Managing Innovation to Increase Manufacturing Productivity

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***Abstract*—Technological progress is a key factor for economic growth. However, innovation requires attention from management and decision making at the various stages of the innovation process. Manufacturing, being a major producer of tradables, is a driver of technological change. In this paper we test the impact of innovation and other determinants on manufacturing productivity for 2015-2019, using panel data for 1,333 Portuguese firms. We estimate a model linking Total Factor Productivity growth to innovation, by technological groups and regions. Results suggest that innovation is a driver of productivity, although its magnitude is small. By contrast, Information and Communication Technology appears to exert a negative effect on productivity growth, especially in scale-intensive industries. A possible explanation is that the Portuguese workforce in such industries does not have enough skills to deal with up-to-date ICT. This appears to be corroborated by the positive impact of human capital accumulation on the TFP growth only in the Northern region.**

Keywords—innovation management, information and communication technology, productivity, manufacturing

I. Introduction

Innovation is the inherent driver of firms' productivity which is considered as the key driving force for sustained economic growth [1]. Thus, a growing literature has investigated the impact of innovative activities on firm productivity at micro-level, suggesting a positive relationship between innovation and productivity growth [2]. A well-established theory of technological change and economic growth through process or product innovations is derived from Endogenous growth models [3, 4, 5]. However, and despite the recent research linking innovation to productivity growth [6, 7], less effort has been devoted to empirically estimate the magnitude of the impact of innovation to Total Factor Productivity (TFP) growth by technological groups and regions.

The Strategic Leadership View argues that the incentive to innovate derives from the recognition of the potential of the innovation by the top management. Such ability depends on management experiences and on organizational and industry contexts and managerial values.

To allocate funds to an innovation, managers must believe that the innovation will be profitable to cover the investment. Yet, the uncertainty (associated with technologies and markets) that underpins many innovations, turns it difficult to determine the expected cash-flows, especially because the discounted cash flows technique possesses some flaws. Thus, an options-oriented methodology may be better in some cases.

Management establishes systems whereby information will flow in the shortest possible time to the right targets for decision-making.

Corporate strategy provides a road map of how the firm will reap advantages of worldwide sources of innovation and markets. Innovation strategies help drive functional strategies—resource allocation and the actions taken by each function along the value chain (R&D, manufacturing, etc.). Hence, innovation requires attention from management and decision-making at the various stages of its process. Its implementation entails the possession of the appropriated organizational structure, systems or processes, and Human Resources. A strategy, no matter how fundamentally sound, must be implemented well if its full benefits are to be realized.

The manufacturing industry has the potential of generating high rates of innovation and drag capabilities to other sectors. However, there have been significant productivity differences across industries and regions in Portugal. Many empirical studies confirm many of the patterns predicted by the New Trade Theories that account for firm heterogeneity [e.g., 8, 9]. Thus, firm heterogeneity must be understood in a framework of analysis at industry and regional level [10].

This paper contributes to the existing literature by linking firm innovation to firms' productivity growth. Using a sample of Portuguese manufacturing firms, it examines the effects of firm innovation on the productivity of firms across technological groups and regions. The introduction of sectoral and regional dimensions into innovation management analysis allow to further understand what actions are required and in what regions to increase manufacturing productivity and, thus, firms' competitiveness. In addition, unlike most studies that use labour productivity, this paper employs the Total Factor Productivity (TFP) using the Wooldridge-Levinsohn-Petrin

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(2009) method to assess the role of innovation on the productivity of manufacturing firms.

The paper is organized as follows. Section 2 performs the literature framing of the drivers of productivity. Section 3 describes the methodology, and section 4 presents the data. Results are reported in section 5, and section 6 provides the concluding remarks.

II. Drivers of Productivity

Literature has shown that there are significant differences in productivity levels across firms and regions. This finding has shaped research agendas in several fields, including Industrial Organization, Labour Economics, and International Trade. Empirical literature has explained such differences in productivity through the impacts of *innovation, physical capital,* and *human capital accumulation* [11]. Moreover, *business dynamism* and *openness* have been reported as capable of affecting firms' incentives to improve resource allocation and raise the productivity level.

