THE EFFECTS OF HUMAN CAPITAL ON THE PRODUCTIVITY OF SMES IN CATALONIA

Mª Teresa Fibla Gasparín

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Mª TERESA FIBLA GASPARIN

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Mª Teresa Fibla Gasparin

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Ph.D. Dissertation

Ph.D. Advisor: Ferran Mañé Vernet

Department of Economics

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FAIG CONSTAR que aquest treball, titulat "The effects of human capital on the productivity of SMEs in Catalonia", que presenta Mª Teresa Fibla Gasparin per a l'obtenció del títol de Doctora, ha estat realitzat sota la meva direcció al Departament d'Economia d'aquesta universitat i que acompleix els requeriments per poder optar a Menció Europea.

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El director de la tesi doctoral
Dr. Ferran Mañé Vernet

This thesis is dedicated to my parents
for their endless support
and encouragement

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I. INTRODUCTION

"Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker."

Paul Krugman, The Age of Diminished Expectations, pp.9[1]

Catalonia, located in the northeast of Spain, is a region of considerable size in Europe. With more than seven million inhabitants, it is the main contributor to the Spanish economy with around 19% of GDP and has 16% of its population. In the last years, Catalonia has had a positive growth trend. Its real GDP has grown 3.1% annually on average cumulative rate from 2000 to 2006, and at 3.5% in 2007 allowing the economic convergence with the European countries.

The Catalan GDP per capita has gone from 96.3% in 1995 to 111.7% in 2007 of EU-16. If we compare this data with other European regions with the same industrial tradition, as Baden-Württemberg, Bavaria Rhône-Alpes and Lombardy, we can see that while, in 1986, the GDP per capita of these regions were between 112% and 136% of the EU-15 level, in Catalonia it was at 84%. Twenty years later the rang of GDP per capita for these regions has shrunk, to between 101% and 121.7%, in contrast, in Catalonia it has rose to 110.9%.

Unfortunately, the current economic crisis has highlighted that the economic and productive model that allow the economic growth of Catalonia during the last years has been exhausted. Gone are the days when the Catalan GDP growth rate rose above the European average. The growth of Catalan real GDP declined to 0.7% in 2008 and become negative in 2009 and 2010. This fact has deteriorated the relative position of Catalan economy with respect to European Union countries[2].

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[1] Krugman, P. (1992): "*The Age of Diminished Expectations: U.S. Economic Policy in the 1990s*". MIT Press, Cambridge.

[2] See Ghemawat, P. and Vives, X. (2009): "*Competitiveness in Catalonia. Selected topics*". Report of the Public-Private Sector Resarch Center. IESE Business School.

It is true that the crisis not only affects the Catalan economy and some experts point out that it is the worst World crisis after the Great Depression of 1929, but it would be an error to consider that once the crisis ends Catalonia will come back to the same path of economic growth. This is because the reasons for the Catalan recession go beyond the global financial crash and are related to other factors that contributed to the loss of Catalan competitiveness. Factors such as, high levels of unskilled workers, low value-added products and services, and low levels of productivity.

As Oliver, J. (2010)[3] points out, the economic conditions that contributed to the Catalan economic growth in the last twenty years are unlikely to return. The last economic growth can be explained by the efforts that the Spanish and Catalan governments were made to satisfy for the Treaty of Maastricht (1992) and allowed them to integrate to the single European currency, the euro. From then, Spain and Catalonia had to introduce some changes such as the labour reform in 1997, which kept labour cost and prices moderate, the reduction of interest rate, currency depreciation and tax cuts. All these changes together with the arrival of a large number of immigrants and the children from a baby boom generation into the labour market resulted in a higher domestic demand. In sum, the GDP and employment growth of the past decade was due to the increase in private consumption and construction sector investments.

Unfortunately, growth in the GDP has been accompanied by a low cost production model and low levels of firm productivity that has made the Catalan economy more vulnerable and less competitive to external markets. Therefore, the actual situation in Catalonia is quite complicated because of the low levels of competitiveness - it makes it more difficult to access the international market and its demands - and the weakness of the internal demand –due to the high levels of families and firms debts and the financial constrictions reduce domestic demand. Then, it is difficult that the future of Catalan economic growth will come

[3] Oliver, J. (2010): *"Després de la crisi: el pacte social necessari per afrontar una dècada difícil"*. En Reformes més enllà dels tòpics: com pot Catalunya sortir reforçada de la crisi. Col·lecció Informes nº4. Fundació Rafael Campalans.

from the domestic demand. To get out of the crisis and achieve economic growth it will be necessary to increase the Catalan capacity to attract international demand.

As some experts say, the way to attract more international demand depends on the Catalan's economy capacity to leave the current competition model based on low cost and price and achieve high levels of competitiveness by producing high value-added products and service and improving firm productivity. It is in this context that firm productivity becomes crucial to improve Catalan competitiveness and to allow the Catalan economy to get out of the crisis. In fact, productivity increments not only affect economic competitiveness but also the long term economic growth and the standards and quality of life of the population[4]. For this reason, we decided to focus this research on the determinants of firm productivity. Only if we can identify which factors affect firm productivity and how they do, can we then design the right policies and actions that drive firm productivity.

<u>Definition of firm productivity</u>

Before we start to talk about the determinants of firm productivity, let us to attempt to establish a definition of what we understand by the term firm productivity.

In general terms, firm productivity represents the relationship between the outputs and the inputs of the production processes, in other words, the inputs that a firm needs to produce a determinate outputs level. Then, a firm is more productive than another if it can produce more outputs from the same inputs or if it produces the same outputs with less inputs.

We can measure a firm productivity by either taking into account only one production factor, such as labour or physical capital, or we can measure it by

[4] Find a discussion of the relationship between productivity and standard of life in Baumol, W. Blackman, S.A. and Wolff E. (1992): "*Productivity and American Leadership: The Long View*", MIT Press.

using all the production factors, this is the case of Total factor productivity (TFP). Measuring productivity using only one production factor has some limitations. First, firm output depends on different production factors and it is difficult to choose one to calculate firm productivity. Second, the importance of each factor for the production process could change over time. For example, in some stage of the production process, labour capital may be crucial, but for others the most important factor may be physical capital. In this case, labour productivity is not the best measure to analyse the evolution of firm productivity. It is for these reasons that most studies use Total Factor Productivity as a measure of firm productivity, because it takes into account all the production factors to calculate productivity, thereby avoiding the problems arising from use only one factor.

In sum, firm productivity is defined as the ratio of the output, commonly measured by gross sales or gross value-add, and the production factors. Although the aim of this thesis is not to focus on the different methods to calculate firm productivity, we would like to point out that from the literature we can identify different methods, parametric and nonparametric, to calculate firm productivity. The most common used are index numbers, nonparametric frontiers such as DEA, and parametric methods based on a firm's production function. Since each method has its own strengths and weaknesses, the choice between them depends on the characteristics of the data. For instance, nonparametric methods do well when the production function is heterogeneous and parametric methods do well if there are measurement errors[5].

[5] For a discussion of different methods see Biesebroeck, J.V. (2007): "Robustness of productivity estimates". The Journal of Industrial Economics. Vol.LV. Nº3.

Determinants of firm productivity

> *"Regions with insufficient human capital will not grow, while those with increased levels will reap the benefits of endogenous elements of growth."*
>
> (OCDE, 2009, pp. 17)[6]

The literature points out that, although there are different factors that affect firms productivity, human capital and technological capital are the most important ones. If this is true, we should expect that those Catalan firms who invest in human capital and new technologies achieve higher productivity levels. Unfortunately, evidence does not support it.

In the last years, the Catalan economy shows a positive evolution of its human capital levels, measured by the education level of its population. For instance, if we measure human capital in terms of education, in 2000, 49.8% of the active population had studies up to secondary education, 22.4% up to high school and vocational training, and 27.8% university education. Seven years later, in 2007, the corresponding percentages were 43%, 25.7% and 31.2%, respectively. In terms of firm human capital investment, over the period 1995-2006, the number of firms that employ graduates increased from 67% to 78.8% for small and medium firms and from 98.8% to 100% for large firms. During the same period, the proportion of graduates employed in each firm also increased from 12.2% to 22.4% for small firms and from 10% to 20% for large firms.

In respect of technological investment, if we measure it using R&D spending as part of GDP, the intensity of the R&D effort has increased in Catalonia from 0.89% in 1995 to 1.48% in 2007. Looking over the wider set of Catalan firms, the proportion of firms with R&D expenses increased from 30.7% in 1991 to 35.5% in 2006 in the case of small firms, in contrast it reduced from 79.8% to 77.6% in the case of large firms. In terms of new technology adoption, the proportion of

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[6] OCDE (2009): *"How regions grow: Trends and analysis".*

firms that invest in advance manufacturing technologies like digitally-controlled machine tools, computer-aided design and robots increase during the same period either in small and large firms.

In sum, over the last years Catalan firms have increased their endowments in human capital and new technologies but it doesn't seem to translate in higher levels of productivity. The growth of labour productivity in the Catalan economy has been clearly lower than the average growth in European countries. If we measure labour productivity as GDP per worker, it has gone from 111.7 of EU-25 in 1995 to about 104.6 in 2005. And if we consider it as a reference to the EU-15, Catalonia has gone from being above at 102 in 1998 to being below at 98 in 2005. With regard to total factor productivity growth, in the period 1996-2000 it has negative growth rate, achieving -0.04% in 2000[7].

The evidence shows that the negative evolution of the Catalan firm productivity doesn't come from a scarce accumulation of human and technology capital - over the last two decades the levels of these two production factors converge to the European average-, but maybe it comes from the way in which firms use these factors. It would be possible that the characteristics of the Catalan economy based on a large number of small and medium size enterprises (SMEs) - these firms represent 99.8% of the total firms in Catalonia in 2008- make the adoption of human capital or new technologies more difficult, and therefore the effects of both factors on firm productivity is not the expected one. It is also possible that to invest in only one of these two factors is not enough to improve firm productivity, but it is the combination of both factors that allow firms to achieve higher productivity levels. In this case, the effect of human capital on firm productivity depends on others production factors such as technologic capital and vice versa. Hence, firms must invest in human capital and in new technologies at the same time if they want to improve their productivity levels (Complementarity theory). Finally, it is also possible that firm productivity not only depends on factors endowments. Some evidence points out that it is the way in which a firm

[7] Gual, J., Jódar, S. and Ruiz, A. (2006): "El problema de la productivitat a Espanya: quin és el paper de la regulació?". Documents d'Economia "La Caixa". Nº1.

combined human capital and new technologies that will determine firm productivity levels. In this context, new work organisational practices used by the firms become crucial to obtain higher productivity levels of these two production factors.

The aim of this thesis is to shed some light to these issues by means of three empirical essays. Each essay will be treated on an individual basis in relation to the others. Therefore, each one has different sections with an introduction, theoretical and empirical background, data and variables definition, methodology, results and conclusions. The relevant references and appendices will also be added at the end of each essay.

In the first one we analyse whether human capital has a positive contribution on Catalan firm productivity taking into account the potential synergies existing between new technologies and human capital. The main contribution of this essay in particular is the fact that, for the first time, we provide empirical evidence for the possible complementarity effects between human capital and new technologies on firm productivity for each occupational group.

In the second essays, we analyse whether invest in human capital and new technologies is enough to increase firm productivity or it is the way in which these production factors are organized the key to improve firms productivity. In order to answer this question we analyse the effects of new organizational practices on new technologies and human capital productivity at firm level. This essay contributes to the previous literature in several aspects, but one of the most important is the fact that existing evidence analyses the synergies between these factors using a pair-wise test (testing only the complementarity effects between two practices), in contrast we test the complementarity effects among these three factors together by carrying out a new test based on the supermodularity theory definition.

The evidence reported by the analysis of firm productivity allows us to confirm positive effects of human capital on Catalan firm productivity, although to raise human capital productivity firms also needs to combine it with new technologies and new work organisational practices. Therefore, investment in human capital is not enough to achieve higher levels of productivity. It is the way in which this production factor is combined and organised that make firms more productive.

Once we arrived to this point, some other questions about how firms adjust their levels of human capital arise. The third essay tries to answer this question by taking into account that firms can adjust their skill-mix using internal or external labour markets. The main problem is the possibility that firms combine in some way both strategies instead of using one at the expense of the other. It is for this reason that, in contrast with the previous literature, in this analysis we focus on a specific case, when firms have a vacancy. In this particular case firms cannot use both strategies together, but they have to decide to adjust the skill-mix of the workforce by filling this vacancy using internal or external candidates. In particular, our interest is focused on how firms' characteristics such as technological capital, innovation activity or location, can affect the Catalan firms decision to the use internal or external labour market in order to fill a job vacancy. Another difference from the existing evidence is the fact that in the third essay we take into account the effects of external labour market characteristics on firm decisions. The idea is that as much easier is to find a perfect worker in the external labour market higher the probability to use external labour market to adjust the firm human capital levels.

Finally, to answer these questions we focus on Catalan SMEs. The relevance to analyse the SMEs behaviour is based on the fact that the vast majority of enterprise in Europe and Catalonia are SMEs, and they provide two out of three of the private jobs in Europe and three out of four in Catalonia. Therefore, SMEs are very important in terms of employment and economic growth. On the other hand, their behaviour in terms of production factors endowments and its effects on firm productivity would be different in respect of large firms, hence a deeper analysis would be necessary to better understand the determinants of SMEs productivity levels and their human capital adjustment decisions. To achieve this goal we use two different and unique data sets of SME firms in Catalonia that we describe in each essay.

II. FIRST ESSAY

PRODUCTIVITY AND HUMAN CAPITAL: A BUSINESS-LEVEL ANALYSIS

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Abstract

This paper aims to analyse the impact of human capital on firm productivity, focusing the analysis on the possible effect of the complementarity that exists between human capital and new production technologies, particularly advanced manufacturing technologies (AMTs) for the specific case of small and medium size enterprises (SMEs) in Catalonia. Additionally, following the theory of skill-biased technological change, the paper analyses whether technological change produces bias exclusively in the skills required for managers, or whether the bias extends to the skills required of production staff. With this objective, we have compared the possible existence of complementarity between AMTs and the level of human capital for different occupational groups. The results confirm the complementary relationship between human capital and new production technologies. The results by occupational group confirm that to maximise the productivity of new technologies, skilled staff are needed both in management and production areas, with managers and professionals as well as skilled operatives playing a vital role.

1. Introduction

In recent years the Spanish and Catalan economies have invested heavily in human capital and new technologies with the aim of improving business competitiveness. Unfortunately, despite the efforts made, productivity growth remains small compared to in other European Union (EU) countries.

The data confirm that, before the current economic crisis, the overall growth of the Catalan and Spanish economies, measured in "gross value-added (GVA)", was higher than in other euro-zone countries. In 2000-2004, for instance, the annual GVA growth rate was 2.78% in Catalonia and 2.89% in Spain as a whole, both of which were above the overall rate of 1.5% for the EU (EU-15) during the same period. But this growth was primarily due to a higher rate of employment rather than improved business efficiency. So, while employment growth over the same period stood at 2.46% in Spain and 0.44% in the EU-15 countries, labour productivity growth in Spain (0.43%) was below the EU-15 rate (1.07%). In Catalonia, growth in employment stood at 2.4% for 1995-2003, while the year-on-year increase in labour productivity was a meagre 0.5% (or just 0.45% for 2000-2003) (Mas and Quesada, 2007; Oliver, 2009).

Given that growth in firm productivity is strongly linked to improved living standards of the population, it is not surprising that economic agents are striving to find mechanisms to increase firm productivity. This is especially true in Catalonia and Spain, where data confirm that apparent labour productivity stagnated for 2001-2006 (Amarelo, 2007).

We must therefore ask why the Spanish and Catalan economies are still not seeing improvements in productivity, despite investment in education[8]. One

[8] Spain has undergone a major transformation in job skills. In 1985, 63.3% of the Spanish population only had primary-school qualifications, and 12% had no qualifications. Seventeen years later, in 2002, these figures had fallen to 18.4% and 3.6% respectively. But the most radical change has taken place in secondary education, where the ratio increased from 26.5% in 1985 to 57.2% in 2002. The percentage of employees with university qualifications increased from 4.9% to 11.5% (Mas and Quesada, 2005).

explanation could be the region's production structure, which is heavily weighted towards traditional, labour-intensive sectors whose productivity is relatively low compared to that of technology-intensive sectors. Another possible explanation, which goes beyond the country's structural conditions, is that Spanish and Catalan firms are not using available technological and human resources efficiently to improve productivity[9].

This paper presents an in-depth study of the effect of human capital on the productivity of Catalan firms and an analysis of the impact of new technologies on both firm productivity and human capital productivity. It is essential to recognise the scope of these effects to assess the improvement in the competitiveness of firms and thus identify their strengths and weaknesses. Moreover, as Huerta (2003) underlines, the uncertainty of the impact of human capital can sometimes lead to the development of approaches in which investment in technologies is presented as the only valuable dimension of business transformation and the importance of human capital as a determining factor in firm productivity is ignored.

In this regard, while knowledge of Spanish companies is steadily increasing and many studies have been carried out on firms R&D decisions, internalisation, diversification and pricing and on the effects of technologies, size and innovation activities on productivity, almost no studies have directly analysed the relationship between human capital and firm productivity. This is largely because it is difficult to find databases that combine information on the characteristics of companies with information on the characteristics of workers. This problem is not limited to Catalonia. Analysis of global evidence shows that on the one hand firm-

[9] Another possible explanation is that new technologies do not really affect business productivity (Solow's "productivity paradox" [1987]). In this respect, the first company-level works to analyse the relationship between investment in new technologies and firm productivity (1980s and 1990s) found not evidence for this relationship, which contributed to broadening the debate on the productivity paradox. Today, the emergence of new studies, especially since the 1990s, shows that these new technologies do indeed contribute to productivity growth, thus putting an end to the debate surrounding the productivity paradox. These studies propose various explanations for the lack of evidence of a relationship between new technologies and firm productivity in the early studies. These include the sample size, the quality of the data, the analysis methodology, the fact that the effects do not occur in the short term but in the medium-to-long term, the fact there is a learning curve for the company, or the fact that these effects appear after only minimal investment (Billión, Lera and Ortiz, 2007).

level studies are a recent phenomenon, and on the other, very few works have successfully analysed the effects of human capital on firm productivity due to the lack of available data[10].

Therefore, although the database used in this study is a cross-section, it presents a number of advantages that should not be neglected. First, unlike the vast majority of works, firm and employee data were compiled using a single firm survey, thus avoiding the problems associated with merging distinct databases. Second, because we had firm and employee information we were able to carry out this pioneer type of analysis on the Catalan and Spanish economies. Third, we can analyse the particular case of micro, small and medium-sized enterprises, which account for a very high proportion of the Spanish and Catalan firms.

It is also significant that, unlike in existing studies, we did not focus only on analysing the impact of human capital on firm productivity, but we also considered the possibility of complementarity effects between the human capital and technologies used in the production process, the Advanced Manufacturing Technologies (AMTs), and how those effects can lead to higher productivity gains when combined properly[11]. Additionally, following the theory of skill-biased technological change, we analysed the effect of complementarity between new technologies and existing human capital in the various occupational groups with the aim of analysing whether investment in new technologies produces bias exclusively in the required skills for managers, or whether the bias extends to the skills required of production staff.

To do this we estimated the augmented Cobb-Douglas production function. Aware of the econometric problems arising when estimating production functions,

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[10] Hellerstein, Neumark and Troske (1999) first used a database combining company and employee information in the American manufacturing sector to analyse the impact of the level of education on firm productivity. Meanwhile Doms, Dunne and Troske (1997) also used a database combining company and employee information to analyse the impact of the change in the workforce structure (producers versus non-producers) on firm productivity.

[11] In the literature we can find some studies that analyse the effects of complementarity between human capital and technology, but these focus on the particular case of information and communication technologies (ICTs), such as investment in computers or Internet and Intranet use. We looked instead at the specific case of advanced manufacturing technologies (AMTs).

we used an alternative estimation method for the ordinary least squares (OLS) method proposed by Levinshon and Petrin (2003) to address the problems of unobservable heterogeneity and therefore endogeneity.

The results confirm the positive effect of human capital on firm productivity, although this effect occurs indirectly through the use of AMTs, thus confirming the complementary relationship between the two. The results by occupational group confirm the importance of skilled staff in both management and production areas to maximise the productivity of new technologies, with managers and professionals as well as skilled operators playing a vital role. In sum, investment in human capital or new technologies alone is not sufficient; to ensure a significant improvement in firm productivity we must combine both forms of investment.

We shall now explain how the different sections of this paper are distributed. The first section contains the theoretical discussion and empirical evidence of the effects of human capital on firm productivity. The second section describes the database and the variables used in the analysis. The third and fourth sections present the methodology and results respectively. And the final section sets out the main conclusions from the work.

2. Theoretical framework and empirical evidence

The economics literature refers to three different effects of human capital. Firstly, it refers to human capital as an input factor in research and development (R&D) activities. This is the "research effect", on which there has been particular emphasis since the emergence of the endogenous growth theory (Romer, 1990 and Van Cayseele, 1990). The second, the "diffusion effect", refers to human capital as a factor in the diffusion of new technologies, and although there is no consolidated theory, the contributions of Nelson and Phelps (1966) and Bartel and Lichtenberg (1987) are significant. Third is the importance of human capital as a production factor, with the human capital theory (Becker, 1975) having focused on analysing the consequences of investment in human capital on the productivity of workers. This is known as the "work effect" or "assignment effect" (Cörvers, 1999).

The purpose of this paper is to analyse the relationship between the level of human capital and firm productivity. We will therefore now focus on describing the theories that have analysed this relationship (the third effect).

As mentioned above, the impact of human capital as a production factor on the production function has been studied according to the "human capital theory", although other theories have also analysed its impact, such as the "screening theory" and the "assignment theory".

Human capital theory is based on the premise that workers invest in education to increase their level of human capital and this in turn increases productivity. According to this theory, education improves the labour productivity of individuals, resulting in higher wage increases. In order to improve their production efficiency, firm should therefore invest in education either by training their existing staff or by hiring more-skilled staff (Becker, 1975; Psacharopoulos 1987; Blaug, 1976 and 1985).

Human capital theory thus argues that there is a causal relationship between education and productivity. But the screening theory challenges that relationship[12]. The latter is founded upon the idea that individuals have certain skills that make them more productive than others, irrespective of their level of education. The cost of investing in the education of more skilled people is lower, since they need less time to acquire educational credentials. For this reason, individuals with higher productive skills (on average) invest more in education (Becker, 1975 and Hartog, 1993). If we accept this assumption that skills are related to academic success and productivity in the workplace, this means that educational credentials indicate the most productive workers. Companies in search of indicators that can be correlated with productivity thus use these credentials to classify the most skilled people[13].

According to the screening theory, people's skills are not increased by initial education, but rather most of the necessary skills to be productive are learnt in the workplace, meaning education does not increase productivity. The main difference between the two theories is on the issue of whether education increases people's productive ability during their school years. The human capital theory claims it does; the screening theory claims it does not. The existing empirical evidence rejects the strictest premises of the screening theory: that education does not increase productivity. A new version of the theory, referred to as the "weak" screening theory, subsequently appeared. This watered-down version no longer denies that there is a relationship between education and productivity through the provision of knowledge and skills. Indeed, according to Cövers (1999) "the 'weak' signalling theory can be considered complementary to the human capital theory in that educational qualifications also indicate the abilities, aptitudes and attitudes of individuals and that those are partly shaped and developed by the educational system". Thus, according to these theories human capital, measured by education, positively affects firm productivity.

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[12] Although there are several versions, we retain the ideas proposed by Arrow (1973) and Spencer (1973).

[13] Similarly, in Thurrow's labour queue model (1975), companies use skills for signalling. This means workers at the top of the queue are hired first by the companies, because they have greater trainability and therefore cost less to train.

One thing to note when analysing the effect of human capital on firm productivity is that workers develop their productive activity in a specific environment. This means the characteristics of the workplace could help individual workers to fully utilise their abilities and skills, which could affect their productivity. Thus, unlike the two previous theories, the assignment theory (or job-matching theory) proposes that the productivity of workers is determined both by their educational qualifications and by their workplace characteristics (Tinbergen, 1956; Jovanovic, 1979; Sattinger, 1993). Workers with a certain level of education will therefore be more productive in certain workplaces than in others. This idea emphasises the importance of the optimal allocation of workers for firm productivity (Hartog, 1988 and 1992).

It is in this context that the skill-biased technological change (SBTC) theory makes sense. The main idea of SBTC is that there is a complementary relationship[14] between technology and human capital as a result of the improved learning capacity of skilled workers that maximises the potential of technology (Arrow, 1962)[15]. This means the introduction and diffusion of new technologies produces a relative increase in demand for skilled workers, which in turn results in an increase in the relative salaries of the most educated workers[16]. So, as these theories suggest, the introduction of new technologies in the workplace changes the skills required to achieve production efficiency. We can therefore expect the effect of human capital on productivity to be even greater in technologically advanced work environments.

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[14] As for the hypothesis of complementarity between capital and skills, Griliches (1969) and Fallon and Layard (1975) proposed a relationship of dependence between the marginal productivity of human capital and the capital stock. But it was not until the development of new technologies and the emergence of the "theory of skill-biased technological change" that this relationship of complementarity between human capital and capital – specifically technological capital – began to gain strength.

[15] Arrow's theories (1962) focus on the concept of "learning-by-doing" and how skilled workers are able to get the most out of the technology acquired by a company. A second view of the SBTC theory, which includes the ideas of Nelson-Phelps and focuses on explaining the complementary relationship between technology and human capital based on the premise that human capital facilitates the diffusion of technology, which means the positive correlation between the two factors is because companies with higher levels of human capital will incorporate new technologies faster.

[16] See Chennells and van Reenen (2002) for a summary of the literature.

In conclusion, the positive correlation between education and productivity can be explained by three alternative theories: the human capital theory, the screening theory ("weak" version) and the assignment theory. An important point to note is that some theories complement others, since each theory is based on different arguments that are not mutually exclusive. The more educated workers not only gain a higher level of human capital, which increases their productivity, but they also obtain certificates that can be used to improve the distribution of workers according to the skills they have acquired and those that are required in the different workplaces (Cövers, 1999)

Empirical evidence

Traditionally, the lack of data has meant that the methodology used to analyse the effects of human capital on productivity has been based on the estimated wage equation of workers. The human capital theory thus considers wages to represent the marginal productivity of individual workers, meaning that a positive impact of education on wages automatically leads to greater productivity. However, as Hellersten et al. (1999)[17] have already pointed out, using the estimated wage equation to determine whether education influences productivity has two serious drawbacks. Firstly, it requires the assumption of perfect competition; only if there is perfect competition do wages reflect the marginal productivity of work. Secondly, wage differentials between workers may be due to differences in productivity or other factors, or to firm characteristics such as different pay policies. This means wages would reflect not only worker productivity but also the characteristics of the different human resource policies used by the firm.

Recently, new approaches have been developed that use the production function of the firm to determine the impact of human capital on firm productivity[18]. These

[17] Hellersten et al. (1999) first analysed the direct impact of human capital on firm productivity using a production function.

