience of Portuguese industry in producing seats and other components for the automobile industry, and (3) the established tradition in Portugal of collaboration among research institutions, industrial technology centres and industrial associations.

Field research data will be collected by means of open qualitative interviews with Portuguese managers, researchers and policy makers and will serve as basis for discussing which policies and strategies could influence the competitive positioning of Portuguese firms in the aircraft interior industry. Since demand for new civilian aircraft is expected to grow in the coming decades, this represents a unique opportunity for the development of this industry in the country. Moreover, this research will also discuss the challenges firms are facing in the process transferring technological know-how across different industrial sectors and from R&D projects.

Interviewees' Profile: (1) managers of companies already supplying components to aircraft interiors industry, (2) managers of companies with the capabilities to supply this industry, (3) participants of R&D projects about aircraft interiors (i.e. 'LIFE' and 'new FACE'), and (4) industrial associations and government agencies.

Planned duration of interview: 30-45 minutes

1. Interview Protocol for managers of companies already supplying components to aircraft interiors industry

- How did you get involved in supplying the aircraft interior industry?
- Could you please tell us what products are you supplying to the aircraft interior industry and how are they integrated into the supply chain?
- Did you need to develop new technologies in order to supply to this industry? Or did you outsource new technologies or technological/design services to third party organizations? What technologies or technological/design services specifically?
- What strategy did your firm or institution used in order to obtain the necessary technologies? Probes: Internal or Collective R&D/M&A
- Did you encounter barriers in entering this industry and if so please tell us about them and how you worked to overcome them. Did government, trade associations or others help you to overcome those barriers?
- If you want to expand your role in this market what additional barriers are you likely to face and what are your thoughts on how they might be overcome?
- In the case of focusing on internal R&D, what contributes to improve the technological capability of your firm or institution?
- In the case of focusing on collective R&D, what do you think is the key point to transfer technology, know-how, and knowledge to your firm or institution?
- Can you list the key players and the key potential players in this industry?

2. Interview Protocol for managers of companies with the capabilities to supply this industry

- How much consideration, if any, have you given to the possibility of entering this market?
- In your opinion, does your company have the technological competencies needed to supply to the aircraft interior industry? Which products could you supply?
- Could you please describe what you see as possible technological and other barriers or challenges to penetrate this industry?
- What strategies might you adopt to overcome these barriers? How could government, trade associations or others help you overcome these barriers? Probes: Internal or Collective R&D/M&A
- In the case of focusing on internal R&D, what contributes to improve the technological capability of your firm or institution?

- To improve technological capabilities, what do you think is the most difficult aspect in your firm or institution? Probes: HR issue/Facilities/Financial issue
- Can you list the key players and the key potential players in this industry?
- Please describe the existent competencies/capabilities

3. Interview Protocol for participants in the 'LIFE' and 'new FACE' R&D projects about aircraft interiors

- Could you please describe how you became involved and what were the motivation and the objective to carry out the 'LIFE' and 'new FACE' projects in the perspective of your institution?

Both projects, the 'LIFE' and the 'new FACE' were focusing on futuristic interior and exterior of aircrafts.

- In your opinion, did the project contribute to improve technological capabilities in your firm or organization, or at national level? If so, how?
- Were the acquired technological capabilities useful to improve the products of your firm or organization?

Post-Project Actions

We could not find post-project actions after the project aiming a technology transfer.

- Are there current post-project actions designed to transfer technology, know-how and knowledge obtained through the projects?
- If not, is there any reason for it? Probes: No market demand / Not initially planned in the project / Funding problem, etc.

Patent/Publication/Database

- What was the policy to protect the intellectual properties acquired through the project?
- Is there any intellectual property such as a patent or publication based on the project results?
- Can you list the key players and the key potential players in this industry?
- What do you think about the prospects for Portuguese firms being successful in this industry?

4. Interview Protocol for industrial associations and government agencies

- Could you please give me your opinion on the aircraft interior industry as a future industry of Portugal?

- Do you think that Portuguese firms have technological capabilities which are necessary in the aircraft cabin interior industry? If so, what kind of technological capabilities? If not, what is the way to improve technological capabilities?
- Portugal has well developed textile, leather and plastic industries. Do you think that technologies in these industries can be applied to the aircraft cabin interior directly? If not, what are barriers?
- Could you please describe a strategy that your association or agency developed to support the aircraft cabin interior industry?
- Does your organization have a role in the national level strategy?
- Can you list the key players and the key potential players in this industry?

Thank you very much for your participation!