A. Innovation

Since the seminal paper of Griliches in 1979, the R&D capital model has been the paradigm to investigate the relationship between firms' innovation and productivity growth**.** Changes in productivity can be driven by technology applications through knowledge capital. In several studies, knowledge capital is the accumulated research capital derived from previous R&D expenditures [12]. In some other studies, "knowledge" includes R&D investment, but also past investments in innovation, organizational techniques, and human capital [13]. However, traditionally empirical studies use R&D expenditures as a proxy of knowledge capital of firms. The reason is that technology improves labour productivity [14]. [15] estimate the long-run relationship between TFP, R&D, human capital, and public infrastructure for Italian regions, in 1980-2001. Using panel co-integration techniques, they find that, in the long-run, human capital has the strongest impact on productivity. Regional productivity is positively affected by R&D activity and public infrastructure of neighbouring regions. [16] examine the impact of innovation on growth of Pakistani SMEs, in 1980-2013. Using a log-linear regression model, they find a causal relationship among innovation and SMEs growth.

B. Control variables

Physical capital- Increasing physical capital of a firm, for example, by acquiring Information and Communication Technology (ICT) can increase the TFP [14]. The authors analyse the determinants of labour productivity growth in Greece, for 1995-1999. Using an OLS estimator, they find that Investments in physical capital, exports and R&D activities are associated with productivity growth. [17] investigates the determinants of labour productivity growth using a cross-country panel data set of 45 countries, for 1980-2005. The author finds a positive and significant impact of education, ICT investment, financial depth and FDI on labour productivity growth. Another author [18] studies the determinants of labour productivity for 74 countries, in 1950-2010. The author finds that labour productivity is stagnant with physical capital stagnation and the decrease of human capital. [19] examine the impact of fixed capital investments on productivity for countries in South-eastern Europe, in 2000-2017. Their regression analysis shows that changes in productivity are explained by changes in gross fixed capital formation in the European Union countries.

Human Capital Accumulation- The impact of human capital on productivity growth is widely acknowledged in the literature since the seminal contributions of [20], [21], [22] and [23]. Human capital contributes to output both like other factors of production and via technological change, by facilitating imitation and innovation [24]. Several studies use firm-level data to estimate the impact of training on firms' productivity [24, 25]. Their results indicate that trainings have positive and significant effect on productivity. Furthermore, [26] argues that human capital contributes to productivity level through allocative and worker effect, and productivity growth through diffusion and research effects. [27] examine the determinants of labour productivity, for the Asia-Pacific region, in 1980-2014. Through panel co-integration and an OLS estimation, the authors find that capital deepening, human capital, technology, institutional quality, government, size, and openness are significant determinants of labour productivity. [28] identify the influence of health and education on productivity of Iranian firms, in 1974-2014. Using an autoregressive-distributed Lag (ARDL) technique, they find that all variables (excluding the index of composite Human Capital flow) have a positive and significant impact on labour productivity.

Business Dynamism- The entry of new firms and the dynamic of young firms contribute considerably to productivity growth [29]. Furthermore, young firms play an important role in employment [30] and productivity growth [31, 32]. [29] studies the link between business dynamism and productivity growth in the US, for 1980-2009. He finds that dynamism and turbulence in the economy have a favourable impact on productivity. However, [33] and [34] find hat changing business dynamism does not impact significantly on aggregate TFP. [32] investigate the link between declining firm entry, aging incumbent firms and sluggish productivity growth in the US, during 1996-2012. Using several estimators, such as OLS, WLS and instrumental variables, they find that the higher productivity growth of young firms is driven almost entirely by selection and reallocation forces.

Openness- Firms in export-oriented sectors usually face greater competition in international markets, when compared to firms that supply the local market. Thus, they are forced to improve their resource allocation and raise their productivity to gain competitiveness [35]. Therefore, these firms are expected to show higher levels of productivity than their rivals that sell their products only in domestic markets. Many empirical studies with firm-level data confirm a positive impact of exports on firms' productivity, such as [36] for Mexico; [37] for Morocco; [38] for Spain, [39] for nine African countries, [40] for England; and [14] for Greece. [41] investigate the main determinants of the TFP of Portuguese manufacturing firms, in 2010-2014. Using a fixed-effects model, they find that exports and human capital prompt TFP growth. [42] analyse the regional dimension of productivity determinants for 24 regions in Ukraine, in 2013. Using the

[43] technique to estimate the TFP and OLS regressions with industry-specific effects, they find a positive relationship between firm productivity and international openness. [44] investigate the link between firm-level innovation, exports, and productivity for the Indian manufacturing sector. Using univariate instrumental estimations, they find that exports and innovation improve firms' TFP.

Thus, the research hypotheses are:

H1: *Innovation* has a positive and significant impact on productivity growth.

H2: *Physical capital* has a positive and significant impact on productivity growth.