[18] Most studies use the Cobb-Douglas functional form. This simple form enables elasticities to be calculated without the introduction of too many terms that can make estimates imprecise (loss of degrees of freedom).

methods include the contributions of Hellerstein, Neumark and Troske (1999), Hellerstein and Neumark, (2004), Haskel, Hawkes and Pereira (2005) and Higon and Siena (2006). Although previous works seem to reach the conclusion that human capital does indeed have a positive impact on firm productivity, there is a serious problem of bias, since none of the works takes into account the possible effects of technological capital on firm productivity, nor the possible complementarity between the two production factors[19].

As mentioned above, this idea of complementarity between technology and human capital has been analysed using the SBTC theory. This theory is based on the fact that new technologies increase the demand for skilled workers, since they are able to use those technologies most efficiently, thus maximising business performance. The existing empirical evidence has shown a positive relationship between the use of new technologies and demand for skilled workers, as well as with wage increases[20]. But can workers with greater levels of human capital really increase the productivity of new technologies? Can a firm improve productivity by having greater levels of technology and human capital?

We must therefore take into account that this positive relationship between new technologies and the demand for workers with a higher level of human capital can also be due to other factors such as the research effect or the diffusion effect of human capital. It is possible that companies operating in highly technological environments are demanding better educated workers because they promote both the diffusion and generation of new technologies (they have a positive effect on innovative capacity) without affecting the level of firm productivity. Analysis of the correlation between new technologies and the level of education is therefore not sufficient to determine that workers who are more highly skilled raise the productivity levels of new technologies.

[19] The positive correlation between human capital and technologies can cause a bias in the estimated coefficient of human capital if technologies are not taken into consideration in the estimation. The coefficient of human capital could be reflecting the positive effects of technology on firm productivity.

[20] For a review of the literature see Acemoglu (2002), Katz and Autor (1999), Link and Siegel (2003) and Dunne and Troske (2005).

Significant works in this area of analysis include that of Bresnahan et al. (2002), which uses data from manufacturing and services companies throughout the EU, and those of Hempell (2003) and Arvanitis (2005), which focus on the services sector in Germany and Switzerland respectively. Those three works lead to the conclusion that technology and human capital are complementary factors on firm productivity. Both Bresnahan et al. and Hempell observe that educational qualifications do not directly affect firm productivity, but rather that the positive correlation is as a result of the use of new technologies, although this relationship exists only for highly educated workers[21]. For example, Hempell observes that complementarity only exists for workers with university qualifications, and that no increase in the productivity of new technologies is found among workers with vocational qualifications.

The reason why these works have only found evidence of complementarity for workers with higher educational qualifications may be because the measures of technology used are based on information and communication technologies (computers, software, hardware, etc.)[22]. As highlighted by Aral et al. (2007), information and communication technologies (ICTs) can be particularly important for "information workers" such as managers, consultants, researchers, sales representatives, lawyers and accountants, and although it is true that technological change has changed the demand for skilled workers and the occupational structure of companies[23], this does not mean production workers should be underskilled[24]. The introduction of new technologies in production processes, such as the use of robotics, computer-assisted engineering programs, flexible-production systems, etc., may have resulted in production workers being

[21] Arvanitis (2005) does not differentiate between different levels of education, but considers the ratio of workers with higher education as a proxy of human capital variable.

[22] Bresnahan et al. (2002) use the logarithm of the value of computer equipment, Hempell (2003) takes the logarithm of ICT capital, and Arvanitis (2005) uses the percentage of workers who use the Internet and intranet as a proxy of ICT capital.

[23] Doms et al. (1997) underline that the introduction of new technologies has increased the demand for workers in the area of management (non-productive) at the expense of the demand for production workers.

[24] See Mañé (2001).

substituted by machinery (Doms et al., 1997), but at the same time it may have increased the skills required for the technology to be used efficiently. This would be the case if it was demonstrated that not only is there a complementary relationship between new technologies and skilled workers in the area of management, but also the introduction of new production processes incorporating more advanced technology requires skilled workers in the area of production.

Because we have information on the AMTs, we are able to test this premise, which means our study goes beyond simply analysing the effects of human capital on firm productivity. The aim of this paper is to analyse whether these effects depend on the firm's level of technology, and in particular the impact of new processing technologies on the productivity of workers in the area of production.

3. Statistical information and constructing variables

With the aim of analysing the effects of human capital on firm productivity, we used microeconomic data from Catalan manufacturing firms taken from the 2001 Pimec-Sefes business survey. The survey was conducted by telephone and included 757 companies with more than five employees.[25] The respondents, managers and heads of human resource departments were asked a series of questions on the characteristics of workers and production processes, as well as on the general characteristics of the firm. The economic data used to measure firm productivity were extracted from the Iberian Balance Sheet Analysis System (SABI)[26]. Due to the interaction of the two databases, the final sample was reduced to 615 companies. The main reason for this reduction was the absence of available data for some companies.

Constructing variables

In this analysis, firm output was measured in terms of gross value added at factor cost, physical capital based on the value of the tangible fixed assets, and the labour factor according to the number of workers on the payroll in 2001.

Regarding the construction of the human capital variable, we can observe that there is no clear consensus on how it should be measured, but we do know that this concept includes aspects related to workers' production skills and abilities. Consistent with the human capital theory, the most common proxies have been the level of education, training and experience. In some studies, wages were also used as a proxy for production skills based on the assumption that workers' earnings reflect their marginal productivity. The main drawback of this approach

[25] See the distribution of companies by size in Table 1 in the Appendix 2.

[26] The SABI database is compiled using data from company accounts and reports in the Companies Register.

is that earnings largely depend on remuneration policies and on the bargaining power of workers within the firm[27].

In this study, we built the human capital measure using data from questions 8 and 9 of the 2001 Pimec-Sefes business survey.

8. Please state how many of the following occupations exist in your company. *(DK/NA 999)*

a) Manager:______
b) Professionals or technician:______
c) Administrative or sales staff:______
d) Skilled workers (workshop managers, tradespersons):______
e) Unskilled labourers:______
f) Operators (production-line workers) :______
g) Public-contact workers:______

9. Level of training (arrival, MULTIPLE). *(DK / NA 999)*

a) How many of the current managers hold a bachelor's degree or higher?
b) How many of the current professionals or technical staff hold a bachelor's degree or higher?
c) How many of the current administrative or sales staff hold an FP2 or COU diploma or higher?
d) How many of the current skilled workers hold an FP2 or COU diploma or higher?
e) How many of the current unskilled labourers hold at least an FP1 or BUP diploma?
f) How many of the current operators hold at least an FP1 or BUP diploma?
g) How many of the current skilled public-contact workers hold secondary school qualifications or higher?

Thus the measure of human capital has been built using the level of education of workers by occupational group. Unlike other studies, this measure puts special emphasis on the assignment theory and on the importance that the characteristics of the workplace has on the worker's skills, and therefore on the minimum required level of education to perform tasks efficiently. Thus, the measure is not so much the level of education of the firm's workers, but also the proportion of skilled workers.

In the classification between skilled and unskilled workers, both managers and professional and technical staff will have the necessary skills to carry out the tasks required in their workplace, and they shall therefore be considered skilled if

[27] To solve these problems, new approaches have emerged that propose the estimation of personal fixed effects using wage equations and by checking company-specific effects (Abowd, Kramarz and Margolis, 1999).

they hold at least a university (bachelor) degree or diploma. Administrative or sales staff (clericals and tradespersons) and skilled workers (supervisors) are considered skilled if they possess a minimum level of education of FP2 or COU. Finally, operators and labourers are required to have skills equivalent to those obtained in FP1 or BUP to be considered skilled in their workplace[28].

Following these criteria, we constructed an aggregate human capital index that was measured as the percentage of skilled workers in the total workforce. We also created various human capital indices according to occupational group, such as the percentage of managers who are skilled[29].

Constructing these human capital indices for each occupational group enabled us to analyse the complementarity between the production technologies and the human capital of the different categories of workers. It also enables us to test the premise that technological change increases demand for skilled production workers.

We constructed the measure of technology based on the work of Doms et al. (1997). The measure is based on the type of production machinery used in the plant (AMTs). Thus, unlike other works that focus on analysing the impact of ICTs – such as office machinery, computers, communication equipment, etc. – we used nine different production technologies, which can be complementary to each other and, by their nature, can be used in any manufacturing industry. These advanced manufacturing technologies include numerically controlled machine tools, robotically assisted production, CAD-controlled machines, computer-assisted engineering (CAE) programs, automated warehouse management systems, flexible production systems, laser technology for work on materials, intranet data sharing and automatic sensors for inputs and output control. The technological measure is based on the assumption that companies that use a

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[28] The Appendix 1 contains the equivalences according to the International Standard Classification of Occupation (ISCO-08), the International Standard Classification of Education (ISCED-97) and the classification of skill workers by occupational groups and qualification.

[29] In the estimation we monitored the structure of the workforce (the percentage of total workers in each occupational group).

greater number of technologies are more technologically advanced[30]. This enabled us to produce a classification of companies with three levels of technological complexity: fewer than two technologies = low-technology; between two and three technologies = medium-technology; more than three technologies = high-technology.

Among the control variables used in the regression we must distinguish between variables that refer to business-specific effects and those that refer to industry-specific or region-specific effects.

The first group includes a dummy variable that attempts to capture the effects of the experience of workers on firm productivity. The value of this variable is 1 if the number of workers with more than two years' experience is above average and 0 if it is not. We also introduced the variable "firm age" as a proxy for experience, and the variable "age squared" in order to capture the diminishing returns from this variable. Regarding the effect of international competition on firm productivity, the available evidence suggests that the greater the foreign competition, the greater the firm productivity. This is not surprising, it is essential to ensure production efficiency to survive in highly competitive environments[31]. We thus introduced a dummy variable into the regression that takes the value 1 if the firm competes in foreign markets and 0 otherwise. We also introduced the variable of the proportion of exports out of the firm's total sales. Unlike the previous variable, which only indicates whether the firm exports or not, this variable measures the extent to which the firm operates in foreign markets.

In order to capture the industry-specific effects we introduced sectorial dummy variables[32]. These dummies allow us in particular to determine sector-specific

[30] Although this way of measuring the company's level of technology does not take into account the intensity of use of this technology, Doms et al. (1997) show that the number of technologies is a good proxy for intensity of use.

[31] Serrano, Requena, Lopez-Bazo and García-Sanchis (2005) analyse the impact of foreign trade and human capital on the total factor productivity of Spanish industry.

[32] Two-digit CNAE code.

variations in companies' outputs that cannot be explained by production factors, such as fluctuations in demand produced by the specific economic cycle of the industry. They also ensure that companies' production can be compared across industries, detecting measurement errors resulting from industry prices, which is one of the main problems that Griliches and Klette (1996) identify in the analysis of productivity at the business level.

With the same aim of monitoring regional productivity stocks, we introduced dummy variables for the different regions: the Barcelona Metropolitan Area, the rest of the province of Barcelona, Terres de l'Ebre, the rest of the Tarragona province, and the provinces of Lleida and Girona.

4. Econometric model

The impact of human capital on firm productivity was analysed using the Cobb-Douglas specification to approximate the production function. The advantage of using this type of function is that we can break down the different production factors, which allows us to easily calculate the contribution made by each factor to the firm's productivity and does not require the restriction of constant returns to scale to be imposed.

The modelling of the human capital factor in the production function can be done in two different ways based on the works of Griliches (1970) and Fallon (1987). The first way is through the use of the measure of actual work or quality of labour[33], and the second is through the introduction of human capital as an additional factor in the traditional production function. In this work we have chosen the second approach, based on the works of Bresnahan et al. (2002), Arvanitis (2005) and Hempell (2003), since it enables to derive the various indices in the production function[34]. The analytic expression of the function will take the following form:

$$\ln Y_i = \ln A_i + \beta_K \ln K_i + \beta_L \ln L_i + \beta_{KH} HK_i + \beta_T TECH_i$$

Where *Y* is the firm's output, *K* and *L* are the traditional production factors "physical capital" and "labour", and *HK* and *TECH* are additional terms we have added that represent the "human capital" factor and the level of technology of the firm respectively, that is, the quality of the factors "labour" and "capital". The parameters are as follows: β represents the output elasticities for each of the production factors, while *A* represents the total factor productivity (TFP), which is calculated as follows:

$$\ln A_i = \beta_0 + \omega_i + \eta_i$$

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[33] See Hellerstein et al. (1999) and Haskel et al. (2003, 2005) for an effective application of actual work or quality of work in the production function.

[34] However, Griliches (1970) shows that it is impossible to differentiate empirically between the two forms of prior specification.

Where: β_0 represents the common technical progress for all companies in manufacturing, η represents the random disturbance term and ω represents the firm's unobserved productivity.

By joining together the two expressions above and reordering them we obtain the Augmented Cobb-Douglas production function.

$$\ln Y_i = \beta_0 + \omega_i + \eta_i + \beta_K \ln K_i + \beta_L \ln L_i + \beta_{KH} HK_i + \beta_T TECH_i$$
$$\ln Y_i = \beta_0 + \beta_K \ln K_i + \beta_L \ln L_i + \beta_{KH} HK_i + \beta_T TECH_i + \omega_i + \eta_i$$

Based on the work of Olley-Pakes (1996), ω cannot be observed from an econometric perspective, but it can from a firm perspective. This implies that decisions to invest in both human capital and technologies will depend on this unobserved productivity, thus creating an endogeneity problem, and therefore a bias in the estimation of the parameters of the regression. We solve this problem by using the methodology proposed by Levinshon and Petrin (2003), which allows the value of ω to be approximated using a semi-parametric estimation technique[35] .

[35] The greatest criticism of the methodology proposed by Olley-Pakes (1996) is that it uses the investment by the company as a proxy for unobserved productivity. This implies that investment must be positive for the condition of invertibility to be fulfilled and thus for the function to be estimated. As Levinsohn and Petrin point out (2003), many companies do not invest, so these should be removed from the sample, which causes a truncation problem. To avoid this problem, Levinsohn and Petrin propose using the variable "material" as a proxy variable for unobserved productivity. This paper has chosen to use "materials" as a proxy variable for productivity due to the large proportion of companies that did not invest during the period we analysed.

5. Results

Table 2 of the Appendix 2 shows the descriptive statistics of the variables, taking into consideration the entire sample and classifying the companies according to apparent labour productivity (value added per worker). We can see that the variables "human capital" and "level of technology" increase in value as the average productivity increases[36]. We can also see that the companies in the sample generally have a low level of technology, as only 18.8% of them have implemented four or more technological elements into their production processes. Regarding the level of human capital, we can observe that on average 44% of workers in Catalan companies appear to be skilled to do their job efficiently. We can also see that the greatest gap between the level of education needed in a workplace and the level actually attained is found among production workers. Finally, we should mention that the data show that the most productive companies tend to be larger (in terms of number of staff), older (age) and bigger exporters.

Table 3 of the Appendix 2 shows the results of the estimation of the production function without taking into account the effects of complementarity between human capital and production technologies[37]. The first three models were estimated using ordinary least squares (OLS), while the others were estimated using the methodology proposed by Levinshon and Petrin (2003), which enables to solve the problems of endogeneity caused by companies' unobserved productivity. This means that, as we might expect, the results obtained using the OLS method create an upward bias for both the "labour" factor and the "human capital" factor[38]. The main reason for this bias is the nature of the "labour" factor and the ease of adjustment to productivity changes or shocks compared with

[36] The difference of means test rejects the null hypothesis of equal means between groups and confirms that the more productive companies are those with higher average levels of both human capital and technologies.

[37] In all estimates, workforce distribution was introduced as a control variable along with the sector-specific and region-specific dummy variables.

[38] To identify the physical capital coefficient we should complete the second stage of the LP procedure, but this would require having the variables delayed for at least 1 period. The cross-sectional data only allow us to complete the first step of the LP procedure, making it impossible to calculate the physical capital coefficient (see Arnold et al., 2005).

other factors such as the level of technology.[39] Since the OLS method produces a bias in the estimation of the parameters, we will focus on the discussion of the results obtained using the Levinshon and Petrin (LP) method. Model 4 includes the "human capital" variable but not the "technology" variable; Model 5 includes the "human capital" variable and the "technology" variable; and model 6 includes the different human capital indices by occupational group as well as the "technology" variable.

The coefficient of the dummy variable for workers' experience should be interpreted with caution. Remember that this dummy variable takes the value 1 if the percentage of workers with more than two years' experience is higher than the industry average. We would therefore expect that the companies experiencing the most growth would be those with a lower percentage of workers falling into that category, so the value of this dummy variable could be 0 for companies in expansion. This means that the dummy variable may be detecting productivity differences between companies that are growing and those that are not, so the negative sign of the variable should not surprise us, even though it is not very significant (Model 4) or insignificant (Model 5). If we look at the variables referring to the companies' experience (age and age squared), we see that the accumulation of experience by a firm has a significant positive effect on its firm productivity, although that effect decreases over time. An inverted-U relationship is thus confirmed between the age and productivity of the firm, as is postulated by the industrial development models of young companies. These models assume that new companies have lower productivity levels but that they gradually learn as they make new investments, operate in international markets or increase their scale of production. There is a learning-by-doing process, which increases firm productivity through the accumulation of experience, especially during the firm's first years, but then the accumulation of knowledge through learning-by-doing loses weight in the explanation of productivity improvements (Fernandez, 2006).

[39] See Ackerverg, Caves and Frazer (2005) and Van Biesebroeck (2007) for an empirical study of the effect of unobserved productivity on the value of the coefficients in the production function.

Regarding the impact of exports on firm productivity, in the literature on international trade we find two hypotheses to explain higher levels of productivity in firms that export. The first refers to the premise of selection and the fact that the existence of sunk costs (e.g. the internal organisation) associated with entry into foreign markets means that only the most productive, most competitive companies can enter. The second hypothesis is based on learning-by-exporting, and assumes that companies involved in international markets can benefit from international contacts and spillovers of technological knowledge. The main difference between the selection hypothesis and the learning-by-exporting hypothesis is that the former does not consider there to be a causal relationship between exports and firm productivity. In our study, we found very different results depending on the estimation method used. The estimation by OLS suggests that participating in international markets has a positive effect on firm productivity[40]; however, when we control for the firm' unobserved productivity using the LP methodology, we observe a decrease in the value and significance of the "export" variable. These results support the selection hypothesis, so the significant positive value of the coefficient obtained using OLS could be detecting the positive effect of better organisation and higher levels of unobserved productivity in companies that export. That is why once unobservable productivity has been brought under control, the effects of whether a firm competes in international markets disappears[41]. Indeed, not only does the coefficient of this variable become insignificant, but also the companies that export the most are the least productive. One possible explanation for these results could be linked to the country's specialist export product, since traditionally companies with the largest export capacity belonged to low-technology sectors, and therefore less productive sectors. This would imply that although these companies might be the most productive in their sector, they cannot compete with the productivity levels

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[40] These results are coherent with those obtained by Kraay (1999), Blalock and Gertler (2004) and Fernandes and Isgut (2006).

[41] Delgado et al. (2002) analyse the effect of exports on productivity in Spanish manufacturing firms and obtain evidence to support the selection hypothesis. However, the evidence in favour of learning-by-exporting is very weak and is limited to younger firms. Arnold and Hussinger (2005) find the same results for German manufacturing companies.

achieved by companies in sectors with more advanced technology that also compete in international markets but with a lower volume of exports[42].

As mentioned above, the difference between models 4 and 5 is that in Model 4 technology variables have not been introduced into the regression. This means that the aggregate human capital (KH), approximated as the percentage of skilled workers out of the total workforce, makes a significant positive contribution to firm productivity. However, the introduction of the level of technology into the estimation makes the human capital coefficient insignificant [43](Model 5). This is explained by the positive correlation between the two factors, causing an overestimation of the coefficient if one of them is omitted from the equation[44]. Thus, according to Model 5, aggregate human capital would not have any effect, at least not directly, on the productivity level of Catalan companies.

The problem of considering the aggregate measure of human capital is that we cannot analyse the contribution of different types of workers on firm productivity. In order to solve this problem, in model 6 we have introduced different human capital indices by occupational group, allowing us to test whether there exists any kind of key worker that directly influences productivity. The results showed that one crucial element affecting productivity is the percentage of skilled professionals: a 1% increase in this type of worker would lead to a 9.7% increase in productivity irrespective of the firm's level of technology[45].

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[42] Therefore of the 271 companies in the sample that compete in international markets, 55.2% are low-technology and 44.7% are high-technology. Regarding the percentage distribution of sales, we see that companies in the highest quintiles of distribution belong to the low-technology sectors, which shows that companies with greater penetration into foreign markets are companies in sectors in which there is a low technological intensity, such as food and beverages, wood and rubber, and textiles.

[43] These results are in line with those given in existing literature. Hellerstein et al. (1999), Hellerstein and Neumark, (2004), Haskel et al. (2005) and Higón and Siena (2006) find that human capital has a positive effect on firm productivity, but they do not include the effect of technologies in their analysis. Instead Bresnahan et al. (2002) and Hempell (2003), who do include the technology variable in the production function, do not observe a direct effect of human capital on firm productivity.

[44] These results seem to corroborate the premises of the SBTC theory and to highlight the importance of analysing human capital and technology as two complementary factors in the production function.

[45] The introduction of different rates of one-to-one human capital does not alter the results of joint estimation.

The impact of AMTs on firm productivity appears to be positive and significant, as companies with high or medium level of technologies have productivity levels that are respectively 17.3% and 7% higher than those obtained by low-technology companies (Model 5).

6. Complementarity effects

We analysed the effect of complementarity between human capital and the level of technology on the production function using the formulation postulated by the theory of supermodularity (Topkis, 1998 and Athey and Stern, 1998). The theory assumes that if there are two types of activities (A_1 and A_2), each activity can be transformed into $(A_i=1)$ if the firm carries it out and $(A_i=0)$ if it does not. Thus the function $F(A_1,A_2)$ is "supermodular" only if it satisfies the following condition:

$$F(1,1)-F(0,1)\geq F(1,0)-F(0,0)$$

If this condition exists we can say that A_1 and A_2 are complementary activities. If a firm decides to conduct a certain activity, the effects on the function F will be greater if the firm also conducts the second activity. In our study, the function F represents the firm's productivity, the activity A_1 defines whether the firm's human capacity is above average (A_1=1) or below average (A_1=0), and the activity A_2 defines whether the firm has a high technological capacity (A_2=1 for four or more technologies, and A_2=0 for fewer than four). If the premise of complementarity is true, then the effects of having skilled human capital on firm productivity would be greater in companies with more advanced technology.

In our estimation we standardised $F(0,0)=0$, so the conditioned complementarity becomes:

$$F(1,1)\geq F(1,0)+F(0,1)$$

An alternative to the theory of supermodularity to analyse the complementarity between human capital and technology is simply to introduce the interaction of the aforementioned variables in accordance with the methods proposed by Bersnahan et al. (1999) or Hempell (2003). However, this method is not recommended if continuous variables are not available, since intermediate cases would not be identified (Leiponen, 2002 and Arvanitis, 2005).

Tables 4 and 5 show the results of estimating the production function considering the hypothesis of complementarity between the firm's human capital and level of technology[46]. Comparing the results according to the OLS and LP methods shows that the main difference is in the value of the estimated coefficients and not in the significance. As we have already mentioned, the OLS method produces a bias in the estimation, so we focused on analysing the results obtained using the LP method (Table 5).

In order to test whether there is complementarity between human capital and technologies we introduced three dummy variables into the production function that represent the possible statuses of the companies. The S_{11} status takes the value 1 for high-technology (more than four technologies) companies with an above-average percentage of skilled workers, and 0 otherwise. The S_{10} status takes the value 1 for non-high-technology companies with an above-average percentage of skilled workers, and 0 otherwise. The S_{01} status takes the value 1 for high-technology companies with a below-average percentage of skilled workers, and 0 otherwise. And the S_{00} status (reference category) takes the value 1 for non-high-technology companies with a below-average percentage of skilled workers, and 0 otherwise.

The introduction of dummy variables into the regression will subsequently allow others to test the condition of complementarity:

$$F(1,1) \geq F(1,0) + F(0,1)$$

If we translate the previous expression in terms of the regression coefficients we find:

$$\beta_{11} \geq \beta_{10} + \beta_{01}$$

The hypotheses to be tested will therefore be:

$$H_0 : \beta_{11} - \beta_{01} - \beta_{10} \geq 0 \qquad vs \qquad H_1 : \beta_{11} - \beta_{01} - \beta_{10} < 0$$

[46] The control variables "workforce distribution", "sector" and "region" were introduced into all estimates.

To perform a one-tailed test in which the null hypothesis includes both equal and unequal values is the same as to test the following two contrasting hypotheses:

Contrast 1;

$$H_0 : \beta_{11} - \beta_{10} - \beta_{01} = 0 \quad vs \quad H_1 : \beta_{11} - \beta_{10} - \beta_{01} \neq 0$$

Contrast 2;

$$H_0 : \beta_{11} - \beta_{10} - \beta_{01} = 0 \quad vs \quad H_1 : \beta_{11} - \beta_{10} - \beta_{01} < 0$$

Non-rejection of the null hypothesis in contrast 1 is sufficient to consider that the condition of complementarity has been found. Only if the null hypothesis in Contrast 1 is rejected is it necessary to use contrast 2[47].

The results of the estimation (Table 5) firstly showed that the value of the "labour" factor coefficients and the control variables (workers' experience, firm age and international competition) are not altered when the previous human capital and technology variables (Model 5 and 6 and Table 3) are replaced by the new status variables S_{11}, S_{10}, S_{01}. Second, the results of Model 1 show that a complimentary relationship does indeed exist between human capital and technology, since the value of the statistical test of Contrast 1 is 0.06, which means the null hypothesis of complementarity cannot be rejected. Moreover, the coefficient of the status S_{11} is positive and significant, indicating that high-technology companies with an above-average percentage of highly skilled workers are 15.4% more productive than companies with less-skilled workers and lower technology. At the same time, when these companies are compared with those with status S_{01}, that is, high-technology companies with a low human capital, the (S_{11}) companies' productivity is 4.2% higher.

In sum, the evidence indicates that human capital does indeed have a significant positive effect on firm productivity, although this impact passes through the use of new technologies. Therefore, as predicted by the SBTC theory, to maximise

[47] See Delgado, Fariñas and Ruano (2002).

the potential of new production technologies, a skilled workforce is required. Only the combination of these two factors can maximise a firm's productivity.

The question we still must analyse is whether this complimentary relationship that is satisfied at the aggregate level is also fulfilled for different types of workers. To analyse whether the productivity of new technologies depends on workers' skills only in the area of management or whether the skills of production workers is also important, we tested the aforementioned complementarity hypothesis on each occupational group. Model 2, for instance, compares the hypothesis of complementarity between new production technologies and skilled managers. The variable status S_{11} now acquires the value 1 for high-technology companies with an above-average percentage of skilled managers and 0 otherwise. The S_{10} status takes the value 1 for non-high-technology companies with an above-average percentage of skilled managers. Finally, the S_{01} status takes the value 1 for high-technology companies with a below-average percentage of skilled managers and 0 otherwise[48].

From the results we must first conclude that in all cases the test statistic leads us not to reject the null hypothesis, thus confirming the importance of having skilled workers in all occupational groups to maximise the productivity of advanced manufacturing technologies (AMTs). As highlighted by Arvanitis (2005) a more skilled workforce can on the one hand increase the benefits of using new technologies, and on the other hand, these new production systems that incorporate advanced technology generate a lot of information that requires highly skilled workers who can use it properly. The results thus cast doubt on the assumption that production workers are underskilled as a result of the introduction of new technologies.

Secondly, there are differences in the contribution of different occupational groups to firm productivity. Thus, within the area of management and leadership, both managers and skilled professionals (Model 2 and 3) play a crucial role in

[48] As control variables, in addition to occupational structure, industry and region, the percentage of skilled workers in the other occupational groups was also introduced.

explaining the impact of technology on productivity (the coefficient S_{01} is not significant in any cases). High-technology companies with skilled managers are on average 13.6% more productive. This figure increases to 25.8% among high-technology companies with skilled professionals. With regard to skilled professionals, the above conclusions remain as they form the only occupational group that positively and significantly affects the productivity of the firm regardless of the level of technology (S_{10} positive and significant). Thus, low-technology companies with an above-average percentage of skilled professionals are 8.2% more productive than low-technology companies with an below-average percentage of skilled professionals.

In the remaining occupational groups, we see that the productivity of technologies depends exclusively on the skills of workers (S_{01}, for the other groups there is a significant positive correlation), but the combination of technologies and highly skilled workers does produce higher productivity levels (complementarity hypothesis). Among production workers, skilled operators are an important factor for the impact of new technologies on firm productivity. High-technology companies with a below-average percentage of skilled workers increase productivity by only 12.1%; however, high-technology companies with an above-average percentage of operators increase productivity by 16.5%.

Finally, we should mention the results obtained from administration and sales staff (Model 4) and skilled labourers (supervisors) (Model 7). Firstly, they are the only groups with a positive but insignificant coefficient for the S_{11} dummy variable, although the complementarity hypothesis cannot be rejected. This seems to indicate that although the productivity of new technologies does not seem to depend much on the skills of these workers, companies do obtain a greater performance from this type of human capital when they have higher levels of technology, so the S_{10} coefficient is lower in both cases than the S_{11} coefficient. The reason why the low impact of skills of administration and sales staff on the productivity of new production technologies is that these technologies are used in the production process, which means they have little influence on the daily tasks of these workers[49]. Perhaps the results would have been different if information and communication technology had been taken into consideration. The low impact of skilled labourers on the productivity of new technologies may be because these technologies automate production processes, completing the tasks of the labourers and thus replacing them with machinery. This means the productivity of these workers does not depend so much on the labourers but more on the operators responsible for supervising and monitoring the production processes to ensure they function correctly.

[49] The effect of complementarity between skilled administrative or sales staff and new production technologies cannot be rejected, possibly because companies with advanced production processes have also invested in information and communication technologies, since the coefficient of technological complexity may in part be reflecting the effects of complementarity between ICTs and administrative staff and sales representatives.

7. Conclusions

The aim of this study is to extend existing knowledge on the impact of human capital on firm productivity based on the premise of complementarity effects between human capital and new technologies. The differences with other works are: First, the human capital index was constructed with special emphasis on the assignment theory and the importance of the skills needed by each occupational group. Second, the level of technology of the firm refers to technologies used in the production process (CAD, CAE, automated warehouse management systems, etc.) and not to information and communication technologies (computers, software, hardware, etc.). Third, to test the existence of groups of key workers in firm productivity, we analysed the hypothesis of complementarity between technology and human capital for each occupational group.

We performed the analysis taking into consideration data on Catalan manufacturing companies from the 2001 Pimec-Sefes business survey (2001). To do this we estimated the Augmented Cobb-Douglas production function using the semiparametric method proposed by Levinshon and Petrin (2003) to correct the problems of endogeneity caused by unobserved productivity.

The effect of complementarity between human capital and new technologies on firm productivity was analysed following the formulation postulated by the theory of supermodularity, testing the hypothesis that the effects of human capital on productivity are greater for high-technology companies.

$$F(1,1) - F(0,1) \geq F(1,0) - F(0,0)$$

The results lead us not to reject the hypothesis of complementarity between human capital and technologies and confirm the premise of the theory of skill-biased technological change. Thus, high-technology companies with an above-average percentage of skilled workers are 15.4% more productive than companies with less skilled workers and lower levels of technology, and 4.4% more productive than high-technology companies with low human capital.

The results by occupational group confirm the importance of skilled staff in both occupational group to maximise the productivity of new technologies. In the area of management, both managers and skilled professionals play a crucial role in explaining the impact of technology on productivity. Among production workers, operators play an important role in the production efficiency of new process technologies. Therefore the combination of high levels of both factors increases firm productivity by an average of 16.5%, an increase that is 4 percentage points higher than that achieved by high-technology companies.

In short, the evidence provided shows that having skilled workers in management area is not enough to reach the highest level of productivity in technologically advanced environments. The skills of production workers, especially operators, are essential in order to achieve greater productivity through efficient use of new process technologies.

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Appendix 1

Table 1: International Standard Classification of Occupation (ISCO-08) Structure, Group Titles and Codes

Code	Description	Categories
1.	Managers	▪ Managers ISCO-08: 1
2.	Professionals	▪ Professionals and technicians ISCO-08: 2 and 3
3.	Technicians and associate professionals	▪ Clerical and sales workers ISCO-08: 4 and 5
4.	Clerical support workers	▪ Skilled workers ISCO-08: 6 and 7
5.	Service and sales workers	▪ Machine operators ISCO -08: 8
6.	Skilled agricultural, forestry and fishery worker	▪ Labourers (help production workers) ISCO-08: 9
7.	Craft and related trades workers	
8.	Plant and machine operators and assembles	
9.	Elementary occupations	
10.	Armed forces occupations	

Table 2: International Standard Classification of Education (ISCED-97)

Code	Description	Equivalences
x.	No schooling	▪ Bachelor degree ISCED-97: 5 and 6
0.	Pre-primary education	▪ FP2/COU ISCED-97: 3 and 4
1.	Primary education or first stage of basic education	▪ FP1/BUP ISCED-97: 2
2.	Lower secondary or second stage of basic educatior	
3.	Upper secondary education	
4.	Post-secondary non-tertiary education	
5.	First stage of tertiary education	
6.	Second stage of tertiary education	

Table 3: Classification by qualifications

- Managers are skilled if their educational level is 5 or 6
- Professionals and technicians are skilled if their educational level is 5 or 6
- Clerical and sales workers are skilled if their educational level is 3 or 4
- Skilled workers (supervisors) are skilled if their educational level is 3 or 4
- Machine operators are skilled if their educational level is 2
- Labourers are skilled if their educational level is 2

Appendix 2

Table 1- Distribution of firms by size

Size	Number of firms	% of the sample
Micro	187	30.4
Small	380	61.8
Medium	48	7.8
Total	615	100

Note: Micro firms (5-9 workers), small firms (10-49 workers), medium firms (50-250 workers).

Table 2- Characteristics of the sample

		Total		Low productivity		Medium productivity		High productivity	
	Variable	Medium	St. Dev.	Medium	St. Dev.	Medium	St. Dev.	Medium	St. Dev.
Gross value added per worker	VABpo	31397	31634	14349	4561	26521	3666	53452	46754
Physical capital per worker	Kpo	20529	34637	11782	32562	15460	19444	34438	43402
Number of workers	L	23.55	44.72	18.96	22.65	19.83	20.99	31.93	70.59
% skilled workers	KH	0.440	0.282	0.394	0.285	0.425	0.267	0.503	0.284
% skilled managers	KHmanag	0.433	0.452	0.372	0.453	0.395	0.452	0.532	0.436
% skilled professional and technical staff	KHprof	0.348	0.446	0.228	0.396	0.352	0.445	0.465	0.465
% skilled clerical and sales staff	KHcler	0.678	0.425	0.620	0.461	0.701	0.416	0.714	0.389
% skilled supervisors and tradespersons	KHsuper.	0.384	0.417	0.365	0.417	0.361	0.408	0.426	0.425
% skilled operators	KHoper	0.156	0.316	0.142	0.307	0.156	0.334	0.170	0.306
% skilled labourers	KHlabour	0.215	0.353	0.200	0.348	0.211	0.344	0.235	0.369
Dummy: companies with above-average % of workers with more than 2 years' experience	Exper	0.583	0.493	0.609	0.489	0.601	0.490	0.539	0.499
total number of technologies	----	2.01	1.69	1.72	1.71	1.93	1.62	2.38	1.67
Dummy: low-technology firms	TECH low	0.443	0.497	0.526	0.500	0.466	0.500	0.338	0.474
Dummy: medium-technology firms	TECH medium	0.367	0.482	0.331	0.472	0.383	0.487	0.387	0.488
Dummy: high-technology firms	TECH high	0.188	0.391	0.141	0.349	0.150	0.358	0.274	0.447
Dummy: exporting firms	Expor	0.440	0.496	0.312	0.464	0.470	0.500	0.539	0.499
% sales in international markets	%Expor	0.109	0.194	0.092	0.195	0.098	0.169	0.138	0.212
age	age	26.16	24.46	22.84	24.25	26.92	23.40	28.72	25.46
Total		615		205		206		204	

Note: Firms classified by productivity tertiles

Table 3 – Estimation of the augmented Cobb-Douglas production function

	Model 1 (OLS)		Model 2 (OLS)		Model 3 (OLS)		Model 4 (LP)		Model 5 (LP)		Model 6 (LP)	
	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.
logK	0.1650***	*0.0208*	0.1596***	*0.0211*	0.1537***	*0.0215*						
logL	0.8286***	*0.0416*	0.8083***	*0.0439*	0.7913***	*0.0455*	0.5635***	*0.0449*	0.5417***	*0.0463*	0.5348***	*0.0473*
KH	0.2255***	*0.0838*	0.1983**	*0.0849*			0.1327*	*0.0693*	0.1008	*0.0707*		
KH(manag)					0.0056	*0.0564*					-0.0350	*0.0458*
KH(prof)					0.1602***	*0.0519*					0.0973**	*0.0418*
KH(cler)					-0.0006	*0.0523*					-0.0144	*0.0435*
KH(super)					0.0318	*0.0567*					-0.0035	*0.0459*
KH(oper)					0.0386	*0.0729*					0.0196	*0.0624*
KH(labour)					-0.0392	*0.0608*					0.0017	*0.0522*
Exper	-0.0869**	*0.0432*	-0.0807*	*0.0433*	-0.0812*	*0.0440*	-0.0652*	*0.0359*	-0.0557	*0.0354*	-0.0533	*0.0358*
TECH												
medium			0.0269	*0.0484*	0.0199	*0.0488*			0.0684*	*0.0411*	0.0701*	*0.0418*
high			0.1555**	*0.0721*	0.1679**	*0.0724*			0.1566***	*0.0566*	0.1734***	*0.0574*
%Expor	-0.0982	*0.1645*	-0.0945	*0.1659*	-0.1036	*0.1721*	-0.2324*	*0.1300*	-0.2299*	*0.1294*	-0.2241*	*0.1329*
Expor	0.1367**	*0.0573*	0.1319**	*0.0573*	0.1367**	*0.0579*	0.0387	*0.0478*	0.0329	*0.0476*	0.0364	*0.0486*
age	0.0057***	*0.0016*	0.0055***	*0.0016*	0.0052***	*0.0016*	0.0037***	*0.0013*	0.0033**	*0.0013*	0.0032**	*0.0013*
age*age	-3.14E-05***	*1.10E-05*	-3.11E-05***	*9.88E-06*	-3.06E-05***	*9.52E-06*	-2.21E-05***	*7.39E-06*	-2.13E-05***	*7.17E-06*	-2.09E-05***	*7.25E-06*
N	615		615		615		615		615		615	
R^2	0.7694		0.7716		0.7735		0.8447		0.8469		0.8476	

Note: the dependent variable is the logarithm of the gross value added . Heteroskedasticity-robust standard errors (White procedure). Control variables: occupational structure, sectoral and regional dummies. ***, ** and * denote statistical significance of 1%, 5% and 10% respectively.

Table 4 – Estimation of the augmented Cobb-Douglas production function taking into consideration the complementarity effect (OLS).

	Model 1 (KH)		Model 2 (KHmanag)[a]		Model 3 (KHprof)[a]		Model 4 (KHcler)[a]		Model 5 (KHsuper)[a]		Model 6 (KHoper)[a]		Model 7 (KHlabour)[a]	
	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.
logK	0.1599***	*0.0211*	0.1542***	*0.0216*	0.1548***	*0.0215*	0.1543***	*0.0215*	0.1538***	*0.0215*	0.1538***	*0.0216*	0.1534***	*0.0216*
logL	0.8129***	*0.0440*	0.7929***	*0.0451*	0.7854***	*0.0454*	0.7872***	*0.0453*	0.7929***	*0.0454*	0.7921***	*0.0453*	0.7975***	*0.0459*
Exper	-0.0772*	*0.0433*	-0.0829*	*0.0437*	-0.0808*	*0.0437*	-0.0843*	*0.0437*	-0.0799*	*0.0436*	-0.0826*	*0.0435*	-0.0824*	*0.0436*
ss11	0.2137***	*0.0778*	0.1872**	*0.0733*	0.3459***	*0.0868*	0.1006	*0.0807*	0.1883**	*0.0840*	0.1964**	*0.0950*	0.0404	*0.1071*
ss10	0.0636	*0.0508*	0.0073	*0.0573*	0.1255**	*0.0529*	-0.0107	*0.0485*	0.0021	*0.0512*	0.0106	*0.0701*	-0.0427	*0.0533*
ss01	0.1443	*0.0999*	0.1254	*0.1080*	0.1161	*0.0903*	0.2678***	*0.0883*	0.1242	*0.0886*	0.1412*	*0.0818*	0.1831**	*0.0789*
%Expor	-0.0814	*0.1661*	-0.1102	*0.1736*	-0.1087	*0.1736*	-0.1024	*0.1721*	-0.0989	*0.1706*	-0.1033	*0.1720*	-0.0890	*0.1749*
Expor	0.1330**	*0.0577*	0.1381**	*0.0578*	0.1387**	*0.0585*	0.1335**	*0.0574*	0.1376**	*0.0579*	0.1379**	*0.0579*	0.1349**	*0.0581*
age	0.0053***	*0.0016*	0.0051***	*0.0016*	0.0052***	*0.0016*	0.0050***	*0.0016*	0.0051***	*0.0016*	0.0052***	*0.0016*	0.0053***	*0.0016*
age*age	-3.06E-05***	*1.04E-05*	-3.01E-05***	*9.46E-06*	-2.98E-05***	*9.28E-06*	-2.91E-05***	*9.62E-06*	-2.96E-05***	*9.68E-06*	-3,03E-05***	*9.56E-06*	-3.17-05***	*9.70E-06*
N	615		615		615		615		615		615		615	
R^2	0.7698		0.7735		0.7735		0.7743		0.7734		0.7734		0.774	
F value	0.06		0.2		0.8		2.13		0.32		0.15		0.77	
P value:	0.962		0.6515		0.3705		0.1446		0.5719		0.6963		0.3811	

Note: the dependent variable is the logarithm of the gross value added. Heteroskedasticity-robust standard errors (White procedure). Control variables: occupational structure, sectoral and regional dummies. ***, ** and * denote statistical significance of 1%, 5% and 10% respectively. F value: value of the statistical test of the null hypothesis of complementarity. (a) control variables were also introduced for the percentage of skilled workers in the other occupational groups.

The columns show the complementarity effect between technology and: skilled workers (column 1), managers (column 2), professionals (column 3), clerical and sales staff (column 4), skilled workers (supervisors) and tradespersons (column 5), operators (column 6), and labourers (column 7).

Table 5 – Estimation of the augmented Cobb-Douglas production function taking into consideration the complementarity effect (Levinshon-Petrin).

	Model 1 (KH)		Model 2 (KHmanag)[a]		Model 3 (KHprof)[a]		Model 4 (KHcler)[a]		Model 5 (KHsuper)[a]		Model 6 (KHoper)[a]		Model 7 (KHlabour)[a]	
	Coef.	St. Err.	Coef.	Est. Err.	Coef.	Est. Err.	Coef.	Est. Err.	Coef.	Est. Err.	Coef.	Est. Err.	Coef.	St. Err.
logK														
logL	0.5500***	*0.0464*	0.5446***	*0.0472*	0.5386***	*0.0468*	0.5406***	*0.0471*	0.5435***	*0.0470*	0.5417***	*0.0473*	0.5463***	*0.0476*
Exper	-0.0581	*0.0360*	-0.0600*	*0.0362*	-0.0585	*0.0362*	-0.0606*	*0.0361*	-0.0589	*0.0364*	-0.0595	*0.0363*	-0.0603*	*0.0362*
ss11	0.1537***	*0.0589*	0.1361**	*0.0578*	0.2583***	*0.0642*	0.0952	*0.0631*	0.1216*	*0.0636*	0.1648**	*0.0740*	0.0774	*0.0815*
ss10	0.0210	*0.0421*	-0.0296	*0.0473*	0.0819*	*0.0445*	-0.0205	*0.0405*	-0.0184	*0.0431*	0.0076	*0.0604*	-0.0399	*0.0442*
ss01	0.1103	*0.0745*	0.0880	*0.0820*	0.1064	*0.0689*	0.1758**	*0.0702*	0.1291*	*0.0668*	0.1214**	*0.0620*	0.1354**	*0.0593*
%Expor	-0.2191*	*0.1294*	-0.2274*	*0.1341*	-0.2248*	*0.1331*	-0.2212*	*0.1331*	-0.2225*	*0.1330*	-0.2241*	*0.1345*	-0.2187	*0.1351*
Expor	0.0349	*0.0484*	0.0408	*0.0486*	0.0407	*0.0487*	0.0378	*0.0486*	0.0406	*0.0486*	0.0410	*0.0488*	0.0409	*0.0488*
age	0.0033**	*0.0014*	0.0032**	*0.0013*	0.00323**	*0.0014*	0.0032**	*0.0013*	0.0033**	*0.0013*	0.0032**	*0.0014*	0.0033**	*0.0014*
age*age	-2.13E-05***	*7.47E-06*	-2.08E-05***	*7.35E-06*	-2.09E-05***	*7.45E-06*	-2.09E-05***	*7.41E-06*	-2.16E-05***	*7.36E-06*	-2.12E-05***	*7.40E-06*	-2.18E-05***	*7.37E-06*
N	615		615		615		615		615		615		615	
R^2	0.8455		0.8475		0.8470		0.8471		0.8469		0.8469		0.8471	
F value	0.06		0.73		0.64		0.48		0.02		0.16		0.04	
P value	0.8024		0.3923		0.4251		0.4909		0.8937		0.6899		0.8343	

Note: the dependent variable is the logarithm of the gross value added. Heteroskedasticity-robust standard errors (White procedure). Control variables: occupational structure, sectoral and regional dummies. ***, ** and * denote statistical significance of 1%, 5% and 10% respectively. F value: value of the statistical test of the null hypothesis of complementarity. (a) control variables were also introduced for the percentage of skilled workers in the other occupational groups.

The columns show the complementarity effect between technology and: skilled workers (column 1), managers (column 2), professionals (column 3), clerical and sales staff (column 4), skilled workers (supervisors) and tradespersons (column 5), operators (column 6), and labourers (column 7).

III. SECOND ESSAY

PRODUCTIVITY IN SOUTHERN EUROPEAN SMALL FIRMS: WHEN AND HOW WORK ORGANISATION COMPLEMENTS PROCESS INNOVATION

PRODUCTIVITY IN SOUTHERN EUROPEAN SMALL FIRMS: WHEN AND HOW WORK ORGANISATION COMPLEMENTS PROCESS INNOVATION

Abstract

The aim of this paper is to analyse the effects of human capital, advanced manufacturing technologies (AMT), and new work organisational practices on firm productivity, while taking into account the synergies existing between them. This study expands current knowledge in this area in two ways. First, in contrast with previous works, we focus on AMT and not ICT (information and communication technologies). Second, we use a unique employer-employee data set for small firms in a particular area of southern Europe (Catalonia, Spain). Using a small firm data set, allows us to analyse the particular case of small and medium enterprises, since we cannot assume they have the same characteristics as large firms. The results provide evidence in favour of the complementarity hypothesis between human capital, advanced manufacturing technologies, and new work organisation practices, although we show that the complementarity effects depend on what type of work organisation practices are used by a firm. For small and medium Catalan firms, the only set of work organisation practices that improve the benefits of human capital and technology investment are those practices which are more quality oriented, such as quality circles, problem-solving groups or total quality management.

1. Introduction

In the past years we have observed how the use of new technologies has spread among firms with the aim to improve productivity. Although the existing evidence shows a positive relationship between new technologies and firm productivity, some recent studies point out that investment in new technologies is not enough to archive higher productivity levels, in addition to new technologies firms also needs to change their production process by implementing new work organizational practices, such as total quality circles, work teams, problem solving groups, or information sharing systems, in order to achieve higher productivity levels through the use of the new technologies (Black and Lynch, 2004b; Osterman, 1994; Bresnahan et al. 2002).

At the same time, as Cozzarin and Percival (2010) point out, although firms invest in new technologies or implement new organisational practices, unless employees make efficient use of these elements the firm will not see high levels of returns on their investments. In these cases, the evidence suggests that only skilled workers can make better use of other production factors like new technologies or improve benefits to use new work organisational practices. The idea is that new technologies change the production systems, which has an impact on the internal organisation of firms. As Bayo-Moriones, et al. (2006) point out, investment in new technologies improves production process complexity, and hence problem-solving demands increase while generating greater information flows. In order to cope with these changes, firms need to decentralize the decision-making process and flatten their hierarchy levels, which would make organisational structures based on teamwork, quality circles, or problem solving groups more appropriate. It is in this new competitive context, where technological change and organisational change take place, that the requirements for more skilled workers increase. This is because more skilled workers have a greater ability to use new technologies, handle information, communicate and interact with other people, while tending to be more autonomous.

The difficulty to find data at firm level has led to a smaller number of econometric studies that have examined the impact of human capital, new technologies, and new work organisational practices on firm performance, while taking into account the synergies existing between them. Among those studies that we do have, many contain the following aspects. First, they have focused on the effects of information and communication technologies (ITC), like office, computing and accounting machines, or communication equipment, and not on advanced manufacturing technologies (AMT), which automate the manufacturing process with computer-controlled equipment. In contrast, in this paper we focus on the effects of AMT, such as computer-aided design (CAD), robotics, flexible manufacturing systems, and computer numerically controlled machines. Second, the empirical results about the complementarity between ICT, work organisational practices, and human capital are not clear. While Bresnahan et al. (2002) have found evidence in favour of the synergies between these three factors, Arvanitis (2005) only found evidence in favour of the synergies between ICT and human capital while Giuri et al. (2008) found a negative impact of new organisational practices on the complementarity between new technologies and human capital.

In terms of AMT, we found evidence about the relationship between AMT and human capital improvements (Doms et al , 1997; Dunne et al. 2005; Snell et al., 1992 and Patterson et al., 2004), as well as AMT and the implementation of new work organisational practices (Siegel et al., 1997 and Patterson et al. 2004). Particularly, Bayo-Moriones et al. (2006) offer empirical evidence for the positive relationship among AMT, the implementation of new work organisational practices, and upskilling for Spanish manufacturing firms. None of these works, however, address the issue of the complementarity effects of these three factors on firm productivity, except for Cordero et al. (2009), who analyses 89 firms in the micro electro-mechanical systems industry. In this study, they found a positive and significant relationship between AMT, human capital, and work organisational practices on firm productivity, but when they combine the interaction of these factors with the aim to analyse the complementarity effects, they did not find any significant effect, which does not satisfy the complementarity hypothesis.

Following these results, it seems there is no clear evidence regarding the existence of complementarity effects among these three factors on firm productivity. With the aim to shed some light on this topic, we divide our paper into two basic issues. The first one concerns the relationship among human capital, AMT, and new work organisational practices on firm productivity. The second analyses what type of work organisational practices can improve the productivity of human capital and AMT.

In order to achieve the goal of the paper, we use a unique employer-employee database[50] for Catalan SMEs. Previous research has mainly focused on large firms, but one can argue that the specificities of small and medium size firms call for a deeper understanding of the impact of these factors on firm productivity. This is especially relevant in southern European regions, where SMEs account for a very important share of the economy. In this sense, as Geroski (1998) points out, the firm dimension can affect its productivity in two different ways. First it is the direct effect, which shows that large firms are more efficient per se, second it is the indirect effect, which shows that firm dimension can determinate the efficiency of the production factors. Under the last assumption, it would be logical to find different behaviour patterns of investment decisions among large and small firms. For example, large firms have more information to process and more workers to lead and coordinate, therefore the implementation of new work organisational practices that allow coordination of shared information among employees and the speeding up of decision making could improve firm productivity. In contrast, the implementation of these practices in small and medium firms with less workers and financial resources may result in higher costs and fewer benefits. It is possible, then that limited size may not call for formal new work organisational practices such as job rotation or teamwork. It is also possible that SMEs have greater difficulties in implementing and managing a cluster of co-inventions as opposed to with large firms. Therefore, simultaneous investments in new technologies, new work organisational practices, and skills could make SME firms less productive. In this sense Giuri, et al. (2008) did not

[50] It is very difficult to find information at firm level. For this reason there is few evidence at micro level about the effects of human capital, new technologies, and new work organisational practices on firm productivity.

find evidence for the complementarity among new technologies (ICT), new organisational practices, and human capital for small and medium Italian manufacturing firms. In fact, they found that new work organisational practices actually yielded negative effects on the complementarity between new technologies and human capital. Their results are consistent with the hypothesis that small firms experience a trade-off between new technologies and new work organisational practices.

Finally, to test the hypothesis of complementarity among AMT, human capital, and new work organisational practices, we follow the supermodularity theory. The existing evidence analyses the synergies using a pair-wise test (testing only the complementarity effects between two practices), but this approach is problematic, since it ignores the impact of additional cross-terms. This approach examines only a partial expression for the cross derivate and is prone to an omitted variable bias that affects all coefficients. In order to solve this problem we use a test proposed by Lokshin et al. (2007), which is based on a multiple inequality restrictions framework corresponding to a definition of supermodularity theory[51].

The results of this test show a positive and direct impact of human capital and AMT on firm productivity. In the case of work organisational practices, they do not have a significant direct impact, except for those practices which are more oriented to a work team that, and in this case they have a significant negative effect. When we analyse the relationship among these factors, the results provide evidence in favour of the complementarity hypothesis between human capital, AMT and new work organization practices, however these complementarity effects depend on what type of practices are used by the firm. The conclusion is that, for small Catalan firms, the only set of work organisational practices that improve the benefits of human capital and new technology investments are those practices which are more oriented to quality production process, such as quality circles, problem-solving groups, and total quality management. A possible

[51] See Kodde and Palm (1986), Athey and Stern (1998), Leiponen (2002), Mohenen and Röller (2005) and Lokshin, Carree and Belderbos (2007).

argument that justifies the negative effect of work teams and job rotation is that these practices are more difficult to implement than quality circles or problem-solving groups and for this reason the firm needs more time to see any benefit. These results are in line with those found by Giuri et al. (2008), although they focused on information and communication technologies.