H3: *Human capital accumulation* has a positive and significant impact on productivity growth.

H4: *Business dynamism* has a positive and significant impact on productivity growth.

H5: O*penness* has a positive and significant impact on productivity growth.

III. METHODOLOGY

According to [45], estimating growth equations with firm level panel data can lead to specification problems as well as the invalidity of instruments for capital and employment at the firm level. A way to address the issue of endogeneity in capital, and the possibility of productivity shocks, consist in using a two-step procedure and estimate the TFP using the [46] modifications to the original [43] value-added approach from the following equation:

$$Y_{it} = A_{it} K_{it}^{\beta k} L_{it}^{\beta l} M_{it}^{\beta m} \quad (1)$$

where Y_{it} represents the output of firm *i* in period *t*, K_{it}, L_{it} and M_{it} are the inputs: capital, labour, and materials, respectively. A_{it} is the Hicksian neutral efficiency level (our concept of TFP) of firm *i* in period *t*. For a given level of A, higher output levels demand higher input (K, L and M) levels.

It is assumed that $L = L^P + L^{NP}$, where L^P stands for production worker (unskilled) labour and L^{NP} stands for non-production worker (skilled) labour.[1]

Although Y_{it}, K_{it}, L_{it} and M_{it} can observed, A_{it} is not observable and hence, needs to be estimated. The estimation of A_{it}, (firm efficiency level) depends on several different components such as skills, knowledge, and firm-level capabilities, including managerial and organisational competences. It is assumed that A_{it} or TFP in logs is given by:

$$\ln (A_{it}) = \beta_0 + \varepsilon_{it} \quad (2)$$

where β_0 measures the mean efficiency level across firms over time; ε_{ijt} is the time- and producer-specific deviation from that mean. Taking natural logs of (1) and inserting equation (2), a linear production function is obtained

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_{lP} l^P_{it} + \beta_{lNP} l^{NP}_{it} + \beta_m m_{it} + \varepsilon_{it} \quad (3)$$

where lower-case letters refer to natural logarithms. The error term ε_{it} can be further decomposed into an observable (or at least predictable); and an unobservable i.i.d. component, representing unexpected deviations from the mean due to measurement error, unexpected delays, or other external circumstances, i.e., $\varepsilon_{it} = v_i + u^q_{it}$. Hence, equation (3) becomes

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_{lP} l^P_{it} + \beta_{lNP} l^{NP}_{it} + \beta_m m_{it} + v_{it} + u^q_{it} \quad (4)$$

Since the firm-level productivity[2] is $\omega_{it} = \beta_0 + v_{it}$ and rearranging the terms of (2)

$$\omega_{it} = y_{it} - (\beta_k k_{it} + \beta_{lP} l^P_{it} + \beta_{lNP} l^{NP}_{it} + \beta_m m_{it}) - u^q_{it} \quad (5)$$

And the estimated productivity is

$$\hat{\omega} = \omega_{it} + u^q_{it} \quad (6)$$

This empirical model allows to address the simultaneity bias in traditional OLS regression techniques to estimate the TFP when unobserved productivity or TFP shocks, *i, j* and *t*, are correlated to the choice of inputs. Since the [47] and [48] techniques, while controlling for the simultaneity bias, suffer from collinearity problems, [49] and, later, [46] suggested modifications to the original LP approach aiming to correct the collinearity issue.

Defining the value added as $va_{ijt} = y_{ijt} - \beta_m m_{ijt}$, then it can be estimated through equation (4) as a residual

$$\hat{\omega}^v_{it} = va_{it} - (\widehat{\varepsilon^v_P}\, l^P_{it} + \widehat{\varepsilon^v_{NP}}\, l^{NP}_{it} + \widehat{\varepsilon^v_K}\, K_{it}) \quad (7)$$

TFP is an important tool for researchers in evaluating the implications of various policy measures on firm performance.

This paper applies a two-stage empirical strategy. First, it employs the Wooldridge-Levinshon and Petrin estimator, which is considered a robust method, to estimate the TFP. Then, the TFP growth is regressed on the determinant factors using Stata 16.0. The estimated TFP is regressed on R&D, physical capital, human capital accumulation, business dynamism (measured by the rate of birth of new firms), and openness (measured by exports)

$$\widehat{\omega_{it}} = \beta_0 + \beta_1 rd_{it} + \beta_2 k_{it} + \beta_3 hac_t + \beta_4 bir_{it} + \beta_5 \exp_{it} + \varepsilon_{it} \quad (8)$$

[1] The variable L^{NP} is the human capital (*h*) and it is constructed as described in the Appendix B.