The remainder of the paper is organized as follows. Section 2 discusses the determinants of firm productivity. Section 3 presents a methodological model that analyses the impact of human capital, new technologies, and new work organisational practices on firm performances. Section 4 presents the data collection, variables and descriptive analysis. Section 5 shows the direct effects of these elements on firm productivity. Section 6 discusses the methodology used to analyse the complementarity effects and presents the principal results. Lastly, section 7 presents the concluding remarks.

2. Determinants of firm productivity

The impact of advanced manufacturing technologies

Since the end of the 1980s, we have witnessed how the use of AMT has spread among businesses, whatever sector they might operate in. The assumption is that investments in new digital based technology improve the efficiency of all stages of the production process by reducing setup times, run times, and inspection times. Using advanced systems such as computer-aided design (CAD) or computer numerically controlled (CNC) machines, provides a crucial advantage for businesses by allowing a quick and efficient answer to market shifts and better adaptation to shorter product life cycles. Additionally, these technologies allow the automatic detection of errors in the production process, which results in a reduction in inspection times and improvements in product quality (Bartel et al. 2007).

In general, new machines based on computer applications improve the process coordination, provide more efficient support for control and quality improvement, and achieve better performance by reducing time and production waste. Finally, the reduction in organization times makes possible the reduction in costs of change, and therefore, allows the firms to move from a large batch production to a small batch without any additional cost. In this sense, shift in process technology has facilitated increases in product variety, adjustment capacity, and allows for greater flexibility by the organization.

Much of the early empirical studies dealing with the relationship between new technology and productivity use country or sector level data. The early 1990s, however, analyses at the firm-level were beginning to find evidence that new technology had positive effects on a firm's productivity levels. The empirical evidence here is focuses most on the effects of ICT on firm productivity[52], but we can also find evidence about the positive relationship between the use of AMT and high productivity levels like in Cordero, et al. (2009), Bartel et al. (2007),

[52] See for exemple Gretton, Gali and Parham (2002).

Brynjolfsson et al. (2003) and Doms et al. (1997) for USA firm data, or in Matteucci et al. (2005) for a comparative analysis among USA, UK, German and Italian firms.

The effects of new work organisational practices

In the literature on management, there is a broad discussion about the advantages and disadvantages of different work organization designs[53]. The most traditional work design is the work organized in line and based on Taylorist principles, which are characterized by task cycles of short duration, which are very specialized, well-defined, and standardized. In this framework, the workers have a low level of discretion, and the quality controls, routine maintenances and changes in the machines are designed by specialists. The aim of these work divisions is to reduce production cost and to take advantage of the economies of expertise. This organisational scheme is valid when a firm operate with large production lines and little variety of products, because the nature of highly specialized human resources and hardware allow the firm to take advantage of scale economies, but at the same time making the firm less flexible.

Unfortunately, in the past years, the pressure on firms has been increasing as a consequence of the change of consumer demand and competence intensification. For this reason, firms are forced to offer more specialized and adjusted products to the particular needs of each customer. In this context, firms must be able to adjust their product portfolio more quickly and respond with greater speed to the new developments and ranges of models driven by the competitors[54]. To do that, a firm needs to increase the adaptation capacity and coordinate the various activities and production processes that appear. It is in this context that new work organisational practices become more important because, unlike traditional practices, they can improve the communication and response time of workers through the use of work teams, share information programs and quality circles.

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[53] See Appelbaum and Batt (1994).

[54] Invest in new technologies, like ICT or AMT, also contribute to the versatility and flexibility of the production system.

The core of new work organisational practices is that work is organized to allow front-line workers to participate in decisions that alter organisational routines. Although in the literature there is no strict definition of what practices must be included in this new organisational design, we can identify common features. For example, these practices encourage employee participation, organize work around groups or teams, and involve a restructuring and redesign of tasks. Under this new work organisational design the labour tasks are broader, more versatile, and less specialized. For example, work teams are designed with the goal that employees take on more responsibilities for a set of tasks and make decisions about task assignments and work methods. In the case of quality circles, a firm tries to involve employees on a regular basis in various activities in order to identify and suggest improvements for work-related problems. In conclusion, the new organisational practices give the employee greater autonomy and flexibility, which in turn enable companies to adapt more quickly to changes or fluctuations in demand and become more productive.

Unfortunately, evidence for the relationship between firm productivity and new work organisational practices is not clear. We found evidence for the positive relationship between new work organisational practices and firm productivity in Huselid (1995), Ichniowsky et al. (1997), Cappelli et al. (2001) and Black et al. (2001, 2004a, 2004b) for American firms; Wolf et al. (2002) for German firms; Addison (2005) for USA and German firms; Eriksson (2003) for Danish firms; Bryson et al. (2005) for British firms; Kato and Morishima (2002) for Japanese firms; and MacDuffie (1995) for the automobile industry in different countries. However, we also found evidence of negative effects of some work organisational practices on firm productivity. For example, Black et al. (2001, 2004b), and Bartel et al. (2007) found a negative impact of work teams on firm productivity. In this case, the decentralization caused by the introduction of some work organisational practices increased the risk of duplication of information, the probability of mistakes due to a lower level of control, and reduced returns to specialization, hence reducing worker efficiency and firm productivity. In order to solve this problem, the skill-bias organisational change theory predicts that investment in human capital reduces the cost of decentralization, since skilled workers have a greater ability to handle information, communicate, interact with other people, and trend to be more autonomous (Giuri et al. 2008).

Effects of Human Capital

Traditionally, researchers have shown great interest in understanding the role of human capital on the production process. The existing research allows us to identify two basic mechanisms by which human capital can affect the firm productivity; direct and indirect mechanisms.

Direct mechanism has been analysed most by the Theory of Human Capital. This mechanism deals with the direct impact of a worker's skills on their own productivity, and in turn, on firm productivity. For example, workers with higher skill levels perform their tasks more quickly and with fewer mistakes. They also have the ability to recognize and solve problems that may occur during the workday, thus they require less supervision and can reduce production and organisational times. At the same time, educated workers are more functional and versatile, and for this reason they are able to adapt themselves better to changes in production processes and produce more complex goods with higher quality.

In this case, researchers usually have been analysing the effects of education on individual wages, under the assumption that wages reflex the worker marginal productivity. In the last years, however, new employee-employer data has appeared allowing one to investigate the direct effects of human capital on firm productivity. In this sense, we highlight works such as Hellerstein et al. (1999, 2007) that found, for an American case, a positive effect of education on firm productivity, and for a British case Haskel et al. (2005), and Galindo-Rueda et al. (2005) that also found positive effects. In contrast, Arvanitis (2005) highlights some research that does not show a positive effect of human capital on firm productivity for some American firms and concludes results unclear for firms in others countries.

The second mechanism coexists with those theories that analyse the relationship between human capital and new technologies (skill-bias technological change) or human capital and new work organisational practices (skill-bias organisational change). This mechanism, referred to as an indirect mechanism, is based on the assumption that highly skilled workers can improve firm productivity by making better use of other production factors such as new technologies (complementarity effects). In this way, firms with higher levels of human capital can improve the efficiency of their production processes and achieve higher returns from new technology investments. Additionally, higher capacity to recognize and solve problems and the greater ability to communicate that a skilled worker possesses, allows a firm to achieve better performance not only from technological change but also from organisational change. Therefore upskilling is expected in those firms that use new technologies and new work organisational practices. Evidence about skill-bias technological change can found in Acemoglu (1998), Autor et al. (1998), and Machin et al. (1998), and for skill-bias organisational change in Caroli et al. (2001).

Complementarity effects

As previously stated, there is a large amount of research that analyses the relationship between new technologies and workers skills. From the existing evidence we can identify three principal reasons that explain why the adoption of new technologies require a more educated workforce (Doms et al., 1997; Dunne et al., 2005; Abowd et al., 2007; and Bartel et al., 2007).

The first reason suggests that the introduction of these technologies has increased the productivity of skilled workers, since now these workers are able to perform the same tasks more efficiently. The second reason is that new technologies are a substitute for the routine tasks that low-skilled workers do. Because of this, a firm demands less low-skilled workers and therefore the structure of firm skill mix could be modifier. The third reason is not only related to the implementation of new technologies, but is also linked to changes in the economic environment. As Bartel et al. (2007) noted, the intensification of the competence and the introduction of new technologies encourage greater diversification of production and increase the complexity of products, since the time and the amount of effort needed to produce this type of goods is increasing. Because of this, the firm needs skilled workers who are responsible for carrying out such activities.

The first reason is related to the existence of complementarity effects between skilled workers and new technologies, and it highlights the importance of the indirect mechanism as an explanation of the human capital effects on firm productivity. By contrast, the other reasons are not based on these synergies, but in the substitution effect between a low-skilled workforce and new technologies that produce a change in the workforce composition.

In a recent paper, Autor et al. (2003) used a U.S. database to analyse the change in occupational characteristic over time, identifying shifts in the task composition. They found that over the past three decades, new technologies have replaced workers in manual, routine and repetitive task. In contrast, they have complemented workers engaged in tasks that are less routine and more related to problem solving and communication activities. The introduction of new technologies into a production processes is associated with a reduction in labour demand to perform routine tasks, but at the same time it produces an increase in labour demand for those who can perform more complex tasks. In the end, they found that the net result is an increase in demand for highly skilled workers who can more easily perform analytical and non-routine tasks.

In the works of Bresnahan et al. (2002) for U.S., Yasar et al. (2008) for Turkey, and Hempell (2003) for Germany, they, as well, analysed the relationship between new technology and human capital demand, but additionally they investigate the complementarity effects of these two factors on firm productivity. The results confirm the existence of synergies between human capital and new technologies (ICT) that result in higher productivity growth.

Although the evidence points out that technological change induces increments in skilled labor with the aim to improve firm productivity, new evidence shows that investment in organisational change is also required to achieve higher productivity from technological change. Milgrom and Roberts (1990) stated that a firm needs to invest not only in new technologies but also in other factors as an integrate system in the firm. In this sense, technological change must be accompanied by organisational changes[55].

The assumption is that the introduction of new technologies reduces production times, inspection times and organization times, but also enhances diversification of production and therefor increases the need to organize and coordinate production processes and different job tasks better. In this context of production diversification, organisational change allows production processes to become more efficient and reduces the downtime that exists between the manufacturing of products. This is only if these changes give a worker more decision power and autonomy.

In this case, Caroli (2001) observes that organisational changes help to increase productivity gains obtained by the adoption of new technologies. Black et al. (2001, 2004b), using data from 1994 and 1997 from a representative sample of U.S. manufacturing firms, have analysed the effect of changes in work organization on productivity and wages at the plant level. The practices considered in this research include work teams, wage incentives, and benefits associated with greater employee participation in decision-making. Although they found a weak relationship between the overall educational level and the productivity levels, they observe a significant and positive relationship between the proportion of non-managerial workers who use computers and high levels of productivity. They also found that the effect of technological change on the productivity level is more limited in those firms who have not invested in organisational change, although these results cannot be extended to all new organisational practices since they observe that the use of autonomous teams reduces firm productivity.

Until now we have discussed the relationship between new technologies and human capital, as well as, new technologies and work organisational practices.

[55] Also see Brynjolfsson and Hitt (2000), and Cristini, Gaj and Leoni (2003).

Recently, however, some evidence about the relationship between work organisational practices and human capital also has appeared. The hypothesis is that new work organisational practices are associated with greater autonomy and discretion of workers, which involve the deployment of work teams, problem-solving groups or quality circles, suggestion programs for workers, worker information-sharing systems, rotation and redesign of the workplace, among other practices, have also increased the demand for skilled workers. Piva, et al. (2005) have made a review of the research about the impact of technological and organisational changes in the demand for skilled workers, concluding that these changes are complementary and have a positive influence on the demand for skilled labour. Caroli et al. (2001), using French and British establishment data, find evidence regarding the effects of organisational change on skill demand and a firm's productivity. First, they observe that establishments who introduce organisational changes are more likely to increase demand for skilled workers, and second they note that organisational change allows a faster growth of productivity in those human capital intensive firms than less intensive ones.

The review of the research shows the importance of human capital, new technologies, and new organisational practices on firm productivity by examining only the individual effects or the complementarity effects between two factors, but we know less about effects on firm productivity in cases that consider all three factors together. The lack of firm level databases has hindered the research in this area. Even so, we can highlight the pioneering work of Bresnahan et al. (2002) which uses a database of approximately 300 large manufacturing and service firms from the U.S. This research observes that new technologies (ICT) and new work organisational practices have a positive effect on the demand for skilled worker. They argue that the investment in human capital, new technologies and new organization are related for different reasons. The first reason is the substitution of new technology and low-skilled labour for those more repetitive tasks. But, more important, is the role human capital plays as a key factor in the adoption of new technologies and new organisational practices. According to these authors, there is a high correlation between changes in technological, organisational, and human capital levels, and the combinations of these three elements result in higher productivity gains. Another result is that high levels of human capital are associated with high levels of productivity only in those firms who also have high levels of technology and have adopted new work organisational practices.

Arvanitis (2005) explores the case of manufacturing and service firms in Switzerland. He analyses the complementarity hypothesis between human capital, organisational practices, and new technologies (ICT), including the use of intranet and internet, on firm efficiency and performance. He obtains evidence only in favour of the synergy existing among human capital and new technologies, but not for the case of work organization[56]. In the same work, Arvanitis also reviews what little research there is that tries to analyse the relationship between these factors and firm productivity, but the results are unclear. Not all the studies show positive effects of new technologies, work organization and human capital on firm productivity, and the hypothesis of complementarity is not satisfied among all these factors. In European case studies, the results confirm complementarities between new technologies and human capital or new work organisational practice and human capital, but there is no evidence for the complementarity effects when we consider all three practices together[57]. In this respect, Giuri et al. (2008), that use a sample of Italian small manufacturing firms, found evidence of complementarity among human capital and work organisational practices, but not among human capital and new technologies (ICT). Moreover, they found that new organisational practices have a negative effect on the complementarity between new technologies and human capital.

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[56] Particularly, he analyses the use of work teams.

[57] See Bertschek and Kaiser (2004), Wolf and Zwich (2002), Hempell (2003) and Bauer (2003) for German firms.

3. Methodological framework

In this section, we describe the methodology used to analyse the effects of human capital, new technologies, and new organisational practices on firm productivity.

We consider the basic Cobb-Douglas production function:

(1) $$y_{it} = a_{it} + \beta_k k_{it} + \beta_l l_{it}$$

where y is log of real value added, k is log of real capital input, l is log of labour input and β is the output elasticity with respect to inputs[58]. The term a can be interpreted as the firm efficiency or total factor productivity, and can include other factors that will affect the firm output such as labour quality or human capital (KH), advance manufacturing technologies (AMT), or new work organisational practices (WO). Also included another firm characteristics which the econometrician cannot observe but the firm know (ω), and the idiosyncratic productivity shocks (u).

Therefore, the total factor productivity can be expressed as:

(2) $$a_{it} = \beta_0 + \beta_{KH} KH_{it} + \beta_T ATM_{it} + \beta_{WO} WO_{it} + \omega_{it} + u_{it}$$

If we replace (2) in (1), we obtain the augmented Cobb-Douglas production function:

(3) $$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \beta_{KH} KH_{it} + \beta_T ATM_{it} + \beta_{WO} WO_{it} + \omega_{it} + u_{it}$$

The most straightforward approach to estimate equation (3) is simply to run the ordinary last square (OLS) in the cross section, but this approach is problematic

[58] We use the Industrial Production Index to obtain the real value added, and the Industrial Price Index to obtain the real capital input, both are developed by the National Statistic Institute (INE). Our physical capital measure is the firm book value following Black and Lynch (2001, 2004a), Bresnahan et al. (2002) and Brynjolfsson et al. (2003). Finally we measure the labour factor as the total number of employees.

since it does not take into account the potential correlation between input levels and the unobserved firm-specific productivity shocks (ω) in the estimation of production function parameters. If those firms that have a large positive productivity shock respond by using more inputs, the OLS will yield biased parameter estimates.

Taking into account that our data is a cross-section, except for those economic variables for which we have three year information (2003-2005) such as labour and capital, we solve the simultaneity problem using the two-step estimator proposed by Black and Lynch (2001), and used by Bloom and Van Reenen (2007). Since our aim is to determine the effects of human capital, new technologies, and new work organisational practices on firm productivity, and the simultaneity problem may be most prevalent for inputs that adjust rapidly, such as labour or physical capital, we measure the (TFP) in stage one using the panel structure of the economic data. Then in stage two, using the cross section data, we estimate only the effects of our interest variables on TFP, where labour and physical capital are not included.

Stage one

Among the methods that researches have used to measure TFP (stage one), the index number approach is the most popular. However, this method requires the imposition of a set of restrictive assumptions to get unbiased measurement of productivity and fails to address the simultaneity problem among inputs (Fariñas and Martín-Marcos, 2007) as well as measurement errors (Van Biesebroeck, 2007). Since we have economic panel data, we are able to use a production function approach to estimate the unbiased coefficients on capital and labour. With this information, we are then able to build our total factor productivity measure.

To archive this goal, we estimate equation 1 using the methodology proposed by Levinshon and Petrin, (2003). Black and Lynch (2001) is used within and GMM methods because they have a large six year panel data. Bloom and Van Reenen (2007), which has ten year information, is use within, GMM, and Olley and

Pakes[59] estimators, and obtain the same conclusions independently from the estimation method. In our case, we only have a three years unbalanced panel data[60], and therefore the best estimator given the sample size is the Levinshon and Petrin estimator. This estimator may resolve the problem of simultaneity by using the information about a firm's material consumption as a proxy of unobserved firm-specific productivity shocks.

Therefore, the equation for the first stages is[61]:

(1b) $$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + u_{it}$$

Next, we use the estimates of the efficient coefficients to build our measure of firm productivity by subtracting the predicted output from its actual output at time t.

(4) $$a_{it} = y_{it} - \beta_k k_{it} - \beta_l l_{it} = y_{it} - \hat{y}_{it}$$

We then average that value over the sample period 2003-2005 for each firm to get an estimate of the average TFP ($\overline{a}_i$).

Stage two

In the second stage, we regress the average of TFP on human capital, new technologies, new work organisational practices, and other sets of control variables (X_j).

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[59] Our economic data does not include investment information, it is for this reason that we use Levinshon and Petrin and not Olley and Pakes (1996) estimation. Even so, when firms make intermittent investments or when there are higher observations with zero-investment values, the investment decision fails. This is because the monotonicity condition does not hold for these observations.

[60] In our sample, more than 98% of the firms are observed over three years (2003, 2004 and 2005). As a result, the results obtained in the first stage using a balanced or unbalanced panel data are the same.

[61] We estimate the first stage using a sample of 350 firms, because we did not limit the sample to information on human capital, new technologies, or work organisational practice. This fact allows us to include large a number of observations in the first stage, hence the precision of our estimates for capital and labour improve.

(5) $$\bar{a}_i = \beta_0 + \beta_{KH} KH_i + \beta_T ATM_i + \beta_{WO} WO_i + \sum_{j=1}^{J} \beta_j X_j + \varepsilon_i$$

Note that a two-stage method allows us to deal with the biases issue in the estimates of capital and labour, however biases can still arise in estimating the coefficients in the second stage. But, as we mentioned above, the simultaneity problem is more likely to appear for inputs that adjust rapidly, and is not the case for human capital, new technologies, and new work organisational practices. Nevertheless, there could be some omitted variable that may be correlated with our interest variables and consequently generate biases. It is for this reason that we introduce in the regression a large set of control variables[62].

[62] For an extensive discussion of the biased in the second stage, see Black and Lynch (2001).

4. Statistical information and constructing variables

To build our database, we merged information from different surveys. The first is the PIMEC-URV Survey (2006-2007). This survey provides information about employee-employer characteristics. The second survey is the *Iberian Balance Sheet Analysis System* (SABI), which is a source of firm information from commercial registers, and contains annual financial and account data on employment, sales, materials, capital, exports and imports, etc., for more than 1.2 million Spanish firms.

Due to the difficulty in finding data that contains information about human capital, new technologies, and new work practices, we believe it is necessary to explain how we designed our firm survey and how we collected the data.

Firm Survey

To obtain the data required to conduct this kind of analysis, we collaborated with the small and medium firms association (PIMEC) to design, pre-test, and conduct a firm survey in 2006-2007[63]. The survey was designed following the Employer's Skill Survey (2001-2004) and the Work Skills in Britain Survey (1986-2002), although previously field research was carried out with the purpose of understanding and identifying reliable measures for our interest variables. Plant visits and interviews with industry experts allowed us to identify common features between firms and industries that help us to design and build our measurement of human capital, new technologies, and work organisational practices. For example, to identify a firm's technological level, we introduced in the survey a specific question with a set of technological elements. The respondents had to report which are used by the firm in the production process, but before this, we used the interviews of experts to verify that these technological elements are common in all industry production systems.

[63] This project was financed by the Catalan government.

This survey was divided into two parts. The first one consists of a questionnaire, which consists of information about general characteristics, product and competitive strategy, and technology and work organisational practices that a firm uses. This part was answered by the general manager or the owner. The second part consists of three different questionnaires, one for the managers, one for the supervisors, and another for key production workers. In this second part, we find information about education, job satisfaction, training, wages, and other personal characteristics[64].

Sample composition

Table 1 reports sample distribution according to the sector. Initially, the sample included 360 firms in the manufacturing sector, but after removing firms that had missing values in any of our interest variables, the sample was reduced to 224 small and medium firms[65]. In terms of occupation, the firms in the sample accumulate to a total of 7566 workers, 696 of which are managers, 688 are supervisor, 2820 are operators, and 3362 have other positions within the firm, such as clerical workers or unskilled production workers. Table 2 shows the distribution of the respondents for each occupational group.

To build our measurement of human capital, we use production workers' information. There are several reasons for this. The first reason is our interest in analysing the direct effects of the skills of production workers on firm productivity. The second reason is that work organisational practices and production technologies affect production workers' performance more than other non-production workers such as managers or clerical. Thus, it is reasonable to think that if any relationship exists between human capital, new work organisational practices, and AMT, this comes from the production workers' skills.

[64] Initially, telephone contacts were made to gain participants. The surveys were sent by post to each firm, and with which were followed up by phone contacts. Finally, a courier picked up the completed surveys.

[65] The mean of inequality test confirms that there are no significant differences in terms of value added, total factor productivity, and firm size between the initial sample and the final sample.

Because of this assumption, our measure of human capital has been built using information from approximately 63% of the production workers in our sample[66].

Variables

Although in literature there is no clear consensus on how to measure the skill of a workforce, we know that these measures must include those individual aspects related to productive skills. Traditionally, researchers have used education, training, or a worker's experience to approximate the level of a firm's human capital. Alternatively, some authors have also used wages as a proxy for the capacity of firm productivity, assuming that the remuneration of labour reflects their marginal productivity. The main problem of this approach is that wages depend on firm wage policies and the bargaining power of workers within the firm[67]. For this reason, we use the educational level of the worker as a proxy of a firm's human capital. Particularly, our human capital variable is measured by the proportion of production workers with a college degree, according to Black et al. (2001, 2004a), Bresnahan et al. (2002) or Bloom et al. (2007).

The measure of technology we employ is similar to that used in Doms et al. (1997) and Gale et al. (2002), and is based on technological elements used in firm's production process, such as advanced manufacturing technologies. Instead, other studies that try to analyse the complementarity effects between human capital, new technologies, and work organisational practices, as in Bresnahan et al. (2002), Hempell (2003), Arvanitis (2005) or Guri et al. (2008), have used as a proxy of technology the investment in computers, software, hardware, or the use of internet or intranet. It is important to emphasize that our measure of technology are quite distinct from computer equipment, since the

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[66] 9% of firms have information about only 1 or 2 operators, which represents 11% of the total firm operators. With the aim to account for possible measurement errors, we analyse the sensibility of the results by reducing the sample to those firms with more than 3 questionnaires by operators (represents as minimum 14% of total firm operators). In the reduced sample, the mean of operators respondent represents 70% of total operators in the firm, the sample being composed of 204 firms. The results are consistent with the results obtained with the large sample (224 firms).

[67] Some authors develop a new method consist in the use of personal fix effects as human capital measure. They regress a wage equation to obtain this personal fix effects controlling by firm specific effects. See Abowd, Kramarz and Margolis (1999).

technologies that we use is directly employed in the production of manufactured goods, whereas computing equipment is often a main tool of managerial and clerical labour.

In the survey we asked the manager to indicate whether they used any of eight different AMT in the firm, which by their nature can be complementarity to each other, and used in any manufacturing industry. These technologies include such innovation as computer controlled machines, computer-aided design (CAD), automatic storage, flexible production systems, factory data network, automated sensors used on inputs and final product, and computer vision machines and automatic quality control systems.

Our measurement is built on the assumption that firms using a large number of technologies are more technologically advanced[68]. Taking into account this fact, we consider that firms who use less than two elements are low technological firms, these that use between two or three elements are medium technological firms, and those that use more than three are advanced technological firms.

Finally, we use eight organisational practices questions asked in the survey to build our measurement of work organisational development. These practices are considered in the literature as new work practices that allow a firm to improve their flexibility and productivity levels. The purpose of these practices is to improve employee participation by implementing employee suggestion systems, information sharing manager-employees, job rotation, job redesign, problem solving groups, self-directed work groups or teams, quality circles, and total quality management (TQM)[69]. According to the complementarity hypothesis about work organisational practices[70], we built our index by adding the number of

[68] Although this technology measure doesn't take into account the intensity of use, Doms et al. (1997) realizes several exercises to check whether the number of technologies used is related to the intensity of use. They find that the counts act as a reasonable proxy for technological intensity.

[69] See in table 3 (annex) a brief definition of each practice.

[70] See Ichniowski et al. (1997), Laursen et al. (2003), Black et al. (2001), Becker et al. (2006) and Lawler (1986).

practices used by the firms[71]. Therefore, we consider that the most advanced firms in terms of work practices are those firms that use 5 or more practices, firms that use between two and four practices are in an intermediate situation, and the less advanced are those who use less than 2 practices.

Although this index will enable us to assess the impact of new work organisational practices on firm productivity while considering the synergies between them, we must take into account the fact that some organisational practices are more likely to be implemented together than others. In order to identify different sets of practices, we follow the work of Osterman (2006) and Laursen et al. (2003)[72] by using the principal component method. From the analysis we obtained three factors or sets of practices, the first one is composed of practices that are more related to the production process quality, such as employee suggestion systems, problem solving group, quality circles, and total quality management with the information sharing manager-employee included. We will call this process quality practices, and the argument that justifies the introduction of information sharing in this bundles is based on the fact that these practises are related to the delegation of decision making and responsibilities to the workers. For this reason, it is essential to deploy new systems that allow information sharing between workers and management, thereby improving the decision-making process. The second bundle of practises is called team practices and is composed mainly of self-direct teams. The last bundle is called rotation practices and is composed of job redesign and job rotation.