[2] The productivity term is identified assuming that ω_{it} is a state variable in the firm's decision problem (i.e., it is a determinant of both firm selection and input demand decisions), although u^q_{it} is either the measurement error or a non-predictable productivity shock [47]

where *rd, hac*, *bir* and *exp* are the respective proxies of innovation, human capital accumulation, business dynamism and openness.

IV. Data

Data sources include SABI, Quadros do Pessoal and PORDATA. The empirical part of the paper uses financial data obtained from SABI database financial reports of manufacturing firms over the period 2015-2019. Bureau van Dijk (BvD) collects and harmonises the data from the mandated firm reports. In the. Portuguese case, financial data come from *Informação Empresarial Simplificada* (IES).[3] This information is collected in a massive way by Coface, BvD's partner for Portugal, that send it to BvD for consequent upload in SABI database. The data set is like the usual data used by empirical researchers when estimating TFP, i.e., it delivers information on outputs and inputs at the firm level in nominal values.[4] The analysis excludes microenterprises and firms from Azores and Madeira. This happens because *Quadros do Pessoal*, the data source to construct the proxy for human capital, does not provide information on employees, according to qualification level, for the Islands. The balanced panel data set includes 1333 manufacturing firms for the 5 years. Table I shows the basic statistics

TABLE I. Descriptive Statistics for the main variables in Production Function

Variable	Obs	Mean	Std. Dev.	Min	Max
Y	6489	10,481	34,701	0	1,400,000
K	6489	2,724	12,305	0	352,139
H	6665	502	294	7	1,270
L	6489	55	88	0	1,471
MAT	6489	7,885	40,848	0	1,300,000

Notes- y is the output, *k* is capital, h is the human capital *l* is labour and *m*at is the materials. Source: Author's calculations using Stata 16.0

The definition of firm-level output and inputs, as well as of the proxy variables, follows common practice in the literature. The variables are output, value added, physical capital, human capital and the traditional proxy variable introduced by LP, materials. The *difference between* the value of a *firm's* output (*revenue)* and its purchase of energy and *materials* (including *intermediate* inputs) is known as *value added*. Thus, materials are defined as consumption of intermediates at the firm level and are calculated as the difference between turnover and the value added. Industrial Price Indices (by industry) from PORDATA (*www.pordata.pt*) were used to deflate nominal values. For industry 1 (mixed farming), the implicit price index in agriculture was used (*www.gpp.pt)*. For the remaining sectors (services) the consumer price index from PORDATA was used. The variable R&D expenses is proxied by the value of intangible assets obtained from financial reports provided by SABI database. The variable *bir* (the rate of birth of new firms) is calculated as the difference between the number of firms of each year, obtained from Quadros do Pessoal. To calculate the variable human capital (*h*), the number of employees of each firm (*l*) was multiplied by the industry*year and the region*year coefficients. The first coefficient is the share of high skilled labour, i.e., the ratio of employees with at least a degree to the total number of employees, by industry and year from Quadros do Pessoal. The second coefficient is the share of researchers in R&D activities in private firms, by NUTS II, from PORDATA. The human capital accumulation (*hac*) is the share of high skilled labour, as described above, but at sectoral level. The value of exports is turnover multiplied by the regional and sectoral coefficients of exports, from PORDATA.

[3] Simplified Business Information.

[4] Nominal values were deflated by the appropriated price indices. See appendix for further details.

V. Results and Discussion

Results for the coefficients of TFP estimation (Table 2) performed with command *prodest* on Stata 16.0., show decreasing returns to scale.

TABLE II. Beta Coefficients of TFP Regression

log_y	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
Log_l	0.4855	0.0182	26.60	0.000	0.4498	0.5214
Log_h	0.0129	0.0066	1.96	0.050	0.0000	0.0260
Log_k	0.0424	0.0078	5.42	0.000	0.0271	0.0579

Source: Authors' estimations in Stata 16.0

Regression of TFP changes on innovation and other control variables were performed with a fixed-effects model, instrumental variables, and difference–GMM (Diff-GMM).