In order to classify the firms in low, medium, and high levels of work organisational practices, we divide each factor into three equal parts. For example, in the case of process quality practices (factor 1) we classified the firms into three groups, the first belonging to the first tertile and representing those

[71] This strategy has been used by Ichniowski et al. (1997), Bresnahan et al. (2002) and Gale et al. (2002). Osterman (2006) use both additive and principal component (1 factor) methods and he obtains the same results.

[72] Some authors point out the problems with using principal component methods with discrete variables. For this reason, we use the method proposed by Kolenikov and Angeles (2004) to calculate the principal component factors. This method uses the polychorical correlations to identify the factors. The results are consistent with those obtained using the traditional principal component method.

firms with a low level of process quality implementation, the second belonging to the middle tertile and representing those firms with a medium level of process quality implementation, and in the third group there are those firms in the top tertile, which represent those firms with high level of process quality implementation.

Descriptive analysis

Table 4 presents summary statistics for our sample of firms. One of the characteristics of the sample is that it is composed mainly of small firms. The proportion of small to medium firms is 71% and 20% respectively, and only 9% are micro enterprises. The percentage of firms with a majority of foreign capital participation is only 4.4%, and the percentage of firms who participated in a business group is also very low, 10.7%. In respect to the export status of firms, we observe that the exporters are a high percentage of the total number of firms, approximately 64% of the firms report exporting products. However the proportion of total sales on foreign markets accounts for, on average, only 14.7% of the total sales of the firm, which means that exporters sell most of their output domestically.

In respect to our interest variables, table 4 also reveals that the proportion of production workers with a high educational level is only 9%, and firm investment in new technology and new work organisational practices is also low. On average the firms use between two and three production technologies, and the number of work practices implemented are approximately three. The most common technologies used by the firms in their production process are flexible production systems, factory data network, and computer-aided design (CAD). In the case of work practices, we observe that the employee suggestion systems, information sharing manager-employee, and job rotation are the most common extended.

In conclusion, the descriptive analysis shows low levels of human capital, new technologies, and new work organisational practices among Catalan manufacturing firms. Since these factors are determinants of firm productivity, the low endowment levels of these factors could explain the low level and growth of Catalan productivity[73].

[73] During the period 2003-2005, the TFP growth is about 0.35% for the sample. This result is similar to the results obtained by Mas y Quesada (2005 and 2007) for the Spanish economy during the period 2000-2002.

5. Results

In this section, we discuss the econometric results concerning the direct effects of human capital, AMT and new work organisational practices on firm productivity.

To measure TFP we estimate the production function (first stage) in a variety of ways. The first way is OLS, but as we argued above, this measure will be biased by the simultaneity problem. For this reason we also use the Levinshon and Petrin (2003) method[74]. Next we calculated the average TFP for the period 2003-2005, and as a last step we regress this measure in respect to our interest variables (stage two) using OLS.

The results from the second stage estimation using OLS and LP to calculate the average TFP are reported in table 5 and 6. Although the results do not seem very sensitive to the estimation method, we observed high value for the coefficients obtained using LP method. The results confirm positive and significant effects of human capital and AMT on firm productivity after control for other firm characteristics. In contrast, we not can observe any significant direct effect of work organisational practices except in the case of those bundles of practices more related to self-direct teams. In this case, the coefficient of the variable takes a negative value, but at low significant level.

Since the results using OLS are biased, from now on we will focus on describing the results in table 6. In column 1, we only introduce the human capital *(HK)* as a determinant of TFP and other control variables. The results show that an increase of 1% in the percentage of graduate production worker is associated with an increase in productivity of 44%. In contrast, when we introduce new technologies and new work practices into the production function, this coefficient is a slightly

[74] Using OLS , the estimated elasticity of production with respect to physical capital is 0.123 and respect to labor 0.926, both are statistically significant, and the hypothesis of constant return to scale is rejected. Using LP, the estimated elasticity of physical capital and labour is 0.025 and 0.691 respectively. It should be noted that the capital coefficient is not statistically significant, and the hypothesis of constant return to scale is also rejected. The LP results are similar to the results obtained by Fariñas and Martín-Marcos (2007), using System GMM for a sample of Spanish manufacturing firms.

smaller (column 4 and 5). This change can be explained by the synergies existing among these factors. If the firms who use more educated workers are those who also use a large number of new technologies and new work practices, then the human capital coefficient also reflects the effects of these others practices on productivity.

The effects of AMT on productivity are captured by two dummies that represent medium and advanced technological firms. We also find a significant and positive relationship, particularly in those firms that have implemented four or more technologies are 22.4% more productive than those firms who have implemented less than two practices. These results are consistent with Doms et al. (1997) and Bartel et al. (2007) results for a US manufacturing firms.

In column 3 and 4 we analyse the effects of new work practices on productivity. In the first case, we consider as a measurement of new work organisational practices the number of total practices implemented by the firm. In the second case we differentiated between different bundles of practices (principal component). When we consider the pull of practices, the effects on firm productivity are not statistically significant. Unfortunately, this result does not change when we analyse the effects of different sets of practices on firm productivity, except for those practices related to work teams. The results indicate that adopting self-direct teams has a negative and low significant impact on firm productivity. Particularly, those firms who adopt this set of practices are, on average, between 15.8% and 13.8% less productive[75]. This result may be due to the fact that these firms are small and medium in size and some of them can work as a team even if they are not conscious of that. Since this occurs, this result could be biased. Another reason could be that work teams are not easy to implement, and those firms who use this practice needs to invest in training of how to work in teams. For this reason, in a short period of time, this practice has had a negative impact on firm productivity.

[75] These results are in line with those found by Black et al. (2004a) and Bartel et al. 2007.

At last, we comment about the effects of control variables on productivity. We use the age and the age square as a proxy of firm experience. The results show an inverted U-shaped relationship between experience and productivity. This means that experiences increase firm productivity, but productivity gains that have an extra year, are reduced over time. The results also reveal that size and worker experience have a positive and significant effect on firm productivity as well.

Another interesting result is the impact of exports on firm productivity. The results confirm a positive and significant effect of the percentage of foreign sales on productivity before controlling for human capital, new technology, and new work organisational practices. In contrast, this coefficient loses significance when we introduce these factors into the TFP. Theoretically there are two main arguments to explain why exporters are more efficient than non-exporters. The first reason is the self-selection hypothesis, which considers that firms self-select into the export market according to their productivity level. The second reason is the learning-by-exporting hypothesis, which, as an alternative, considers that those firms in the export market can take advantage of economies of scale or acquire knowledge and experience from a greater exposure to better practices. In the second case, the export firms are more productivity per se, but in contrast, in the first case exporter firms are more productive because they invest more in those factors that increase firm productivity like human capital, new technologies, and new work organisational practices. Since our variable lost significance after controlling for these factors, we conclude that our findings are consistent with self-selection hypothesis[76].

In conclusion, the evidence suggests that firm productivity depends directly on human capital and AMT, but not on new work organisational practices. If we take into account only these results, our conclusion will be that new work practices have a negative, if any, effects on firm performance, and it will be better for Catalan manufacturing firms to invest more in human capital and new

[76] Delgado et al. (2002) and Fariñas et al. (2007), using a data set of Spanish manufacturing firms, find evidence favourable to the self-selection hypothesis.

technologies only. In reality this is not completely, because we do not take into account the synergies among these practices. For this reason, an important issue is analysed if there are some bundles of new work organisational practices that can improve the productivity of human capital and new technologies. In the next section, we attempt to analyse the complementarity effects between these factors.

6. Complementarity effects

In this section we address the complementarity effects among human capital, AMT, and new work organisational practices on firm productivity.

The assumption is that firms choose between different levels of human capital, new technologies, and work practices in order to maximize their productivity. At the same time, productivity levels depend on the production process characteristics. For example, if the firm decides to implement a large-scale production of standardized goods, it could be possible that the mass production system allows the firm to achieve higher levels of productivity. In this case the optimal combination of factors that will be used is low skilled workers, specialized machinery, and traditional work organisational practices that avoid worker initiative. On the other hand, if the firm decides to produce a great variety of products with the aim to compete on the basis of quality and customization, they need a more flexible production process. Research suggests that higher skilled workers, new technologies, or new work practices allow the firm to increase their flexibility and productivity. Since these activities complement each other, the only way to maximize firm productivity is to invest in all together, since because investing in any one of these activities increases the returns in the others. In this case, complementarities imply that firms investing in human capital and new technology will obtain a greater return from their investment in new work organisational practices than those firms that do not.

In the next sections, we describe the theoretical framework used in order to test the existence of complementarity among human capital, new technologies, and new work organisational practices. In conclusion, we present the results of our sample of firms.

Theoretical framework for complementarity effects

In order to analyses complementarity effects among some production factors, we use a production function approach[77]. The idea is to analyse the effects of human capital, new technologies, and new work organisational practices on firm productivity, while taking into account these practices as an integrated system within a firm, as Milgrom and Roberts (1990) and Athey and Stern (1998) point out[78].

With the goal to analyse what is the optimal combination that maximizes a firm's productivity, we use level of factors endowment to identify different production systems[79]. Next we estimate the effects of each production system on firm productivity using a production function approach. Lastly, we use the test proposed by Lokshin et al. (2007) to analyse the complementarity hypothesis among human capital, new technologies and new work organisational practices.

Since the complementarity test uses the coefficients of each system on firm productivity, we need unbiased and consistent estimators. For this reason, we use the two-stage estimator proposed by Black and Lynch (2001), and we regress the TFP respect of each production system.

We can model the expression of the PTF as:

$$\overline{a}_i = \beta_0 + Z_i + \sum_{j=1}^{J} \beta_j X_j + + \varepsilon_i$$

where ($\overline{a}$) is the average TFP for the period 2003-2005, (*Z*) is a set of different production systems, and (*X*) is a set of control variables.

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[77] There is another approach, the correlation approach, which tests conditional correlation base on the residual of reduced form regressions of the practices of interest on all observable exogenous variables. Unfortunately, this test could be affected by omitted variables and measurement errors.

[78] Milgrom and Roberts (1990) argue that to be successful, firms typically need to adopt ICT as part of a system or cluster of mutually reinforcing organisational approaches.

[79] In the case that optimal combination includes higher level of all three factors the compementarity hypothesis holds.

To classify our firms into each system, we take into account its relative position with respect to each factor. In order to do this, we consider two possible cases for each factor. For example, in the case of human capital, a firm is classified as an adopter firm if the percentage of graduate production workers is higher than the industry average, or not an adopted firm if the percentage is lower than the industry average. In the case of new technologies and new work organisational practices, a firm is considered as adopted if it belongs to the advanced level (see IIIC), and not an adopted firm in the other case.

We define a system as s(x,y,z) where x is the human capital dimension, y is the technology dimension, and z is the organisational dimension. Since we have three factors, we can identify eight different systems:

Z= { s(1,1,1), s(1,1,0), s(1,0,1), s(0,1,1), s(0,0,0), s(0,1,0), s(1,0,0), s(0,0,0) }

where Z represents the set of all possible systems, and x, y and z each take a value of 1 if a firm adopts this factor, and 0 if it does not. For example, s(1,1,1) is the production system that uses a high level of human capital, high levels of new technologies and a high level of new work organisational practices.

To estimate the effects of each system on firm productivity we use different binary variables. Note that the adoption of a particular system also implies that a firm does not adopt another system. Next, we test the complementarity effects using the method proposed by Lokshin et al. and based on the Supermodularity theory. Following this theory, these factors are complements if this condition is satisfied

$$f(1,1,z) - f(0,1,z) \geq f(1,0,z) - f(0,0,z) \qquad z = 0,1$$

In our case, f represents firm productivity, and the existence of complementarities among these factors implies that the adoption of one factor produced more returns when the firm also used the other two factors. Next, we have to analyse the following multiple-restriction test:

$$\begin{cases} \beta(1,1,0) + \beta(0,0,0) - \beta(1,0,0) - \beta(0,1,0) \geq 0 \\ \beta(1,1,1) + \beta(0,0,1) - \beta(1,0,1) - \beta(0,1,1) \geq 0 \end{cases}$$

The complementarity effects estimation

Table 8 shows the effects of the production system on Catalan manufacturing firms PTF. In column 1, we present the estimation results without controlling the possible effects of endogeneity, while in column 2 we show the results using the Levinshon Petrin method that allows us control of these problems.

The coefficient values are higher when we control the endogeneity problem, as well as in this case the goodness of fit is higher. The second column corroborates the results obtained when we analyse the determinants of firm productivity in the above section. In this sense, the firms that invest in human capital s(1,0,0) or in new technologies s(0,1,0) are more productive than those firms that do not invest in any of these factors s(0,0,0) or only invest in new work organisational practices s(0,0,1). However, the highest productivity level is obtained when the firm combines these factors and uses them as an integrate system. For example, those firms who implement together high levels of human capital, new technologies, and use new work organisational practices s(1,1,1) are 54% more productive than those firms that not invest in any of these inputs s(0,0,0), and 20% more productive than firms that only invest in human capital and new technologies s(1,1,0) .

Thus, although the results seem to support the hypothesis that those firms who opted for an integrate production system, based on workforce knowledge, advanced technologies, and more participatory work practices obtain higher productivity levels, we cannot identify if these productivity gains are because of individual effects (direct effects) or because of the existence of synergies between them that allow a firm to improve the productivity of the others factors beyond the direct effects (indirect effects). To identify if the combination of these three elements provides higher levels of productivity due to the indirect effects, we use the complementary test proposed by Lokshin et al. (2007). The results are clear and the complementarity hypothesis is satisfied independently of the estimation method. That is, firms that have a higher skilled workforce are more productive for two reasons. The first reason is that the direct effects of workers' qualifications on firm productivity, since they can do their tasks more quickly and with fewer mistakes improving their own productivity and in turn, the firm's productivity. The second reason is that the indirect effects of workers' qualification. In this sense, skilled workers can improve the productivity of new technologies and take advantage of the new work organisational practices that give more discretion to the worker. That is because they are more capable and efficient using these technologies and taking on more responsibilities.

The same thing happens with investment in new technologies, it produces both effects –direct and indirect- on firm productivity. In contrast those firms that decide to implement new work organisational practices do not improve their productivity unless they also invest in human capital and new technologies. That means that work practices have only an indirect effect on firm productivity. This result can be explained under the assumption that new forms of work organisational practices make the production process more flexible, since they give to the employee great autonomy and responsibilities. In this context, the firm improves its productivity by the reduction of the time and cost of task organization, but that happens only when firm has qualified workers that can take over this responsibility in an efficient way. At the same time, new organisational practices facilitate the diversification of the production by reducing the time it takes to change from one product to another (organisational time), but it is not enough to improve its efficiency. The firm needs to reduce production time if it wants to improve its productivity, for this reason a firm also needs to invest in new machines based on information and communication technologies in order to reduce the time of production, inspection and alignment between different batches of products.

In conclusion, the results show that only those firms that combine high levels of human capital and advanced technologies can improve productivity, but the highest efficiency is obtained only when the firm decides also to implement new work organisational practices. The last question that we have to answer is if any bundle of work organisational practices has the same effects on human capital and new technologies productivity for SME Catalan manufacturing firms. We analyse this issue in the next section.

The estimation of complementarity effects for different bundles of work organisational practises

From the principal component analysis, we identified three bundles of work organisational practices. In this sense, we can observe a set of firms that decide to use those practices more related to a quality production process (first factor). There are another set of firms that prefer to use work teams practices (second factor), and the last set is composed by those firms that use more job rotation practices (third factor). The aim of this section is to analyse if any bundle of work organisational practices can improve the productivity of human capital or new technologies. In other words, we want to analyse the complementarity effects between skills, technologies, and work practices, taking into account the different types of work practices[80].

We estimate three different models. The first one analyses the complementarity effects between human capital, new technologies and those practices more oriented toward a quality production process. In this case, to determine the level of work organisational development (z), we use the distribution of the first factor. Thus, if s(x,y,z) represents the production system for each firm, we consider that z takes value 1 when the firm is in the third quartile of factor 1, and zero in the other case. For example, the dummy s(1,1,1) takes value 1 for those firms where human capital endowments are higher than the industry mean (x=1). In the same way, we use advanced technologies (y=1) and advanced quality oriented work practices (z=1)[81].

[80] Arvanitis (2005) uses a similar test, but he considers different types of information and communication technologies (internet and intranet) and human capital and team works. Another difference is that he uses a paid wise test. He only analyses the complementarity effects considering only two elements in each test.

[81] Table 9 shows a firm’s distribution by each production system.

The second model analyses the complementarity among skills, new technologies, and those organisational practices more oriented toward works teams. Hence, z takes value 1 when the firm is in the third quartile of factor 2, and zero in other cases. The last model refers to the complementarity effects between skills, new technologies, and those practices more related to job rotation. In this case z takes value 1 when the firm is in the third quartile of factor 3, and zero in other cases.

The results are shown in table 10. Since the OLS estimation method presents an endogeneity problem, we focus on the coefficients obtained using Levishon and Petrin method.

In the first place, we observe that, independently of the type of work organisational practice that a firm uses, the investment in human capital or new technologies has positive and significant effects on firm productivity in the case of Catalan manufacturing firms. Therefore, those firms that have a percentage of graduate operators that are higher than the industry mean, and have low levels of new technologies or work organisational development s(1,0,0), are between 13% and 19% more productive than those firms with low levels of endowment in all of these three production factors s(0,0,0). Those firms that decide to invest only in new technologies and use more than four new technological elements s(0,1,0) are between 19% and 25% more productive than the reference case s(0,0,0).

In respect to the complementarity effects, we observe that only those practices that relate more to quality process improve the productivity effects on a combination of human capital and new technologies (model 1). In others cases, the results shows that if the firm wants to improve human capital and new technology productivity, it could be more suitable not to use those practices related to work teams or job rotation (models 2 and 3). In this sense, the combination of a high level of human capital, new technologies, and quality production process practices are related in that they improve approximately 50% of a firm’s productivity. The complementarity test confirms that this improvement is caused partly by the direct effects, and partly by the synergies exiting between these three dimensions (indirect effects).

With respect to those practices more related to work teams we observe that the decision to invest only in these practices and not in others production factors s(0,0,1) produce negative and low significant effects on firm productivity. But these results are not surprising, since the use of work teams exists to give more responsibilities and discretion to team members. For this reason, it is more necessary to use a high quality skill force that can deal with these challenges. This is not, however, enough to obtain productivity gains, since these practices are not easy to implement because workers need a certain period of time to adapt and feel confident with other team members. The distribution of roles and responsibilities among team members, as well as the need to coordinate different task, could produce negative effects on work team performance if this distribution and coordination is wrong. This and the fact that a work team is a new practice for the Catalan firms could explain why the use of this practice has a negative effect on human capital and new technologies productivity (model 2).

Finally, from model 3 we observe that the implementation of job rotation practices neither have effects on firm productivity s(0,0,1), nor improve the productivity of human capital or new technologies s(1,1,1). A possible explanation is that the use of advanced technologies requires that workers take time to learn about how to use it in an efficient way. In this sense, the decision to use the job rotation system can produce negative effects on human capital and new technology productivity in a short period of time. This is because workers are moved to another job place making it necessary for these workers to have to learn how to do new tasks and how to use the new technologies associated with this new place. In this sense, these workers were productive in the old job, but now they need time to become productive in the new one. For these reasons, it is not difficult to understand that the firm productivity could be lower in the early stages the implementation of these work practices.

In conclusion, the results show that only those work organisational practices that are more oriented to the process of quality production improve the productivity of human capital and new technologies. In contrast, work teams and job rotation practices have a negative effect on the productivity of the above-mentioned production factors. However, logical thinking makes us believe that these negative effects are produced partly because new work organisational practices for the Catalan manufacturing firms have only been implemented recently. Therefore, it will be interesting to analyse how the effects of these practices on firm productivity change over time.

7. Conclusions

In the past years, some authors have tried to analyse why US firms are more productive than European firms. The first evidence shows the importance of new technology as a determinant of firm performance. Afterwards, some authors started to analyse the effects of human capital, and more recently some research papers tries to look for a relationship between work organisational practices and firm productivity. But as Milgrom and Roberts (1990) said, it is necessary to analyse these elements as a integrate system in the firm production process, taking into account the complementarity effect among these issues. Unfortunately, it is very difficult to find information at employer-employee level which contains data about human capital, new technologies, new work organisational practices, and firm performance. For this reason, there is little evidence that analyses the synergies existing among these production factors and its effects on firm productivity.

In this paper we use a unique employer-employee data set of SME firms in Catalonia (PIMEC-URV Survey 2006-2007) to shed light on the effects of human capital, new technologies (considering AMT) and new work organisational practices on firm productivity, taking into account the synergies existing among these issues. Additionally, we identify different bundles of work organisational practices with the aim to analyse what is the combination that maximizes the impact of human capital and new technologies.

The results confirm positive and significant direct effects of human capital and AMT on productivity, after control for others firms' characteristics. In contrast, we cannot observe any significant direct effect of new work organisational practices, except in the case of those bundles of practices more related to self-direct teams, which take a negative value, but at a low significant level. If we only take into account direct effects, our conclusion will be that new organisational practices have a negative, if any, effects on firm performance, and it will be better for the Catalan firms to use the most traditional work organisational practices such as in a mass production context. But this is not technically true, since we need to analyse the indirect effects of those practices.

The complementarity test points out that the synergies among these factors are a true fact, but they depend on what type of bundles of work organisational practices are considered in the analysis. In the case of Catalan SMEs, there exists a set of practices that, although they do not produce any direct effect on firm productivity, improve the human capital and AMT productivity. This set of practices includes those practices more oriented to quality production process, such as quality circles, TQM and problem solving groups. In contrast, those practices more oriented to work teams and job rotation produce negative effects on human capital and new technology productivity.

A possible argument that justifies the negative effects of work teams and job rotation is that these practices are more difficult to implement than quality circles or problem-solving groups. For this reason, firms needs more time to witness any benefit from it. In this sense, it will be interesting to observe the evolution of the effects of these practices on firm productivity, but to do this we need a series of data over a long period of time that is difficult to obtain today.

In conclusion, the results show that those firms that invest and innovate in all dimensions of the production process obtain great levels of productivity. Unfortunately, in Catalan manufacturing firms, there is more tradition and routine than innovation[82]. This explains the low growth of firm productivity in the last years, far below that of the mean productivity growth for the European Union. The question is why some firms try to adapt to environmental change and invest in human capital, new technologies, and new work organisational practices, while others do not?. As García and Huerta (2004) point out as a possible explanation is financial constraints, the worsening corporate government, and the lower management capacity in the SMEs Spanish firms. If these factors are really the problem, the challenge is to design and promote actions and public policies that allow SMEs easy financial access and consulting services to improve the managerial capabilities.

[82] Huerta et al. (2003) analyses the diffusion of new technologies and new human resource practices in the Spanish firms and he arrives to the same conclusion.

Finally, these findings need to be interpreted with caution because, since the data collected is cross-sectional, we cannot test the causal-effect of these factors on firm productivity, but only the correlation relationships.

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Appendix

Table 1: Firm distribution by sectors

Sector	CNAE Code	% Firms
Food and Beverages	15	16.07
Office, accounting and computing machinery	31-33	13.84
Rubber and plastics	25	8.93
Fabricated metal products, except machinery	28	29.91
Machinery and Equipment	29	24.55
Furniture	36	6.7

Table 2: Survey distribution by occupational group

Occupational groups	Total workers	Workers respondents	% responders
Managers	696	323	46.4%
Supervisors	688	346	50.3%
Operators	2820	1780	63.1%
Others workers	3362	-----	
Total	7566	2449	
Total firms	224	224	

Table 3: Principal Component Analysis (results using polychoricas correlations).

	Factor 1 (process quality)	Factor 2 (work teams)	Factor 3 (job rotation)
Employee suggestion systems	**0.3127**	0.0055	-0.2400
Information sharing manager-employees	**0.1642**	0.1121	-0.0982
Job Rotation	0.1291	-0.2296	**0.5044**
Job Redesign	0.2938	0.213	**0.4432**
Problem solving group	**0.3300**	-0.0019	-0.0886
Self-directed work group/team	0.2741	**0.7293**	0.1466
Quality circle	**0.3467**	-0.2255	-0.1093
Total Quality Management	**0.4650**	-0.4950	-0.1176
KMO	0.7664		

Nota:KMO, Kaiser, Meyer and Olkin test to assess the appropriateness of using factor analysis on data. It takes value 0 to 1. A KMO higher than 0.5 indicates the correlation matrix is suitable for factor analysis. We retain only those factors with eigenvalues upper 1, three factors, which account for 73% of the variation.

Work organisational practices description

Employee suggestion systems

Is a systems to solicit and utilize input form the firm employees in order to archive cost saving, improve product quality, workplace efficiency, customer service, or working conditions. One mechanism consists in placing suggestion boxes in common areas or implementing formal programs with committees to review ideas and propose new ones.

Information sharing manager-employees

It is refers to vertical communication which occurs up and down the organisational structure. Information sharing manager-employees should incorporate both upward communication from the employees to the management and downward communication from the management to the workforce.

Job Rotation

It is a way of extending or enlarging the tasks carried out by employees. Employees are moved from one job to another in a planner manner. Job rotation can often lead to increased job satisfaction and worker skills because expose the employee to different experiences and different tasks.

Job Redesign

Consist in redesign the parameters of an existing job to incorporate additional or different required tasks. Job redesign allows enlarging and enriching jobs that increase employee satisfaction and motivation.

Problem solving groups

It is a group of workers from the same area that meet regularly in order to identify and suggest solutions to different problems that appear. Basically, this group is responsible to identify and clarify the problem, generate potential solutions, evaluate potential solutions, select a solution, implement it and evaluate the outcomes.

Self-directed work group/team

It can be likened to a cell-structure form of production, where the employees themselves decide how the work will be allocated, in what order, what the overall objective are, recruit and hire they members and decide about remuneration.

Quality circle

It is a discussion group which meets on a regular basis to identify quality problems, investigate solutions and make recommendations as to the most suitable solution. The members are employees with specific skills or expertise.

Total quality management (TQM)

It is a set of management practices focused on process measurement and controls as means of continuous quality improvements. Total quality management takes into account all quality measures taken at all levels on involving all firm employees.

Table 4: Descriptive statistics

Variables	*Mean*	*Estand. Desv.*
% graduate workers	0.090	0.167
Automatic sensors used on inputs and outputs	0.182	0.387
Automatic storage	0.227	0.420
Flexible manufacturing systems	0.400	0.491
Computer vision machines	0.102	0.304
Automatic quality control systems	0.213	0.411
CAD-controlled machine	0.276	0.448
Factory network	0.653	0.477
Computer-aided design (CAD)	0.418	0.494
Total new technologies number	2.471	1.742
Employee suggestion systems	0.427	0.496
Information sharing manager-employees	0.689	0.464
Job Rotation	0.516	0.501
Job Redesign	0.373	0.485
Problem solving group	0.329	0.471
Self-directed work group/team	0.253	0.436
Quality circle	0.391	0.489
Total Quality Management	0.209	0.407
Total work organisational practices number	3.187	2.153
Age	29.133	24.700
Exporter firms	0.640	0.481
% external sales	0.147	0.195
% managers	0.135	0.121
% supervisor	0.111	0.082
% operators	0.416	0.228
Operators experience (age mean in the same job)	9.122	5.853
Firms with foreign capital	0.044	0.207
Firm part of a business group	0.107	0.309
Micro firms (less 10 workers)	0.094	0.292
Small firms (10 -49 workers)	0.710	0.455
Medium firms (50-249 workers)	0.196	0.398
Total observations	**224**	

Table 5: Determinants TFP mean to the period 2003-2005. (OLS method)

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
HK	0.310*	0.165							0.307*	0.165	0.295*	0.159
AMT												
medium			-0.003	0.056					0.001	0.057	0.010	0.057
high			0.117*	0.066					0.139*	0.071	0.134*	0.073
WO												
medium					-0.026	0.052			-0.050	0.054		
high					-0.036	0.072			-0.085	0.077		
WO quality												
medium							-0.030	0.063			-0.052	0.065
high							-0.016	0.060			-0.058	0.066
WO team												
medium							-0.009	0.066			0.002	0.066
high							-0.093	0.080			-0.080	0.079
WO rotation												
medium							0.018	0.061			0.004	0.059
high							-0.052	0.065			-0.050	0.064
Age	0.005*	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.005**	0.003	0.006**	0.003
Age2	-2.63E-05**	1.31-05	-1.64E-05	1.26E-05	-1.68E-05	1.26E-05	-1.9E-05	1.26E-05	-2.95E-05**	1.39E-05	3.08E-05**	1.39E-05
Exporter	-0.027	0.070	-0.029	0.070	-0.019	0.071	-0.013	0.069	-0.039	0.070	-0.037	0.069
% exports	0.214	0.198	0.215	0.203	0.226	0.200	0.190	0.193	0.196	0.205	0.170	0.199
Worker experience	0.008	0.005	0.006	0.005	0.007	0.005	0.007	0.005	0.007	0.005	0.007	0.005
Family	0.088	0.145	0.122	0.133	0.109	0.141	0.077	0.151	0.080	0.141	0.054	0.149
Group	0.068	0.087	0.061	0.082	0.074	0.084	0.087	0.100	0.068	0.084	0.083	0.099
Size												
small	0.281***	0.105	0.252**	0.102	0.267***	0.100	0.284***	0.106	0.273**	0.107	0.289**	0.112
medium	0.191	0.144	0.147	0.146	0.183	0.139	0.223	0.144	0.176	0.146	0.212	0.153
N	224		224		224		224		224		224	
Rsquare	0.3361		0.3391		0.3265		0.3401		0.354		0.365	

Note: Robust OLS estimation. Industrial and regional controls are included in all estimations. ***, **, * represents statistical signification al 1%, 5% and 10% respectively.

Table 6: Determinants TFP mean to the period 2003-2005. (LP method)

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
HK	0.443**	0.197							0.417**	0.186	0.412**	0.188
AMT												
medium			0.037	0.060					0.043	0.061	0.040	0.062
high			0.224***	0.068					0.241***	0.075	0.223***	0.075
WO												
medium					-0.041	0.057			-0.084	0.058		
high					0.042	0.075			-0.037	0.076		
WO quality												
medium							-0.009	0.065			-0.049	0.067
high							0.040	0.063			-0.029	0.067
WO team												
medium							-0.069	0.071			-0.054	0.069
high							-0.158**	0.077			-0.138*	0.074
WO rotation												
medium							-0.005	0.069			-0.025	0.065
high							-0.049	0.065			-0.047	0.062
Age	0.005*	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.005*	0.003	0.006**	0.003
Age2	-3.39E-05**	1.37E-05	-1.85E-05	1.34E-05	-1.79E-05	1.31E-05	-2.02E-05	1.34E-05	-3.43E-05**	1.41E-05	-3.6E-05**	0.000
Exporter	0.042	0.072	0.036	0.073	0.054	0.074	0.067	0.073	0.023	0.073	0.031	0.072
% exports	0.361*	0.204	0.348*	0.209	0.383*	0.208	0.338*	0.201	0.330	0.210	0.301	0.203
Worker experience	0.016***	0.005	0.013***	0.005	0.014***	0.005	0.014***	0.005	0.014***	0.005	0.014***	0.005
Family	0.061	0.154	0.112	0.137	0.115	0.141	0.055	0.153	0.077	0.143	0.025	0.152
Group	0.139	0.094	0.122	0.089	0.145	0.090	0.181*	0.104	0.133	0.090	0.172*	0.102
Size												
small	0.375***	0.109	0.316***	0.102	0.354***	0.106	0.359***	0.107	0.346***	0.108	0.356***	0.110
medium	0.633***	0.135	0.547***	0.132	0.609***	0.130	0.633***	0.131	0.580***	0.135	0.604***	0.138
N	224		224		224		224		224		224	
Rsquare	0.4541		0.463		0.4416		0.4553		0.488		0.496	

Note: Robust OLS estimation. Industrial and regional controls are included in all estimations. ***, **, * represents statistical signification al 1%, 5% and 10% respectively.

Table 7: Firm distribution by productive systems

Productive systems	% Firms
S111 Production systems intensive in human capital, new process technologies and new work organisational practices	1.79%
S110 Production systems intensive in human capital and new process technologies	5.36%
S101 Production systems intensive in human capital and new work organisational practices	2.68%
S011 Production systems intensive in new process technologies and new work organisational practices	6.25%
S001 Production systems intensive in work organisational practices	6.70%
S010 Production systems intensive in new process technologies	10.71%
S100 Production systems intensive in human capital	20.98%
S000 Traditional production systems (low levels of human capital, new process technologies and new work organisational practices)	45.54%

Table 8: Effects of each production system on TFP median to the period 2003-2005

	Model (OLS)		Model (LP)	
	Coef.	Std. Err.	Coef.	Std. Err.
S111	0.289	0.214	0.536***	0.142
S110	0.232*	0.135	0.335***	0.123
S101	0.091	0.114	0.267	0.173
S011	-0.019	0.094	0.171	0.112
S001	0.028	0.134	0.004	0.107
S010	0.200***	0.071	0.226***	0.081
S100	0.111	0.071	0.162**	0.077
N	224		224	
R squared	0.363		0.493	
Complementarity test	Satisfied		Satisfied	

Note: Age, age squared, external market competition, belong a group, family firm, worker experience, size, occupational structure, industrial and regional controls variables are included in all estimations. ***, **, * represents statistical signification al 1%, 5%

Table 9: Firm distribution by each production system and each bundle of practices.

	Organisational practices oriented to quality production process (factor1)	Organisational practices oriented to work teams (factor2)	Organisational practices oriented to job rotation (factor3)
Production systems	% Firms	% Firms	% Firms
S111	3.13%	2.23%	1.79%
S110	4.02%	4.91%	5.36%
S101	4.02%	4.46%	9.38%
S011	10.71%	4.02%	5.80%
S001	12.95%	15.63%	16.96%
S010	6.25%	12.95%	11.16%
S100	19.64%	19.20%	14.29%
S000	39.29%	36.61%	35.27%

Note: s(x,y,z) where x is the human capital dimension, y is the technology dimension, and z is the organisational dimension. In column 1 z represents those practices more related to quality production process, in column 2 z represents those practices more related to work teams, and in column 3 z represents those practices more related to job rotation.

Table 10: Effects of each production system on TFP median to the period 2003-2005 (by bundles of work organisational practices)

OLS

	Model1 (quality process)[a]		Model 2 (work teams)[b]		Model 3 (job rotation)[c]	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
S111	0.320**	0.151	0.258	0.190	-0.218	0.165
S110	0.164	0.164	0.210	0.153	0.442***	0.119
S101	0.111	0.101	0.108	0.111	0.073	0.076
S011	0.042	0.077	-0.016	0.144	0.023	0.090
S001	-0.046	0.090	-0.127*	0.076	0.064	0.071
S010	0.191**	0.087	0.124*	0.068	0.222***	0.080
S100	0.098	0.072	0.068	0.072	0.143	0.089
N	224		224		224	
R square	0.3714		0.3752		0.4044	
Complementarity Test	Satisfied		Not satisfied		Not satisfied	

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	Model1 (quality process)[a]		Model 2 (work teams)[b]		Model 3 (job rotation)[c]	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
S111	0.533***	0.126	0.257*	0.156	-0.064	0.165
S110	0.233	0.142	0.393***	0.143	0.540***	0.102
S101	0.290**	0.137	0.127	0.129	0.170*	0.096
S011	0.152*	0.089	0.022	0.153	0.136	0.106
S001	-0.072	0.081	-0.119*	0.070	0.058	0.071
S010	0.222**	0.090	0.197**	0.078	0.252***	0.088
S100	0.133*	0.077	0.155*	0.079	0.191**	0.093
N	224		224		224	
R square	0.512		0.503		0,520	
Complementarity Test	Satisfied		Not satisfied			Not satisfied

Note: Age, age squared, external market competition, belong a group, family firm, worker experience, size, occupational structure, industrial and regional controls variables are included in all estimations. ***, **, * represents statistical signification al 1%, 5% and 10% respectively. a) work teams and job rotation factors are included as control variables, b) quality production process and job rotation factors are included as control variables, c) quality production process and work teams factors are included as control variables.

IV. THIRD ESSAY

STAFFING STRATEGIES IN SMEs: DETERMINANTS OF EXTERNAL RECRUITMENT AND INTERNAL PROMOTION

STAFFING STRATEGIES IN SMEs: DETERMINANTS OF EXTERNAL RECRUITMENT AND INTERNAL PROMOTION

Abstract

The purpose of this paper is to examine the determinants of SMEs' use of the internal or external labour markets to fill firm vacancies for different blue and white collar jobs. We use different theories to identify three main reasons why internal candidates might be chosen over external candidates, these being firm-specific knowledge, adverse selection problems and motivation. However, these theories fail to address others factors that might affect this choice. In this paper we try to shed some light on these other factors that may affect a firm's decision to use the internal or external labour market. In particular, we analyse how the relationship between new technologies, innovation activity and firm location affects staffing strategies. The results show that manufacturing and service firms differ in their use of internal or external labour markets to fill a vacancy, and that their decisions depend not only on internal firm characteristics, such as technological complexity or innovation activity, but also on firm location. The results also support the hypothesis of entry ports, especially in the manufacturing sector.

1. Introduction

How to fill a vacancy is an important managerial decision that affects both the future performance of the firm and the individual's career advancement. When a job opening appears, the employer can either internally promote a current employee into the job or hire a new worker from the external labour market. This is an excellent time for firms to ensure that they are recruiting for the skills they need. Initially, simple market reasoning might suggest that external recruitment would be more efficient because the wider pool of potential candidates increases the probability of finding the correct worker. There is, however, consistent evidence that internal promotion is a widespread practice.

Several theoretical explanations have been developed to explain why firms promote from among incumbent workers rather than recruit externally when filling higher positions. Perhaps the most often cited reason is the importance of specific human capital (Becker, 1964; Gibbons and Waldman, 1999). When part of the human capital needed to perform in the workplace can only be developed inside the firm, both the employer and the employee have incentives to maintain a long-term relationship. From the point of view of the worker, problems of appropriation mean that they must have a signal that their investment in developing those skills will pay off. Employers enforcing promotion rules would provide such a credible signal (Carmichael, 1983; Prendergast, 1993). From the point of view of the employers, if firm-specific human capital is important, it may be very difficult (especially for the higher ranks of the hierarchy where the accumulated level is very high) to find an external candidate who can outperform an existing worker or who would otherwise be very expensive if training has to be provided. The second theoretical explanation put forward is related to learning models (Farber and Gibbons, 1996). The basic idea is that the abilities, motivation and performance of existing workers can be gauged with more precision than those of external candidates. Because of adverse selection problems (Greenwald, 1979) risk-averse employers may prefer to reduce uncertainty by promoting an adequate internal candidate. Finally, the third explanation is the tournament theory, which advances the idea that the decision to promote internally is a mechanism for providing incentives to work hard, particularly when the cost of monitoring workers' efforts is high (Lazear and Rosen, 1981; Chan, 1996). According to these theoretical explanations, employers prefer to recruit externally rather than promote an incumbent worker only when an external candidate shows a significant margin of superiority.

Unfortunately, as Bayo and Ortin (2006: 452) point out, these theoretical developments have not been matched by empirical work of a similar quality and quantity. Our paper expands the literature on the determinants of staffing strategies in two directions.

Our first contribution to the literature is that we carefully consider the relative opportunity costs of each practice. On one hand, internal promotion depends on matching the job requirements with those of incumbent workers; on the other hand, the firm's specific location will determine its likelihood of finding workers with the right skills outside the firm. The balance between the internal "strength" of the workforce and the availability of top quality candidates in the external labour market will set a relative price for each strategy. Furthermore, the location of the firm not only has an effect in terms of the number of potential candidates, but also on the information regarding the characteristics of all employees in that area. When the firm is located in a high-density market (measured by the number of competing or similar firms) there is more information regarding the fluidity and quality of workers' abilities, and this increases the expected payoff (and decreases the uncertainty) of poaching strategies. This can have a dual effect on the decision to recruit externally or promote an incumbent worker. First, having more information about external candidates reduces the uncertainty of the selection process, which in turn reduces adverse selection problems and increases the incentives to recruit externally. Second, greater flows of information increase the probability of other firms learning about the skills of the firm's workforce and thus increase the incentive to use promotion as a retention mechanism. In this regard, the literature on raiding has showed (Lezear, 1986; Bernhardt, 1995; Kim, 2007) that an employer may delay a worker's promotion depending on the extent to which their skills can be appropriated by other firms. Note, however, that this hypothesis heavily depends on the possibility of preventing competing firms from finding out the worker's real abilities until they have been promoted. If this information is made available before that happens, promotion may instead become a strategic move by the current employer in order to keep a valuable worker under contract.

Our second contribution to the literature is related to the discussion on whether firms use internal or external labour market strategies to deal with technical and organisational change (Behaghel et al. 2007 and 2011). It has been claimed that skilled biased technological and organisational change is transforming the workplace by moving it away from routine tasks and towards analytical and interactive tasks, thus changing the skills that workers need to perform efficiently (Caroli and Van Reenen, 2001; Spitz-Oener, 2006). Firms may react to this trend by dismissing workers with "old" skills and incorporating new workers with the right set of new skills (Bauer and Bender, 2004). Alternatively, they can rely on their internal labour markets and invest in training to update their workers' skills (Behaghel and Greenan, 2005). In terms of the impact on the likelihood that a firm will use external or internal candidates to fill a vacancy, it is easy to see that the external strategy would be negatively correlated with promoting people, whereas the opposite would be the case when firms try to protect their investment in training.

In order to test the impact of firms' technological developments and firm location on the likelihood that they will promote their own workers, we use a unique data set on Catalan manufacturing and service industry SMEs. This data set is interesting for several reasons. It covers the whole range of manufacturing and service industries in the economy, allowing for more general comments than when specific sector or even firm data is used. In addition, it fills a gap in the existing literature because most of the empirical evidence available is about large firms. SMEs are supposed to behave differently from large firms in terms of promotion decisions for several reasons. On the one hand, developing internal labour markets is less costly in large firms, and on the other hand, there is literature showing that workers in large firms have lower job satisfaction than in small firms because of differences in their work environment (for instance lower levels of autonomy and participation). To try and compensate for poorer working conditions, employers in large firms, among other things, offer better chances for promotion (Idson, 1990; Idson and Oi, 1999 and García, 2008).

Our results show that for manufacturing firms, new technologies have different effects on the decision to fill a vacancy depending on if this vacancy is for a blue or white collar position. For blue collar jobs the use of new technologies increases the likelihood that a firm will promote internally, especially if the firm is located in a high knowledge area, because it will want to protect its investment in training by retaining the worker. In contrast, for white collar jobs, highly technological firms are more likely to use external candidates to fill a vacancy, although this is not significant when we analyse this variable alongside the location variable. We also analyse the effect of innovation activity and show that it is positively related to the use of promotion as a mechanism to fill blue and white collar vacancies, although this relationship depends on firm location. If the firm is located in a high knowledge area it is less likely to use promotion to fill a blue collar job, and this could be because it is easier to find highly skilled workers in these areas and thus reduce adverse selection problems.

In the case of service firms, innovation activity and new technologies have a positive effect on the probability of it recruiting external workers for both blue and white collar jobs, although in the case of blue collar workers this only happens if those firms are located in low knowledge areas. If a highly technological and innovative firm is situated in a low knowledge area, it is less likely that other less technological and innovative firms will be able to steal its workers. If this is not the case, and services firms are located in high knowledge areas, they need to protect their investment in training by using promotion on blue collar jobs. On the other hand, for white collar workers, highly technological and innovative firms are more likely to use external candidates if the firm is located in a high knowledge area. Hence, highly technological and innovative firms situated in high knowledge areas use a vacancy on white collar jobs to acquire new thinking, skills and knowledge by hiring external workers.

Another important result is the positive relationship between leader quality and the use of the external labour market to fill a vacancy. Those firms with highly qualified managers tend to fill new job vacancies with external candidates. Finally, our results support the hypothesis of ports of entry whereby firm-specific knowledge or human capital is more important for top level jobs.

The paper is organized as follows. The next section presents a detailed description of the variables used in the analysis. The third section provides a detailed description of the data set and the principal descriptive statistics. Section Four presents the methodology, Section Five the main results and Section Six presents the discussion and concluding remarks.

2. Constructing variables

Dependent variable

To analyse the determinants of staffing strategies, we build a dependent variable that takes the value 1 if firms promote their workers or 0 if firms decide to recruit an external worker to fill a vacancy. Since we consider that the determinants of whether a firm promotes or not are different for blue or white collar jobs, we differentiate between these two cases.

Opportunity cost - Quality of internal and external labour market and firm location

As stated above, the likelihood of a firm using internal promotion instead of external recruitment to fill a vacancy depends on its capacity to find a worker with the right skills inside or outside the firm. The quality of the internal labour market will determine whether it can find workers with the right skills inside the firm. In contrast, the specific location of the firm will determine the quality of the external labour market and thus the probability of finding suitable workers outside the firm.

We expect that those firms with high levels of internal skills prefer to fill a vacancy internally because they have more opportunities to find a suitable candidate in the internal labour market. Another reason is because skilled workers are better able to learn new skills and thus need less training to perform new tasks efficiently. In order to measure the *quality of the internal labour market,* we use the educational level of workers as a proxy of the firm's stock of human capital. In particular, our human capital variable is measured by the proportion of qualified workers in each occupational group. We also introduce to the regression the percentage of white and blue collar workers that have been in the firm for more than two years[83]. This is a proxy of worker expertise but it also allows us to control for temporary employees. As Burgess and Connell (2006)

[83] See Fibla and Mañe (2011) for a description of these variables.

point out, temporary employees tend to be excluded from training, career development and promotion, so we expect a positive relationship between the percentage of permanent employees and the probability of generating human capital within the firm (training).

The decision to use external candidates and not incumbent workers to fill a vacancy depends on a firm's ability or capacity to find the appropriately skilled candidates in the external labour market (recruitment cost). Although the importance of external labour market characteristics on the decision to use an external candidate to fill a vacancy is clear (Behaghel et al. 2008), there is no evidence regarding the effects of external labour market characteristics on firm decisions, except in Bayo and Ortin (2006)[84], who introduce an external labour market variable in the form of a dummy variable that indicates if there are other plants belonging to the same sector in the province. The assumption is that if the pool of external applicants increases with the number of firms in the same industry, then the recruitment cost is lower in those areas that have a higher number of firms in the same industry because it is easier to attract correct external workers. Unfortunately, their results do not show that the presence of similar firms has a statistically significant impact on promotion decisions. One reason will be because it is difficult to measure the size of the pool of external applicants using a dummy variable that only indicates if there are other similar firms near to the firm. To correct this we consider not only the number of firms in the same industry but also the skill levels of the external candidates, the density of the local labour market and worker mobility. Another explanation is related the territorial approach used to build this variable. Bayo and Ortin use the province level and this geographical area could be large and heterogeneous. For this reason, the territorial level that we use to build our labour market variables is the travel-to-work area.

Travel-to-work areas are commonly used in the industrial location literature in order to homogenize territorial units from different countries and because local

[84] In this regard Bayo and Ortin (2006) is the first study to provide empirical evidence on the main factors regarding the use of internal promotion instead of external recruitment. They analyse firms' promotion decisions for blue collar workers using Spanish manufacturing data for large firms.

data better illustrate location decisions (Arauzo, 2008). In the particular case of external labour, the market does not seem to be defined by administrative territorial units (states, provinces, countries or municipalities) but by functional territorial units like travel-to-work areas or metropolitan areas. The boundaries of the travel-to-work areas are made in accordance with economic data such as resident working population, total working population and commuting data from the place of residence to place of work. As Arauzo point out, these areas can be defined as local closed labour markets in which most people in the area live and work. Given this definition, it seems sensible to use travel-to-work areas to create our labour market variables[85].

We use different labour market variables. The first one represents the level of general knowledge in the external labour markets, and we use as a proxy the education level of the external candidates and also the percentage of workers in high knowledge sectors in logarithmic and differentiating among manufacture and services sectors. The second one represents the industry specific knowledge and we use as a proxy the log of the number of firms in the same industry. The third one is the log of the distance between the local labour market and the capital of the province measured by time spent; we use this variable as a proxy of the density of the local labour market. Finally, in order to control for worker mobility we introduce a dummy into the analysis that takes value 1 if there is a railway station in the area of the local labour market, and zero if not[86].

Technological development

As we have discussed above, the use of new technologies in the production process has a clear impact on the workers' skills and knowledge requirements. The new workforce needs different skills and knowledge to deal with technological change, which means that firms have to update the skills of their workforce. Firms have two ways of doing this: the first is to hire new workers

[85] In this paper we use the travel-to-work areas defined by Boix and Galletto (2006) and used by Arauzo (2008).

[86] See Annex 1 for a description of the external labour market variables.

with the new skills and knowledge that enable them to work efficiently with the new technologies; and the second is to train their existing workers and provide them with the new skills and knowledge. The second option may be positively correlated with the firm's promotion strategy given that it wishes to protect its training investment.

We use two different types of technological measure to analyse the effect of new technologies on a firm's likelihood of using the internal labour market rather than the external market to fill a vacancy. The first one measures the firm's level of technological complexity, and the second measures how important it is for the firm to have workers with information and communication technology skills.

To measure levels of *technological complexity* in the manufacturing sector we employ a similar measure to that used by Doms et al. (1997) and Gale et al. (2002). It consists of an additive index of the different advanced manufacturing technologies (AMT) that firms use in their production processes. In the survey we ask if the firm used any of nine different production technologies, which by their nature can complement each other, and be used in any manufacturing industry. These technologies include computer controlled machines, computer-aided design (CAD), automatic storage, flexible production systems, factory data networks, automated sensors used on inputs and final products, computer vision machines and automatic quality control systems. We built different dummy variables to indicate whether the firm's level of technological complexity was low or high. In the case of the service sector we used the proportion of workers using computerized equipment, in particular computers, as a proxy of the firm's level of technological complexity. We also built a dummy variable to indicate if the firm's technological level was low or high.

As a second technological measure we used a dummy variable that takes value 1 if the firm considers information and communication technology skills to be essential for business success. This measure allows us to analyse if those firms with worker profiles more oriented toward the new technologies prefer to use the internal or external labour market to fill new blue or white collar vacancies.

Firm control variables

We use different variables such as innovation activity as firm control variables. When firms have strong innovative cultures that improve when workers interact with the organization, the firms' dependence on their workers increases and this makes the worker more valuable to the firms; in other words, if the firms' specific knowledge becomes more important, then they are more likely to promote incumbent workers than to recruit external candidates. On the other hand, it is possible that these more innovative firms also need new thinking and new ideas to constantly be innovating. In this case hiring new workers from the external labour market could be a better option for incorporating such new thinking and ideas into the firm. To measure the *innovation activity* of the firm we build a variable that takes value 1 if the firm has introduced a new product or has made substantial improvements to an old product during the last two years, and 0 if not.

We also introduce *openness to the international markets* as a control variable. This is a dummy variable that takes value 1 if the percentage of sales in the international markets is bigger than the industry mean. We expect this variable to work like the innovative activity variable; that is, workers from exporting firms could accumulate more specific knowledge that makes them more valuable to these firms, in which case, firms may prefer to use an incumbent worker to fill a vacancy due to the difficulty of finding the most suitable worker in the external labour market.

Other control variables are *size (small and medium)*, *belonging to a business group* and *age*. The effects of age on the decision to use internal or external labour markets are not clear. Although the literature indicates that old firms have better knowledge of their external labour market and should thus find it easier to find the right external candidate, the evidence shows that promotion is more common in older firms than in the new ones (Marchante, et al. 2006).

We also take into account the *competitive strategy* of the firm. We differentiate those firms who compete using an adjustment strategy from those firms who use another kind of strategy such as price or quality. The idea is that those firms who adopt a customization (adjustment) strategy need to adapt faster to market changes and customer requests. If this is the case, these firms' specific knowledge could be more important and the incumbent worker more valuable. On the other hand, since these changes imply a change in the production processes and techniques, it may be possible that firms decide to externally recruit workers who possess the new skills and knowledge that allow them to work efficiently with the new production processes and techniques.

If we follow the internal labour market theory, another important issue that we have to take into account is the existence of entry ports (Doering and Piore, 1971; and Lazear and Oyer, 2004). This theory is based on the hypothesis that firms have limited entry points, with the main entry point situated on the bottom rung of the job ladder; however, since this hypothesis is satisfied and we are not controlling for it, our results will be biased. To avoid this effect we introduce a dummy variable to the analyses that reflects to which occupational groups vacancies are made available. In this regard, we expect that firms will be more likely to use the external labour market to fill a bottom-of-the-ladder job vacancy such as that of unskilled production worker in the blue collar group or administrative worker in the white collar group.

Finally, firms may use the same strategy to fill a vacancy in both the white and blue collar groups; therefore, we introduce a dummy variable to the analysis that takes value 1 if the firm use promotion in the other occupational groups.

3. Database and statistical information

To build our dataset we merge two different sources. The first source is the Pimec-Sefes Survey 2001. This survey was designed to analyse the recruitment and promotion processes of firms. It provides rich information about these issues and about employee-employer characteristics such as the worker's educational level and the technological level, innovation activity, exports, and ownership of the firm etc. The data were collected by telephone on the basis of a sample that was stratified according to industry, firm size and region. The second source contains our territorial variables and is taken mainly from the database of Trullén and Boix (2005), the Catalan Statistical Institute (IDESCAT) and the Catalan Cartographical Institute. The final data set contains 728 services firms and 395 manufacturing firms. Table 1 shows the distribution according to size and sector.