TABLE III. Regression Results

	(1)	(2)	(3)
log_rd	-0.0148	-0.238	0.00657*
	(-0.70)	(-1.18)	(2.29)
log_k	-0.0718**	-0.0649*	-0.0355
	(-2.62)	(-2.49)	(-1.38)
log_hac	0.00908	-0.0856*	-0.0169
	(0.23)	(-1.99)	(-0.47)
log_bir	0.00439	0.0149	-0.0254
	(0.31)	(0.63)	(-1.78)
log_exp	1.154***	0.210***	1.212***
	(25.94)	(4.59)	(31.02)
_cons	-5.416***	-0.654*	-5.799***
	(-15.48)	(-2.17)	(-18.54)
N	1275	1275	453

Notes- Models 1, 2 and 3 are fixed-effects, instrumental variables, and diff–GMM. t statistics in parentheses * $p<0.05$, ** $p<0.01$, *** $p<0.001$ Source: Authors' estimations in Stata 16.0.

The Hausman test was performed to validate the choice of fixed effects over random effects.

Models 1 and 2 (Table 3) show a negative (-0.0718, $p<0.01$; -0.0649, $p<0.05$) and significant impact of *physical capital* on the TFP growth; whereas *openness* exert a significant positive (1.154, 0.210 and 1.212; $p<0.001$) impact on the TFP growth, that is strong in models 1 and 3. Model 2 shows a significant negative (-0.0856, $p<0.05$) impact of *human capital accumulation* on the TFP growth; while in model 3, *innovation* has a significant positive but small (0.00657, $p<0.05$) impact on TFP growth.

Thus, the results show that 1% increase in *innovation* (measured by firms' investment in intangible assets) in manufacturing firms, has the potential to raise the TFP nearly in 0.007 percentage points (p.p.). That is to say that if the top management of a manufacturing firm wanted to raise the TFP in 1 p.p., it would have to increase the investment in innovation in 142.86 %. Tables 4 and 5 show the results by NUTS II regions and by technological groups of firms.

From Table IV, it is worth noting that *innovation, physical* and *human capital*, as well as the *business dynamism*, have a significant impact, solely in the Northern region; while *openness* exerts a positive, strong, and significant impact on the TFP growth of firms located in the North, Lisbon and Alentejo regions. *Physical capital* has a negative impact on the TFP growth of Northern firms; while the other factors have a positive impact, with *openness* being the one with the strongest impact.

TABLE IV. REGRESSION RESULTS, BY NUTS II REGIONS

	North	Lisbon	Alentejo
log_rd	0,0368*	1,032	1,074
	(3,05)	(0,05)	(0,14)
log_k	-0.101***	-0.0214	-0.0653
	(-4.14)	(-0.64)	(-1.03)
log_hac	0.104**	0.0569	-0.130
	(2.66)	(1.26)	(-0.85)
log_bir	0.0444**	-0.00273	0.0210
	(2.99)	(-0.14)	(0.64)
log_exp	1.128***	1.038***	1.171***
	(33.72)	(22.69)	(9.10)
_cons	-5.560***	-5.629***	-3.750***
	(-19.17)	(-14.95)	(-5.63)
N	1674	777	181
adj.	0.209	0.260	0.109

Notes- Models 1, 2 and 3 are fixed-effects, instrumental variables, and difference–GMM. t statistics in parentheses * p<0.05, ** p<0.01, *** p<0.001 Source: Authors' estimations in Stata 16.0.

Results by technological groups are shown in Table 5. Scale intensive industries (NACE codes 10, 11, 12, 19, 22, 23, 24, 25, 29 and 30) are characterized by low and medium low technology. Science based industries (NACE codes 20, 21, 26 and 27) are characterized by medium high and high technology. Specialized suppliers (NACE codes 28, 32 and 33) are characterized by medium low and medium high-technology. Finally, supplier dominated industries (NACE codes 13, 14, 15, 16, 17, 18 and 31) are characterized by low and medium low technology.

Results from Table V confirm that *openness* exerts a positive and significant impact on productivity growth across technological groups of manufacturing firms. However, *innovation* appears to impact only in science-based and supplier dominated industries (0.266 and 0.234; p<0.05).