Table 1: Sample distribution according to size and sector

	Manufacturing	Services
Microenterprise (5-9 employees)	97	186
Small firms (10-49 employees)	251	467
Medium firms (50-249 employees)	47	75
Total	395	728

We found that in 2001 about 39.6% of firm vacancies were filled by an incumbent worker. Table 2 shows the distribution according to sector and group. The data clearly show that in this sample internal promotion was used more in the manufacturing sector and for white collar jobs.

Table 2: Promotion decisions according to sector

	% firms using promotion	
	Manufacturing	Service
Vacancy for a white collar position	43.10	39.08
Vacancy for a blue collar position	41.33	37.76

Table 3a and 3b shows the means and standard deviations of the variables included in our analysis. Only 40% of the managers in the sample are qualified and the average percentage of qualified workers in other occupational groups is no higher except for administrative jobs. The average percentage of long-term employment contracts (two or more years) is higher for white collar workers. The percentage of low and medium technology firms is higher than the percentage of high technology ones; quality is the commonest strategy; only 31% of the firms export more than the industrial mean; and 58.5% of the firms have introduced some new product in the last two years. The firms' average size is 30 employees; the average age is 22; and only 20% are part of a group of firms.

The percentage of firms located in high educational areas is higher; and 76% of the firms are located in an area with railway station.

No clear profile can be seen when we compare the characteristics of those firms who promote internally with those who hire external workers. Even so, promoting firms tend to have lower qualified managers, although the percentage of workers with more than two years experiences is higher. The technological level is lower among promoting firms but the innovation activity is higher (although only for manufacturing firms). For services firms the relationship between promotion and innovation activity is not clear.

The same thing occurs with exporting activity; that is, the percentage of exporters is higher among promoting manufacturing firms. Finally, in the case of service firms we can see that those firms who hire external workers tend to be located in knowledge intensive areas where there is a high concentration of knowledge intensive manufacturing and services firms. In contrast, for manufacturing firms the relation between being located in high knowledge areas and hiring or promoting workers is not clear.

Table 3a: Descriptive Statistics

	Total sample		Manufacturing sector							
			Blue collar vacancy				White collar vacancy			
			Hire external worker		Promote internal worker		Hire external worker		Promote internal worker	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Qualif. manager	0.400	0.446	0.445	0.455	0.357	0.428	0.444	0.430	0.456	0.466
Qualif. professional	0.328	0.428	0.358	0.441	0.361	0.450	0.442	0.440	0.392	0.442
Qualif. clerk	0.719	0.397	0.707	0.408	0.631	0.443	0.694	0.388	0.743	0.399
Qualif. supervisor	0.401	0.428	0.368	0.397	0.426	0.417	0.405	0.409	0.459	0.434
Qualf. low skill worker	0.224	0.360	0.249	0.363	0.207	0.347	0.253	0.375	0.213	0.356
Qualf. operator	0.317	0.431	0.114	0.252	0.204	0.355	0.153	0.302	0.182	0.358
Experienced white collar	0.852	0.229	0.852	0.226	0.862	0.240	0.815	0.209	0.885	0.211
Experienced blue collar	0.703	0.307	0.688	0.273	0.760	0.277	0.701	0.304	0.754	0.264
Low technological level	0.359	0.480	0.394	0.490	0.413	0.494	0.313	0.466	0.326	0.471
Medium technological level	0.347	0.476	0.360	0.481	0.350	0.479	0.433	0.497	0.370	0.485
High technological level	0.294	0.456	0.246	0.432	0.238	0.427	0.254	0.437	0.304	0.463
Price strategy	0.167	0.374	0.202	0.402	0.217	0.414	0.127	0.334	0.239	0.429
Quality strategy	0.565	0.496	0.552	0.499	0.524	0.501	0.597	0.492	0.500	0.503
Innovation strategy	0.095	0.294	0.094	0.292	0.126	0.333	0.112	0.316	0.130	0.339
Adjustment strategy	0.172	0.377	0.153	0.361	0.133	0.341	0.164	0.372	0.130	0.339
Innovation activity	0.585	0.493	0.621	0.486	0.664	0.474	0.604	0.491	0.717	0.453
Manager promotion	0.014	0.119	0.010	0.099	0.028	0.165	0.007	0.086	0.054	0.228
Professional promotion	0.251	0.434	0.261	0.440	0.245	0.431	0.455	0.500	0.467	0.502
Clerical promotion	0.371	0.483	0.281	0.450	0.273	0.447	0.537	0.500	0.478	0.502

Supervisor promotion	0.403	0.491	0.325	0.470	0.490	0.502	0.291	0.456	0.370	0.485
Operator promotion	0.167	0.374	0.291	0.455	0.301	0.460	0.216	0.413	0.228	0.422
Low skill worker promotion	0.247	0.431	0.384	0.488	0.210	0.409	0.246	0.432	0.228	0.422
Firm size	30.50	93.34	29.798	58.102	28.608	54.719	39.463	83.493	29.315	37.825
Exporter firm	0.311	0.463	0.443	0.498	0.462	0.500	0.515	0.502	0.565	0.498
Group firms	0.204	0.403	0.138	0.346	0.168	0.375	0.142	0.350	0.228	0.422
Firm age	22.74	21.98	24.557	26.068	25.994	24.318	26.299	29.674	27.088	20.141
Firms in the same industry	7.321	1.918	6.968	2.083	6.584	1.875	7.090	1.998	7.044	2.037
Low educational level	0.224	0.417	0.246	0.432	0.252	0.436	0.201	0.403	0.217	0.415
Medium educational level	0.360	0.480	0.384	0.488	0.399	0.491	0.433	0.497	0.359	0.482
High educational level	0.417	0.493	0.369	0.484	0.350	0.479	0.366	0.483	0.424	0.497
Workers in high knowledge manufacturing	-5.771	1.233	-5.716	1.361	-5.700	1.352	-5.628	1.233	-5.648	1.297
Workers in medium knowledge manufacturing	-3.381	0.956	-3.207	0.875	-3.167	0.821	-3.152	0.823	-3.126	0.804
Workers in high knowledge services	-2.110	0.785	-2.207	0.775	-2.339	0.888	-2.160	0.759	-2.175	0.813
Capital distance	4.362	0.215	4.349	0.225	4.369	0.203	4.337	0.229	4.329	0.203
Railway station	0.761	0.426	0.729	0.446	0.706	0.457	0.784	0.413	0.761	0.429
Number of observations	1123		203		143		134		92	

Table 3b: Descriptive Statistics

	Service sector							
	Blue collar vacancy				White collar vacancy			
	Hire external worker		Promote internal worker		Hire external worker		Promote internal worker	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Qualif. manager	0.410	0.437	0.292	0.415	0.491	0.448	0.340	0.437
Qualif. professional	0.264	0.395	0.286	0.413	0.391	0.436	0.323	0.422
Qualif. clerk	0.722	0.397	0.706	0.399	0.760	0.363	0.743	0.375
Qualif. supervisor	0.382	0.430	0.466	0.436	0.422	0.452	0.421	0.447
Qualf. low skill worker	0.247	0.368	0.239	0.378	0.203	0.341	0.235	0.372
Qualf. operator	0.415	0.467	0.400	0.460	0.422	0.468	0.461	0.467
Experienced white collar	0.851	0.237	0.853	0.238	0.802	0.221	0.874	0.199
Experienced blue collar	0.686	0.295	0.732	0.291	0.643	0.352	0.744	0.295
Low technological level	0.389	0.488	0.407	0.492	0.235	0.425	0.286	0.453
Medium technological level	0.338	0.474	0.347	0.477	0.332	0.472	0.330	0.471
High technological level	0.273	0.446	0.245	0.431	0.433	0.496	0.384	0.488
Price strategy	0.151	0.358	0.139	0.347	0.138	0.346	0.130	0.337
Quality strategy	0.551	0.498	0.639	0.481	0.564	0.497	0.584	0.494
Innovation strategy	0.091	0.288	0.065	0.247	0.111	0.314	0.092	0.290
Adjustment strategy	0.207	0.406	0.157	0.365	0.187	0.390	0.195	0.397
Innovation activity	0.580	0.494	0.514	0.501	0.567	0.496	0.600	0.491
Manager promotion	0.014	0.119	0.005	0.068	0.024	0.154	0.011	0.104
Professional promotion	0.165	0.372	0.292	0.456	0.349	0.478	0.373	0.485
Clerical promotion	0.327	0.470	0.343	0.476	0.626	0.485	0.616	0.488

Supervisor promotion	0.503	0.501	0.644	0.480	0.346	0.477	0.459	0.500
Operator promotion	0.142	0.350	0.157	0.365	0.111	0.314	0.108	0.311
Low skill worker promotion	0.355	0.479	0.199	0.400	0.163	0.370	0.184	0.388
Firm size	27.605	41.516	34.731	17.047	36.675	85.957	38.184	18.530
Exporter firm	0.244	0.430	0.204	0.404	0.249	0.433	0.265	0.442
Group firms	0.230	0.422	0.185	0.389	0.266	0.443	0.259	0.440
Firm age	22.279	20.463	18.940	19.429	21.792	19.217	21.454	21.909
Firms in the same industry	7.466	1.718	7.296	1.743	7.807	1.802	7.536	1.792
Low educational level	0.224	0.418	0.236	0.426	0.176	0.382	0.227	0.420
Medium educational level	0.347	0.477	0.361	0.481	0.356	0.480	0.346	0.477
High educational level	0.429	0.496	0.403	0.492	0.467	0.500	0.427	0.496
Workers in high knowledge manufacturing	-5.800	1.135	-5.839	1.248	-5.840	1.123	-5.791	1.188
Workers in medium knowledge manufacturing	-3.554	0.997	-3.643	1.093	-3.379	0.943	-3.530	1.044
Workers in high knowledge services	-2.085	0.782	-2.100	0.753	-1.946	0.708	-2.072	0.798
Capital distance	4.383	0.212	4.393	0.217	4.336	0.215	4.369	0.218
Railway station	0.770	0.422	0.718	0.451	0.796	0.404	0.751	0.433
Number of observations	352		216		289		185	

4. Econometric model

The endogenous variable in our econometric model, y_i , is binary and takes the value 1 if the firm fills a vacancy using an incumbent worker and 0 if it hires an external candidate. We assume that this decision depends on the benefits or utility of each option (U), which at the same time depends on the characteristics of the firms and external labour market. In this case, if the benefit from promoting is higher than a determinate and unobservable value (U*) firms decide to promote, if not firms decide to hire an external worker. The decision rule could be represented as:

$$Y_i = 1 \quad \text{if} \quad Ui = \beta x_i > Ui^*$$
$$Y_i = 0 \quad \text{if} \quad Ui = \beta x_i \leq Ui^*$$

Since each firm has a different U* and we assume a normal distribution function for U*, we obtain a probit model:

$$P(U^* \leq k) = F(k)$$

Then

$$P(Y_i = 1 \mid x_i) = P(U^* \leq x_i \beta) = F(x_i \beta)$$

if $F(x_i \beta)$ is a normal distribution function then our econometric model will be:

$$Y_i = \Phi(x_i \beta) + u_i$$

Where β is a K-vector of parameters, x is a vector of explanatory variables and u~ N(0,1) is an error term. We estimate this model using maximum likelihood, which means that our estimation is consistent and efficient (Green, 2003)

In our dataset we have two types of firm: those firms who have created a new job in the last two years and those firms who have not created any new job. In the latter case we have no information about promotion decisions; therefore, we have a select sample because we only observe promotion decisions for those firms that have created a new job. We cannot observe the equation for the population as a whole[87]. Thus, if those firms who created a new job vacancy tend to promote more than those firms that do not create jobs, then problems will appear in the sample selection and the results will tend to be biased (Heckman, 1979). In order to solve the sample selection problems we used a Heckman probit model[88]. This is the equivalent of Heckman's selection model except in our case we have a probit model in the selection equation and a probit model in the outcome equation. The first probit model estimates whether the firms create a new job or not, and the second probit model is related to the decision on whether to use an incumbent worker to fill the new vacancy. In this case we have three types of observation in our sample with the following probabilities:

$$Y_1 = 0 \qquad P(Y_1 = 0 | x_1) = \Phi_1(-x_1\beta_1)$$
$$Y_1 = 1,\ Y_2 = 0 \qquad P(Y_1 = 1, Y_2 = 0 | x_1, x_2) = \Phi_1(x_1\beta_1) - \Phi_2(x_1\beta_1, x_2\beta_2, \rho)$$
$$Y_1 = 1,\ Y_2 = 1 \qquad P(Y_1 = 1, Y_2 = 1 | x_1, x_2) = \Phi_2(x_1\beta_1, x_2\beta_2, \rho)$$

From this, the log-likelihood function is:

$$\ln L = \sum \{Y_{i1}Y_{i2}\ln\Phi_2(x_1\beta_1, x_2\beta_2, \rho) + Y_{i1}(1 - Y_{i2})\ln[\Phi_1(x_1\beta_1) - \Phi_2(x_1\beta_1, x_2\beta_2, \rho)] + (1 - Y_{i1})\ln\Phi_1(-x_1\beta_1)\}$$

As with the Heckman model, our estimation includes at least one variable in the selection equation that does not appear in the outcome equation. The results are similar to those obtained with the probit model, and because the test of the independent equation has been rejected, then the correlation between both equations is very low. That means there is no relationship between firm job creation and likelihood of internal promotion. In other words, there are no sample selection problems, which in turn means that the use of the Heckman estimation is not necessary. We can estimate the promotion decision equation using the probit model and can obtain consistent results.

[87] A vacancy could rise for different reasons such as sacking, retirement or the creation of a new job. In our case a vacancy occurs because firms create a new job.

[88] See Van de Ven and Van Praag (1981) and Berinsky (2004) for a special application of Heckman's sample selection model when the second stage equation is also Probit.

5. Results

Table 4 reports the regression results of our analysis into how new technologies, internal labour market characteristics and firm location affect employer strategies when filling vacant positions in manufacturing and services firms. The first two models analyse the manufacturing firm's decision to promote or recruit external candidates and differentiates between blue and white collar jobs. The following two models focus on services firms.

As expected, the results for the blue collar group in the manufacturing sector (Model 1) show that the human capital level of blue collar workers has a positive effect on the decision to fill a vacancy using the internal labour market. The coefficient of the percentage of qualified operator workers is positive and significant, and the coefficient of experienced blue collar workers is also positive and significant when we control for external labour market characteristics.

One of the main results obtained in our analyses is the fact that firms with highly qualified top managers are more likely to fill a vacancy in the blue collar group using the external labour market. This means that when a vacancy rises, highly skilled managers take this as an opportunity to acquire new knowledge and new thinking from outsiders. This could be because higher skilled managers are better at carrying out the external recruitment process more efficiently, which in turn lowers the recruitment costs and encourages outsourcing. Another reason could be because these kinds of managers are better at using the new human resource practices (remuneration practices, training, etc.) to improve worker effort, motivation and satisfaction, which in turn decreases the need to use promotion as a motivation mechanism.

The technological complexity of firms, measured as the number of advanced technology manufactures, does not seem to have a significant effect on the decision to use internal or external candidates, although those firms who require production workers with ICT knowledge tend to use more incumbent workers to fill a vacancy. Since we consider that those manufacturing firms who require ICT knowledge have more technologically advanced production processes, the positive and significant coefficient of this variable could mean that those firms have more firm-specific knowledge and that the way it accumulates this knowledge is essentially through learning "on the job". Thus, incumbent workers are better candidates for filling a vacancy because they possess this firm-specific knowledge. The same thing occurs with innovation activity, the results confirm that those firms with a strong innovation culture tend to use promotion more than external recruitment, which means that firm-specific knowledge in the production area is more important than the new skills, knowledge or thinking that an external candidate would possess.

Other elements that can affect a firm's decision to use internal or external labour markets are its competitive strategy and its openness to the international markets. In the first case the coefficient of the variable is negative and significant, which means that those firms who tend to adapt their products more to their customers' requests tend to use more external candidates to fill a vacancy. We can therefore argue that specific knowledge is less important to the production process. As mentioned earlier, one reason for this may be that in order to efficiently follow a customization strategy firms need to adapt more quickly to changes in market demand and introduce new production processes and techniques. Therefore, firm-specific production knowledge is not as important as bringing in the new thinking, skills and ideas that would allow workers to quickly adapt to changes in demand. Finally, it seems that competing in international markets does not have a significant effect on firms' recruitment decisions.

It also has no significant effect on other firm characteristics such as age, size, or being part of a group. However, our results show how those firms with a higher percentage of workers at the bottom of the hierarchical structure are more likely to use external candidates to fill blue collar job vacancies. This means that the more hierarchical or pyramidal the job structure, the less likely it is that a firm will use promotion to fill a new vacancy.

The result regarding the existence of ports of entry is consistent with the internal labour market theory; that is, a firm is less likely to fill a top vacancy using the external market. Also, the dummy used to control for promotion decisions in the other occupational group had a positive and significant coefficient, this means that firms tend to follow the same strategy for both white and blue collar groups even if some factors affect each group differently. Finally, the variables related to the characteristics of the external labour market also have a significant effect on firm decisions, although the results are mixed.

In the case of formal education we observe that those firms located in a highly educated external labour market are more likely to use promotion to fill blue collar vacancies. One explanation of this could be the fact that firms tend to recruit production workers with a medium educational level; therefore, firms recruiting in markets with highly educated workers find it more difficult to fill vacancies with external medium educated candidates and so prefer to promote incumbents. On the other hand, being located in high knowledge services areas has a negative impact on a firm’s likelihood of using internal promotion to fill a vacancy. A possible explanation for this might be the fact that those manufacturing firms located in these areas tend to be more dynamic and competitive, hence they need use new vacancies to acquire more new thinking, new skills and new abilities from outsiders. Another possible explanation is the fact that those manufacturing firms situated in high knowledge services areas have more access to high quality consulting services and can use these to improve their knowledge of the external labour market, which reduces the uncertainty and cost of the external recruitment process.

In contrast, being localized in a high knowledge manufacturing area or in an area with a high number of firms in the same industry has no effect on firms’ promotion decisions. This might be because, even though the likelihood of finding workers with the right skills or abilities outside the firm is higher in these areas, the difficulty that firms have in retaining skilled workers increases. This might have a double effect on the firms’ promotion decisions. The first effect is negative in that being located in a high knowledge manufacturing or specific industrial area makes it is easier to find a suitable external candidate with lower recruitment cost. The second effect is positive because it is easier for incumbent workers to find another job outside the firm. Consequently, it is much more difficult for firms to retain their workers and this leads them to use promotion as a retention mechanism.

In Model 2 we analyse the determinants of firms' decisions to use internal or external labour markets to fill a vacancy in the white collar group. For this type of worker firms' internal characteristics are more important than external ones. In this case the levels of formal education among clerical workers have a positive and significant impact on promotion decisions. Another interesting result is that when a vacancy arises for a management job, firms tend to fill it using incumbent workers -existence of port of entry in management job-. This result suggests that in order to reduce succession issues, Catalan SMEs prefer to hire internal candidates than recruit an external manager. Since Catalan firms are averse to adopting new strategies, they prefer to hire a person who knows the firm's culture, people and strategy. For this reason, they regard the best candidate to fill a manager vacancy as being someone from within the firm. In contrast, if firms need to re-invent themselves, they may well prefer a candidate with new thinking and skills and thus look for one in the external labour market.

The results also show a positive relationship between product innovation activity and the use of internal candidates to fill a vacancy. As we mention above, one explanation for this pattern might be that firms with an innovation culture prefer to maintain or improve their specific knowledge by promoting their own white collar workers rather than looking for new thinking or new abilities outside the firm. On the other hand, a firm's likelihood of recruiting an external vacancy increases the more technologically advanced it is or the greater its need for white collar workers with high ICT skills.

The competitive strategy and the openness to the international markets affect equally to the promotion decision of blue and white collar workers. However, other firm characteristics such as age or belonging to a business group also positively affect the likelihood of promotion and mean that older firms and business group firms use fewer external candidates to fill vacancies in the management area. The reason for this might be because these firms have a stronger culture and require more specific knowledge that only incumbent workers possess.

Finally, it seems that sector specific knowledge rather than generic knowledge is more important in the recruitment of white collar workers. Being located in an area with other firms in the same industry increases the likelihood of recruiting external candidates to fill a vacancy. In contrast, being located in high knowledge manufacturing or services areas does not affect promotion decisions. This is because in the first case firms can find it easier to recruit other white collar workers with sector specific knowledge and skills.

Models 3 and 4 refer to the services sector. We can see that firm's internal and external characteristics are influential when firms are deciding between internal or external candidates for both management and production vacancies. Both these occupational groups show the same results as those relating to the effect of high qualified managers on the promotion decision in the manufacturing sector. This corroborates the idea that more skilled managers tend to refresh a firm's existing human capital by incorporating new workers from outside, regardless of the sector. Furthermore, the results show that more innovative and technological services firms have a greater need for new thinking and new skills in the production area, which is why they prefer to recruit external candidates to fill blue collar vacancies (Model 3), in contrast to the manufacturing sector, where new technologies and innovation activity increase the likelihood of firms using promotion. The difference between these results might be due to the fact that the manufacturing sector requires more firm-specific knowledge than the service sector, which makes the specific knowledge of their incumbent workers more valuable.

Another interesting result from Model 3 is the negative and significant of the age coefficient, which could mean that old service firms needs two refresh their knowledge and skills, and which could be why they prefer to hire external workers to fill a vacancy in the production area. Finally, firms in the services sector also present ports of entry in the production area; in fact, the higher the proportion of skilled public contact workers, the higher the likelihood that a firm will promote in this area.

Regarding the decision to promote incumbent workers or hire an external one for a management vacancy (Model 4), we can see that white collar workers experience and the openness to the international markets have a positive impact on a firm's decision to use an internal candidate to fill a vacancy. In contrast, being located in intensive knowledge services areas has a negative impact. This means that services firms located in high knowledge services areas and led by highly skilled managers tend to take advantage of a vacancy to acquire new skills, new knowledge and new thinking from external candidates. One explanation for this might be that, since these environments are more complex and competitive, firms need to change and quickly adapt their strategies to the new competitive context. Therefore, they need professionals and managers that can adapt quickly to these changes so they can constantly reinvent the firm's strategy. Consequently, an external candidate's new skills and new knowledge might be more important to the firm than the firm-specific knowledge of an incumbent worker. Another explanation might be that since these areas attract more talented people (Faggian and McCann, 2006, 2009a and 2009b), the cost of attracting and recruiting highly skilled workers from the external labour market are lower, which in turn means that firms prefer to use an external candidate to fill a vacancy unless they can find an incumbent worker with the necessary experience.

Another interesting issue is that there are no entry ports to white collar jobs in services firms. This reflects the lack of professional careers in this area and corroborates the idea that firm-specific knowledge in this sector is less important than in the manufacturing sector.

Table 4: Determinants of use of internal or external labour market to fill a vacancy

	Manufacturing sector				Services sector			
	Model 1 Blue collar jobs		Model 2 White collar jobs		Model 3 Blue collar jobs		Model 4 White collar jobs	
	Coef.	Std. Error	Coef.	Std .Error	Coef.	Std. Error	Coef.	Std. Error
Internal factors								
Human Capital								
%Qualf. manager	-0.1380*	0.0793	-0.0280	0.1071	-0.1345**	0.0559	-0.1263**	0.0600
%Qualf. professional	0.0221	0.0779	-0.0644	0.0977	0.0572	0.0610	-0.0051	0.0613
%Qualf. clerk	-0.1898**	0.0798	0.3183***	0.1080	-0.0093	0.0553	0.0154	0.0692
%Qualf. supervisor	0.0675	0.0828	-0.0093	0.1044	0.1567***	0.0556	-0.0827	0.0591
%Qualf. operator	0.3075***	0.1143	-0.0709	0.1459	-0.0725	0.0497	-0.0044	0.0559
%Qualf. low skill worker	0.0240	0.0842	0.0829	0.1052	-0.0517	0.0621	0.0170	0.0654
Experienced white collar	0.0989	0.1400	0.0457	0.1869	0.0023	0.0975	0.3276**	0.1346
Experienced blue collar	0.2068*	0.1147	0.0325	0.1424	0.0929	0.0849	0.2156***	0.0787
Managers			-0.0479**	0.0228			-0.0018	0.0026
Professionals			0.0140*	0.0074			-0.0063*	0.0034
Clerks			-0.0105	0.0086			0.0009	0.0014
Supervisors	0.0031	0.0028			3.50E-05	0.0016		
Operators	-0.001	0.0012			0.0022**	0.0011		
Low skill workers	-0.0057*	0.0034			-0.0017	0.0011		
Technology								
high level	-0.0643	0.0706	-0.1979**	0.0909	-0.1387***	0.0531	0.0412	0.0589
ICT blue	0.3459***	0.0898	0.1131	0.1107	-0.0298	0.0610	0.0165	0.0682
ICT white	0.0918	0.0693	-0.1674*	0.0925	-0.0033	0.0468	0.0365	0.0516
Competitive strategy								
Adjustment	-0.1387*	0.0802	-0.2541***	0.0807	-0.1027*	0.0539	0.0615	0.0636
Innovation activity	0.1149*	0.0654	0.1511*	0.0818	-0.0972**	0.0452	0.0597	0.0489
Promoted group								
Managers			0.3792*	0.1856			0.0722	0.1743
Professionals			0.0845	0.0916			0.0143	0.0548
Supervisors	0.3520***	0.0750			0.1985***	0.0528		
Operators	0.2115**	0.0837			0.1229*	0.0749		

Region								
Barcelona	0.3717**	0.1376	-0.0529	0.1817	-0.0871	0.1254	0.0721	0.1355
Ebro	0.5081**	0.1633	-0.0545	0.2996	0.1251	0.2082	0.1284	0.2133
Tarragona	0.2161	0.1765	-0.1955	0.1811	-0.0202	0.1336	0.1105	0.1420
Girona	0.5011**	0.1798	0.1700	0.3078	0.0227	0.1674	0.2147	0.1797
Lleida	0.4517**	0.1582	-0.1977	0.2119	0.0678	0.1523	0.0792	0.1616
Firm size	-0.0281	0.0712	0.0528	0.0877	0.016	0.0443	-0.0280	0.0469
Exporting firms	0.0688	0.0683	0.0782	0.0865	-0.0232	0.0555	0.1015*	0.0605
Group firms	0.0664	0.0920	0.2885**	0.1249	-0.0297	0.0562	0.0225	0.0615
Age	-0.0032	0.0025	0.0144**	0.0063	-0.0053**	0.0024	-0.0013	0.0031
Age2	0.0000	0.0000	-0.0001	0.0001	0.0001**	1.90E-05	2.00E-05	2.90E-05
Promotion control	0.4774***	0.0650	0.6414***	0.0671	0.4787***	0.0480	0.5231***	0.0480
External factors								
Firms in the same industry	-0.0038	0.0317	-0.109***	0.0511	-0.0188	0.0369	0.0345	0.0382
Educational level								
Medium level	0.1135	0.1057	0.0567	0.1502	0.0363	0.0820	0.0018	0.0867
High level	0.2868**	0.1365	0.2882	0.2028	-0.0402	0.1074	0.1293	0.1143
Workers in high knowledge sectors								
Workers in high knowledge manufacturing	0.0147	0.0350	0.0484	0.0430	0.0319	0.0243	0.0158	0.0266
Workers in medium-high knowledge manufacturing	0.0710	0.0529	-0.0001	0.0794	-0.0599*	0.0326	0.0240	0.0361
Workers in high knowledge services	-0.1376*	0.0787	0.1268	0.1268	0.0723	0.0774	-0.1683**	0.0753
Capital distance	-0.5279	0.3851	-0.3297	0.4977	-0.3413	0.2626	-0.1161	0.3032
Rail station	-0.0861	0.1123	-0.0148	0.1458	-0.0850	0.0742	0.0289	0.0801
N	343		227		591		500	
Pseudo R2	0.2942		0.3352		0.2318		0.2513	

Note: Probit Model - Dependent variable takes value 1 if firm uses promotion to fill a vacancy, and takes value 0 if firm uses an external candidate. We control for sectoral variables. ***, ** and * show a statistical significance of 1%, 5% and 10% respectively.

Finally, it is interesting to analyse if the effects of new technology or innovation activity on staffing strategy depend on firm location. In order to analyse this issue in Table 5 we interact technological complexity and product innovation dummies with those variables related to being located in high and medium knowledge areas.

In Model 1, the positive and significant coefficient of the technological variables confirms the hypothesis that high technology manufacturing firms are more likely to use a promotion strategy to fill a vacancy in blue collar jobs. When we analyse the interaction variables we can see that high technology firms located in high manufacturing knowledge areas are more likely to use incumbent workers to fill a vacancy than high technology firms situated in low knowledge areas. This result highlights the importance of firm-specific knowledge to these firms. One initial conclusion might be that because the pool of external high skill candidates is higher in high manufacturing knowledge areas, this increases a firm's likelihood of using the external labour market to fill a vacancy. However, since skilled workers have more opportunities of finding a job with good conditions in high knowledge manufacturing areas than in low ones, the need to retain workers might be higher for technological firms located in high knowledge areas than for those located in low ones. Thus, in order to retain skilled workers the likelihood of a firm using the internal labour market to fill a vacancy increases.

In the case of innovative firms, Model 1 in Table 4 shows that being an innovative firm has a positive effect on the decision to promote, but if we interact being innovative with being located in high knowledge manufacture areas we can see how the coefficient sign changes (Table 5). It is possible that, in Table 4, the positive coefficient sign does not indicate that more innovative firms have more firm-specific knowledge but rather that they have more difficulty in finding skilled external workers that enable the firm to be more innovative, especially when these firms are located in low knowledge areas. It is for this reason that when we interact both variables we observe that being innovative and being located in high knowledge areas improves the likelihood that a firm will recruit external workers, and this is because in these areas it is easier to find workers with new knowledge, skills and thinking.

The results in the management area (Model 2 of Table 4) show that innovation had a positive effect on firm promotion decisions, but when we interact this variable with being located in a high technology area, although the coefficient sign does not change, the coefficient becomes non-significant (Model 2 of Table 5). In the case of high technology firms the results show that, in contrast with what happens in the production area, firms prefer to use external workers to fill vacancies in the management area (Model 2 of Table 4). However, if we interact this variable with the location variables the coefficient sign changes and become non-significant in any case. Thus, it is not clear how the interaction between location variables and innovative or technological variables affects the strategies adopted by firms when filling white collar vacancies.

In the case of service firms, Table 4 shows that more technologically advanced firms are more likely to use the external labour market to fill a blue collar vacancy, but when we interact the technological variable with firm location the results change. In this instance, Model 3 of Table 5 shows how technologically advanced firms located in high knowledge areas are more likely to use the internal labour market to fill a vacancy. The same occurs with innovative firms; that is, while being innovative increases a firm's likelihood of using an external candidate to fill a vacancy, this is reduced if the firm is located in a high knowledge area. Both these results might hide the fact that services firms with a high level of innovation and a strong technology culture need to retain production workers, particularly in high knowledge manufacturing areas. Consequently, these firms use promotion as a mechanism to retain workers. However, this only occurs in the production area and not in the management area, where the probability of using incumbent workers to fill a vacancy is reduced for more innovative and technological firms located in high knowledge manufacturing areas.

Table 5: Determinants of use of internal or external labour market to fill a vacancy (Interactions)

	Manufacturing sector				Services sector			
	Model 1 Blue collar jobs		Model 2 White collar jobs		Model 3 Blue collar jobs		Model 4 White collar jobs	
	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error	Coef.	Std. Error
Interactions								
Technology								
High level*Workers in high knowledge manufacture	0.1401***	0.0526	0.0906	0.0763	0.1040**	0.0510	-0.0760*	0.0461
High level*Workers in medium-high knowledge manufacture	0.0283	0.0873	-0.0699	0.1072	0.0771	0.0595	-0.1420**	0.0710
High level*Workers in high knowledge services	0.0362	0.0906	0.0093	0.1292	0.0865	0.0837	0.0564	0.0730
Innovation activity								
Innovation *Workers in high knowledge manufacture	0.0039	0.0609	-0.0299	0.0770	-0.0368	0.0395	0.0674	0.0431
Innovation *Workers in medium-high knowledge manufacture	-0.2002*	0.1071	0.1563	0.1295	0.1573***	0.0482	-0.1296**	0.0604
Innovation *Workers in high knowledge services	0.0033	0.0967	0.1603	0.1219	-0.0723	0.0647	0.0318	0.0708
Internal factors								
Human Capital								
%Qualf. manager	-0.1733**	0.0830	-0.0135	0.1088	-0.1460***	0.0566	-0.1178*	0.0613
%Qualf. professional	0.0295	0.0802	-0.0674	0.0980	0.0713	0.0618	-0.0067	0.0619
%Qualf. clerk	-0.1611**	0.0813	0.3080***	0.1115	-0.0379	0.0562	0.0525	0.0694
%Qualf. supervisor	0.0911	0.0837	-0.0054	0.1060	0.1812***	0.0572	-0.0944	0.0615

%Qualf. operator	0.2705***	0.1148	-0.0499	0.1487	-0.0757	0.0506	-0.016	0.0574
%Qualf. low skilled worker	0.0418	0.0865	0.0810	0.1088	-0.0602	0.0634	0.0387	0.0667
Experienced white collar	0.0551	0.1433	0.1110	0.1957	-0.0270	0.0992	0.3381**	0.1353
Experienced blue collar	0.2231**	0.1154	0.0165	0.1507	0.1197	0.0874	0.2309***	0.0806
Managers			-0.0468**	0.0249			-0.0015	0.0026
Professionals			0.0140*	0.0078			-0.0059*	0.0033
Clerks			-0.0101	0.0071			0.0007	0.0014
Supervisors	0.0031	0.0029			0.0003	0.0016		
Operators	-0.0011	0.0014			0.0021**	0.0011		
Low skilled workers	-0.0057*	0.0035			-0.0018*	0.0011		
Technology								
high level	0.9103**	0.4105	0.1498	0.5726	0.9057***	0.3724	-0.7651**	0.3392
ICT blue	0.3343***	0.0895	0.0788	0.1129	-0.0202	0.0617	-0.0355	0.0696
ICT white	0.0850	0.0701	-0.1569	0.0970	-0.0054	0.0472	0.0453	0.0515
Competitive strategy								
Adjustment	-0.1046	0.0828	-0.2176**	0.0871	-0.1051*	0.0535	0.0699	0.0647
Innovation activity	-0,4441	0.3755	0.6550	0.2784	0.0834	0.2990	0.0909	0.3005
Promoted group								
Managers			0.3927**	0.1591			0.0555	0.1705
Professionals			0.0769	0.0968			-0.0023	0.0549
Supervisors	0.3502***	0.0758			0.1928***	0.0539		
Operators	0.2270***	0.0860			0.0833	0.0740		
Region								
Barcelona	0.3396**	0.1413	-0.1066	0.1773	-0.0814	0.1222	0.0890	0.1364
Ebro	0.4988**	0.1636	-0.1123	0.2837	0.1652	0.2052	0.1189	0.2164
Tarragona	0.2435	0.1764	-0.2388	0.1738	-0.0051	0.1323	0.1058	0.1420

Girona	0.4587**	0.1861	0.1274	0.3107	0.0640	0.1645	0.2090	0.1845
Lleida	0.4345**	0.1633	-0.2689	0.1882	0.0836	0.1528	0.0837	0.1660
Firm size	-0,0192	0.0706	0.0690	0.0900	0.0191	0.0445	-0.0356	0.0468
Exporting firms	0,0777	0.0705	0.0803	0.0862	-0.0345	0.0547	0.1311**	0.0614
Group firms	0,0528	0.0929	0.2124	0.1325	-0.0199	0.0577	0.0151	0.0617
Age	-0,0042	0.0026	0.0147**	0.0065	-0.0050**	0.0025	-0.0016	0.0031
Age2	0,0001	0.0000	-0.0001	0.0001	0.0001*	2.04E-05	2.16E-05	2.90E-05
Promotion control	0,4980***	0.0649	0.6405***	0.0700	0.5083***	0.0476	0.5448***	0.0484
External factors								
Firms in the same industry	-0,0068	0.0322	-0.1137**	0.0524	-0.0203	0.0356	0.0371	0.0387
Educational level								
Medium level	0.0973	0.1086	0.0819	0.1541	0.0603	0.0836	0.0250	0.0853
High level	0.2782**	0.1392	0.3289	0.2005	-0.0256	0.1081	0.1711	0.1160
Workers in high knowledge sectors								
Workers in high knowledge manufacturing	-0.0597	0.0528	0.0332	0.0683	0.0323	0.0328	0.0067	0.0410
Workers in medium-high knowledge manufacturing	0.2278**	0.1078	-0.1034	0.1268	-0.1851***	0.0475	0.1577***	0.0578
Workers in high knowledge services	-0.1424	0.1069	0.0074	0.1511	0.0908	0.0837	-0.2226**	0.0964
Capital distance	-0,4124	0.3820	-0.3277	0.5014	-0.4377	0.2709	-0.0946	0.3139
Rail station	-0,0851	0.1147	-0.0601	0.1486	-0.1116	0.0761	0.0535	0.0783
N	343		227		591		500	
Pseudo R2	0.3161		0.3511		0.2532		0.2723	

Note: Probit Model - Dependent variable takes value 1 if firm uses promotion to fill a vacancy, and takes value 0 if firm uses an external candidate.

We control for sectoral variables. ***, ** and * show statistical significance of 1%, 5% and 10% respectively.

6. Conclusions

Filling a vacancy is an important managerial decision because it is an excellent time to find the most suitable worker for improving firm performance. This may be done by promoting an internal worker or by recruiting an external worker from the external labour market, and each alternative has its own benefits and disadvantages.

Following different theories we can identify three main reasons why firms use internal candidates rather than external ones. First, there is firm-specific human capital; that is, a firm's existing workers can have firm-specific knowledge that external candidates do not possess, which makes it harder for the latter to outperform the former. Second, there is the need to reduce adverse selection problems during the recruitment process. This means that firms may prefer to promote internal workers because it is easier for them to obtain more detailed information about their own workers' abilities, motivation and performance than it is to get the same information about external ones. Third, internal promotion can function as a motivation and retention mechanism insofar as it provides the incumbent workers with the incentive to work harder in order to be awarded the vacancy, thus allowing the firm to retain its best workers.

However, these three theories fail to take into account other issues that may affect firms' decisions to use the internal or external labour market, and it has been the aim of this paper to try to shed some light on what these issues may be.

The first issue that we take into account in our analysis is innovation activities and the use of new technologies. We consider that the decision to use internal promotion depends on the firm finding a match between the vacancy's requirements and the skills of its incumbent workers. In this regarding the implementation of new technologies or firm innovation activities are transforming the nature of work by moving it away from routine tasks towards analytical and interactive tasks, thus changing the skills that workers need to perform efficiently. This creates a situation in which firm-specific knowledge can becomes less important to a firm and increase the difficulty to find an internal worker with the new skills required to use these new technologies and to develop innovations. The fact that the firm is unlikely to have such an incumbent worker increases the likelihood that it will look for a worker with these skills in the external labour market.

The second issue that we consider in our analysis is firm location. On one hand, the specific location of the firm will determine the probability of it finding workers with the right skills outside the firm, thus reducing adverse selection problems and the incentives to use an incumbent worker to fill a vacancy. On the other hand, a firm may be located in an area with lots of other firms who may be interested in hiring its workers, which would increase the firm's incentive to use promotion to fill a vacancy and thus retain its most highly skilled workers (promotion as a retention mechanism).

From these results we conclude that there is a clear difference between manufacturing and service firms when it comes to deciding whether to fill a vacancy using the internal or external labour markets, and that this decision depends not only on a firm's internal characteristics but also on its location.

For manufacturing firms, we can see a positive relationship between innovation and the use of incumbent workers to fill blue and white collar vacancies. Thus, for innovative manufacturing firms the advantages of using internal labour markets are greater because it allows them to draw on the higher firm-specific knowledge of incumbent workers, to reduce adverse selection problems or to use promotion as a motivation and retention mechanism, unless these firms are located in high knowledge manufacturing areas. In this case, the firm is more likely to use external labour markets because the coefficient of the interaction between innovation activity and location is negative and significant for blue collar workers. This may be because in these areas such firms find it easier to recruit the workers with the necessary skills, thus allowing them to reduce the possibility of adverse selection problems.

In contrast, the effect of new technologies on the decision to fill a vacancy is different for blue and white collar jobs. In the case of blue collar jobs, firms that use more new technologies are more likely to use the internal labour market. We can interpret this as a sign that firm-specific knowledge related to the use of these new technologies is more important to these firms. Furthermore, this probability increases if these more technological firms are located in high knowledge manufacturing areas. This could mean that these firms are more likely to use the internal labour market not only because they want workers with firm-specific knowledge, but also because they want to retain their blue collar workers and keep them from working for others firms. In contrast, technologically advanced firms are more likely to use external candidates to fill a white collar vacancy, regardless of their location. Thus, it seems that for these kinds of job the advantages of recruiting from the external labour market are greater than the advantages of recruiting from the internal market. In other words, the benefits of hiring an external candidate, in terms of the new thinking, knowledge or skills that such a candidate can provide, are greater than the benefits of promoting an incumbent worker, which are related to firm-specific knowledge, adverse selection problems and the motivation and retention mechanism.

In the case of service firms, we can see a negative relationship between the use of new technologies, innovation activity and the firm's likelihood of using the internal labour market to fill either a blue collar or white collar vacancy. Therefore, we can assume that for more technological and innovative firms the advantages gained from an incumbent worker's firm-specific knowledge are less than the advantages gained from an external candidate's new thinking, knowledge and skills. Consequently, these companies prefer to hire an external candidate rather than promote an incumbent one, although in the case of blue collar workers this only happens if those firms are located in low knowledge areas because otherwise the likelihood of the firm hiring an external candidate is reduced. This could be because these firms particularly need to retain their blue collar workers in areas where workers have more opportunities to find good jobs at other firms.

Our results also show that those firms with highly qualified managers are more likely to use external labour markets to fill a vacancy rather than internal ones. And finally, the results also support the hypothesis of ports of entry especially in the manufacturing sector, which means that firm-specific knowledge is more important in the manufacturing sector and for top-level jobs.

The empirical evidence provided in this paper sheds some light on the relationship between the characteristics and the staffing strategies of SMEs. Although it would be interesting include the relationship between organisational work practices and the decision to promote or to hire external workers, unfortunately given the limitations of the available data in this respect, this remains a topic for future research, as does the analysis of the effect of staffing strategies on aspects of firm performance such as productivity.

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Appendix

External labour market variables

Variables	Definition
Firms in the same industry	log of the number of firms in the same industry
Educational level	
Medium level	dummy variable that takes value 1 if the average years of schooling of the employee population are in the second tercile
High level	dummy variable that takes value 1 if the average years of schooling of the employee population are in the upper tercile
Workers in high knowledge sectors	
Workers in high knowledge manufacturing	log of the percentage of employees in the high knowledge manufacturing sector
Workers in medium-high knowledge manufacturing	log of the percentage of employees in the medium-high knowledge manufacturing sector
Workers in high knowledge services	log of the percentage of employees in the high knowledge service sector
Capital distance	log of the distance between the local labour market and the provincial capital measured by time spent travelling
Railway station	dummy variable that takes value 1 if there are any railway stations in the local labour market

V. CONCLUSIONS

The debate over the relevance of firm productivity to economic growth has been reviewed as a consequence of the current economic crisis. In this context, the analysis of elements that contribute to improve firm productivity becomes more important, especially in countries with low productivity levels, such as Catalonia.

The purpose of this thesis is to analyse the effects of human capital on firm productivity in the context of Catalan SMEs, taking into account the existent synergies between human capital and other production factors such as, technological capital or the new work organisational practices. Additionally, this thesis also includes an analysis of how SMEs adjust their human capital levels in order to give an answer to the new competitive context.

So to achieve the objective of this thesis we have carried out three different essays. The first one analyses the direct effects of human capital on firm productivity as well as, possible complementarity effects across human capital and new technologies taking into account the different occupational groups. The second one introduces the concept of work organisational practices and analyses the existent synergies between different bundles of work organisational practices and human and technological capital in firms, together with its effects on firm productivity. Finally, the third essay analyses how firms adjust their human capital considering firm technological level, firm innovation and firm location.

The results from the first and second essays indicate that human capital has a direct effect on firm productivity; this means that highly educated workers are more productive than less-educated workers given that the first ones are more efficient and capable to develop a specific task. Moreover, we also found that a high skilled workforce improves firm productivity in an indirect way because, to some extent, human capital improves the productivity of other production factors (such as new technologies) by making a better use of these factors.

In my opinion, the most important contribution done by the first essay would be the separate analysis of occupational groups which provides some interesting further evidence about the effects of human capital on firm productivity. In sum, the separate analysis of different occupational groups points out that investment in human capital, either in the production or management area, improves firm productivity due to the better use of new technologies that they cause. Therefore, to maximise the productivity of new technologies it is necessary to possess high skilled workers in both the production and the management areas.

Thus, highly technological production environment requires highly skilled workers in order to achieve higher productivity levels through these technologies. In other words, skilled workers maximize their productivity when they are in an advanced technological environment and therefore, those firms with skilled workers in each one of the occupational groups are more able to adapt to technological changes and to achieve high productivity levels.

Furthermore, the way in which firms organise themselves to manage their skilled workers and their new technologies has an effect on firm productivity, too. More specifically, the second essay shows how those new work organisational practices related to production quality such as, employee suggestion systems, information sharing manager-employees, problem solving group quality cycles or total quality management improve the productivity of human and technological capital. The contribution of the second work is twofold: first of all, the new work organisational practices index proposed in this paper has some interesting features which could be useful for the analysis of the impact of different bundles of organisational practices on firm outcomes such as productivity, innovations, growth and so on. Secondly, the use of the supermodularity theory to accomplish the complementarity test allows us to examine the existent synergies between human capital, new technologies and new work organisational practices, simultaneously.

The analysis carried out for the third essay suggests that the effects of new technologies and the innovation activity on the decisions to use internal or external labour market to adjust firm human capital levels would depend on both firm location and industrial sector (manufacturing or service sector). The main contribution of this work – in regard to previous studies on this topic- consists on the introduction of external labour market variables that are constructed using the travel-to-work areas, in order to control the characteristics of firm location.

Besides, the separate analysis in this case of different occupational groups could offer interesting evidence regarding the internal or external recruiting strategies. The results indicate that the characteristics of the external labour market become relevant when a firm has to decide how to fill a vacancy either in the production or management area, despite the effects could be different.

To conclude, the three essays that compose this PhD thesis represent a new contribution to the empirical research on firm productivity, with a particular emphasis on the effects of human capital, new technologies and new work organisational practices. Although these analysis are based on a cross-sectional data and therefore, cannot explicitly model the dynamic relationship within the variables, we believe that the empirical evidence reported in these essays is likely to generate a valuable material for the future design of incentive policies when created to improve firm productivity. Moreover, each one of the three essays has several potential extensions which might be worth examining in detail in future research. An interesting extension of this work would consist on complementing the previously used data with a set of human resources practices that could also affect the productivity of human capital.

Measures to improve firm productivity

From the results we can conclude that in order to change the current economic and productive model and to improve the productivity of the Catalan SMEs it is necessary, not only to invest in both human and technological capital, but also to take into account how firms manage their human and technological capital by using the new work organisational practices.

Find below my suggestions of some measures that could encourage firms' investment in new technologies and human capital.

New technologies investment

In the last years, Catalan firms have incorporated the new technologies into their production processes but are still a long way from the European average. Therefore, it would be necessary that the Government designed actions to support the diffusion of technological innovation, not only in the highly technological industries but also, in the medium and low technological ones. We should take into account that the medium and low technological sectors are those with greater importance in the Catalan economy, in terms of employment and production. Another key point is the fact that SMEs have more problems than large firms to obtain funds to invest in human capital and new technologies. Therefore, it would be necessary to design tools that would allow these type of firms to obtain funds - such as subsidies, fiscal incentives, and concessions of credit in favourable conditions suitable to SMEs- to drive the modernisation of the Catalan productive system.

On the other hand, the modernisation of the productive system could also happen through the development of new production technologies within the firms. In this sense, measures to encourage R&D -such as fiscal incentives, public benefits, or agreements with technological centres (or with other firms) to develop R&D- could drive the development of new production technologies that would allow companies to improve their productivity.

Human capital investment

As we mentioned above, firms can adjust their human capital levels using internal or external labour markets. In the first case, the improvement of human capital levels would go through training the existent workers, and in the second case, it would be achieved by improving the general education of population.

Therefore, training within the firms is a way to improve the human capital levels of the firm and allows their adaptation to technological changes and to the competitive environment. From this point of view, Governments could use different measures to encourage firms' investment in training policies and programs. In this sense, the creation of programs to support continuous training, fiscal benefits, the design of advisory programs to help firms to develop training plans or the inclusion of selection criteria in public contracts, based on firm training activity (biddings), are some of the measures that could affect firms positively towards the investment in human capital and at the same time could push up training policies within companies. On the other hand, a key element that effects firm decisions to invest in training is their capacity to obtain benefits from that investment. In this sense, the firm capacity to retain their workers could affect the decision and probability of the firm to invest in training. And so, the diffusion of the best human resources practices in relation to attraction and retention of workers would be, then, an important issue to consider.

In reference to the measures that the Government could use in order to improve the educational level of population (external labour market) we should make a difference between those measures that would affect the generation, the attraction or the retention of human capital.

When we talk about "generation" in the context of human capital we refer basically to the improvement of the educational level of the population, therefore, to those measures oriented to improve the current educational system. In this sense, this improvement would happen in the first place, through the enlargement of the expense in education that would then allow us to reach the average within EU countries, as well as the improvement of the quality of the educational system by implementing more effective evaluation mechanisms, greater autonomy and flexibility of schools, more flexible salary scales for teachers which would be related to the quality and not to the job antiquity and, so on. It is also important to implement measures to reduce current high levels of academic failure and early school leaving, as well as to improve the vocational education training so to provide teachers with greater recognition and more leadership.

It is also necessary to highlight the relevance of improving the adjustment between the human capital offer and demand in order to reduce the existing mismatches. In this sense, to reduce mismatches it is necessary to create instruments that would allow the analysis of the requirements of current and future production system in terms of human capital, followed by the development of those tools that would allow education and training to be closer to those provided by the educational systems currently.

Two elements that are also important to the improvement of the human capital dotation are the attraction and the retention of the existent human capital. As Flowery R. (2002)[89] said, people with greater educational levels tend to move more around the wold looking for the best professional offers. In this sense, the capacity to attract these high skilled professionals and retain their existent qualified work would be vital to guarantee the correct endowment of human capital of the Catalan economy. This capacity depends on different factors such as, the quality of the projects and the people that surround the organisations where these talented people have to work; the professional recognition to their work (meritocratic culture, economic incentives, etc.), and the quality of the environment (living quality, quality of the social and professional relationship, etc.). Along this line Heidrick and Struggles (2007) have developed the Global Talent Index (GTI) that measures the natural potential of the country to generate and attract talent in base to seven fields: The demography, the quality of the educational system, the quality of the university system and the business schools, the quality of the environment where the talent grows, the capacity of mobility and opening of the labour market, the trends in the international investments flows and the capacity to attract talented people. In the year 2007 Spain occupied the position number 11, being the United States, the United Kingdom, Canada, The Netherlands and Sweden those that presented greater capacity of generation and attraction of talent. This index points out that the main fields in which Governments are able to influence in order to improve the Spanish position are the capacity of mobility and opening of the labour market as well as the quality of the university system and the business schools , together with the demography of the country.

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89 Florida, R. (2002): "*The rise of the creative class: And How It's Transforming Work, Leisure, Community, and Everyday Life*". Tandem Library.

Finally, it is necessary to say that in the last year the Catalan Government has driven a series of measures and actions in order to improve the levels of human and technological capital of the firms. In concrete, in the year 2005, the Government of the Generalitat of Catalonia signed the first strategic Agreement for the internationalization, the quality of the employment and the competitiveness of the Catalan economy (2005-2007). Later, in the year 2008 and in front of the economic situation of that moment, the Catalan Government believe necessary to review the Strategic Agreement and impulse new performances measure in order to improve the productivity and the competitiveness of the Catalan economy. These new measure are focused to improve the human capital and the technological level of Catalan firms.

In the case of the human capital, the Strategic Agreement dedicates a set of measures oriented to improve the educational levels and the qualifications of the Catalan population. Among other measures it is necessary to highlight those that make reference to improve the current vocational training system, the university politics and the school failure. The Strategic Agreement also includes different measures to attract and retain talent researcher and entrepreneurs together with other programs such as ICREA or the creation of 22@ in Barcelona. All these measure have to improve the capacity of Catalonia to attract human capital. A different set of measures in reference to the innovation activity and knowledge society, it takes account some specific actions to spread the use of ICT among Catalan firms in order to achieve higher levels of productivity and upgrade the production system of the economy.

In sum, it seems that exist a consensus, not only at the academic level but also at the political level that the improvement of the competitiveness and the growth of the Catalan economy has to be done through the improvement of the business productivity achieved by investment in human capital and new technologies. On the other hand, still remains a lot to do. The analysis in the present work shows that the simple accumulation of this factors are not enough to achieve higher productivity growths, firms also need to introduce new work organisational practices in order to maximise the productivity of human and technological capital. Therefore, Governments also have to include in the political diary measure to impulse and spread of the new organization practices. Unfortunately, the current crisis situation has paralyzed the investments that the Governments have been doing in these fields.

The debate over the relevance of firm productivity to economic growth has been reviewed as a consequence of the current economic crisis. In this context, the analysis of elements that contribute to improve firm productivity becomes more important, especially in regions with low productivity levels, such as Catalonia.

The purpose of this thesis is to analyse the effects of human capital on firm productivity in the context of Catalan SMEs, taking into account the existent synergies between human capital and other production factors such as, technological capital or the new work organisational practices. Additionally, this thesis also includes an analysis of how SMEs adjust their human capital levels in order to give an answer to the new competitive context.

Universitat Rovira i Virgili