TABLE V. REGRESSION RESULTS, BY TECHNOLOGICAL GROUPS

TG	Scale	Science	Specialized suppliers	Supplier dominated
log_rd	-0.071	0.266*	-0.147	0.234*
	(-0,096)	(-2.476)	(1.530)	(-1.990)
log_k	-0,083	-0,007	-0.0759	-0,047
	(-0,360)	(-1,248)	(-1.050)	(-0,574)
log_hac	0,122	-1,583	0.000	0,143
	(-1,384)	(-0,443)	(0.00)	(-1,01)
log_bir	0,039	-0,027	0.022	0,041
	(-1,457)	(-1,368)	(0.600)	(-0,690)
log_exp	0,921***	1,028***	1.069***	0,926*
	(-8,258)	(-9,175)	(7.860)	(-7,964)
cons	-4,91	-4,523**	-4.268***	-1,316***
	(-1,400)	(-4,540)	(-5.250)	(-4,421)
N	1539	318	141	1047
R-sq	0,239	0,465	0.018	0.245

Notes- TG is the technological group; Models 1, 2 and 3 are fixed-effects, instrumental variables nd difference–GMM. t statistics in parentheses * p<0.05, ** p<0.01, *** p<0.001 Source: Authors' calculations in Stata 16.0.

A. *Discussion*

The results confirm the research hypothesis H1 only for science-based and supplier dominated industries in the Northern Region. H2 is not confirmed, *physical capital* appears to exert a negative impact on productivity growth. H3 and H4 are confirmed but only for the Northern region, while H5 is confirmed for all the 3 regions and all technological groups.

In the case of *physical capital*, the results contrast with the studies of [14], [17], [18] and [19]. The negative impact of physical capital on the TFP growth of the Portuguese manufacturing firms can be explained by the lack of skills by the workforce to deal with up-to-date machinery, equipment, and ICT, causing a decline in the marginal productivity of capital, as has been reported in the Portuguese economy in recent years. This explanation appears to be corroborated by the positive impact of human capital accumulation on the productivity growth only in the Northern region.

These results have some implications regarding innovation management and IT management. Thus, considering the results it is recommended that managers in Northern manufacturing firms operating in science-based and supplier dominated industries more than duplicate their investments in innovation. It is also recommended that managers, and especially, Human Resources managers continue to hire highly skilled employees to reverse the tendency to decrease the marginal productivity of physical capital.

In this context, academia has gained increasing interest on the impact of digital transformation and innovation management in the last decade. Digital transformation has been recently placed as an emerging field of management as well as a new research paradigm [50]. However, there is a highly fragmented understanding of this topic [51, 52] in part, because it is a complex and multifaceted phenomenon [50] affecting organizations at many levels. Digital transformation shapes the ways firms innovate by sensing, seizing, and transforming opportunities caused by the new digital paradigm. Examples are smart and connected products with profound and wide-ranging effects on the competitive dynamics, business models, value chains, and required competencies of manufacturing firms.

VI. CONCLUSION

Before the economic crisis, Portugal met a decline in export competitiveness, large current account deficits and a strong development of the non-tradable sector. In this context, the manufacturing sector is a driver of technological change since it is a major producer of tradables; a potential generator of high rates of innovation and capable of dragging capabilities to other sectors. However, this sector is characterized by small firms and innovation dynamics relying on the so-called traditional industries.

This paper tested the impact of innovation and other factors on the TFP growth of Portuguese manufacturing firms in 2015-2019.

Productivity is unevenly distributed across industries and regions which provides good reasons for empirical analysis at the regional level, across technological groups of industries. Results indicate that *innovation* has a positive influence on the productivity growth in science-based and supplier dominated industries in the Northern region of Portugal. In these groups of industries, 1% increase in *innovation* raises the productivity in 0.2 p.p.

The negative impact of *physical capital* on the productivity growth can be explained by the lack skilled Human Resources to deal with technological advanced machinery, equipment, and ICT, causing a decline in the marginal productivity of capital. This appears to be corroborated by the positive impact of *human capital accumulation* on the productivity growth only in the Northern region. In contrast, *openness* appears to have a positive and significant impact in all regions and manufacturing industries.

Government officials should focus on promoting existing and new firms operating in scale-intensive and supplier dominates industries, especially in the Northern region and provide incentives for these firms to innovate. This could be achieved, by providing incentives for R&D cooperation and supporting private sector training programmes. In addition, because evidence for Portugal suggests that manufacturing firms benefit from foreign direct investment externalities in science-based industries [35, 53], the government should support partnerships with foreign affiliates especially in this technological group. This can be attained by several ways: providing linkage information in seminars, exhibitions, and missions; sponsoring fairs and conferences; organising meetings and visits to plants; promoting supplier associations; and providing advice on subcontracting deals. Furthermore, it is also recommended that government and local authorities as well as private institutions such as Entrepreneurs' Associations, help these manufacturing firms to strengthen their export performance and to improve their competitiveness. Such measures can include public support for export promotion, as well as support for SME start-ups, namely, by providing venture capital and equity financing.

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