On the sources and mechanisms of Human Capital Externalities *

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Abstract

Previous research on human capital externalities assessed how the regional concentration of skilled workers generates social returns to education. This work intends to study the sources and mechanisms of these same externalities, focusing on two questions: 1. How the allocation of certain firms and industries to particular regions affects the size of human capital externalities; 2. How the regional concentration of human capital affects the return of different inputs within the firm. To assess the first question we exploit the decomposition proposed by Gelbach (2016). This methodology allows to decompose how different factors impact the size of human capital externalities: we consider the characteristics of firms and industries which operate in a given region to analyse the relative contribution of firms and industries to the final impact of the externality. We observe that firms effects absorb great part of human capital externalities. This shows that the externality effect results mainly from the allocation of highly productive firms to regions where the density of skilled workers is greater. Secondly we assess how the regional concentration of high skilled workers affects the different inputs within the firm. Merging longitudinal worker and firm data with balance sheet information, we estimate how human capital externalities affect differently the wages of high and low skilled workers and the return of capital. We conclude that the regional concentration of skilled workers particularly benefits the returns of capital, finding small impacts on wages of high and low skilled workers within the firm.

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1 Introduction

The existence of externalities makes the social returns on education to exceed the private ones. Traditionally, these externalities arise due to the regional concentration of skilled workers.

For long human capital externalities have been a research topic in economics. [Lucas, 1988] already stated that the size of human capital externalities can be large enough to explain wage differentials across countries. [Acemoglu and Angrist, 2000] and [Acemoglu, 1998] propose two possibilities to justify the existence of human capital externalities: 1. Non pecuniary externalities - The kind of spillovers which arise due to exchange of ideas and transmission of knowledge which increase the worker's individual productivity; 2. Pecuniary externalities - The impact of skill concentration in the productivity of physical capital. This last hypothesis is tested by [Beaudry et al., 2010] which studies the effect of skill concentration in the firm's decision to invest in computers. Several other works assess the existence of human capital externalities. [Ciccone and Peri, 2006] split the labour force into different skill levels and present an identification strategy to isolate the size of human capital externalities. Their empirical assessment uses data from US cities, finding no statistical impact from the concentration of workers with a higher average schooling level. Also using data on US cities, [Moretti, 2004a] exploits the possibility that plants located in cities with higher concentration of human capital are more productive. Further he compares the effects across different sectors (hig tech and low tech), concluding on the existence of human capital externalities, but their positive impact on productivity ends up to be cancelled by the increase in labour costs. Also using data at the city level, [Rosenthal and Strange, 2008] found strong effects from human capital agglomeration, concluding that proximity to areas with high concentration of skilled workers has a significant impact on wages. More recently [Guo et al., 2016] used a structural approach to estimate the aggregate size of human capital externalities finding large and significant effects and [Guo, 2016] shows that the concentration of skilled workers leverages the worker's individual return on experience.

Thus, we observe no consensus on the existence of such externalities. [Iranzo and Peri, 2009] try to reconcile these results, developing a theoretical model with an empirical application which shows no effect from concentration of high school graduates and a positive effect from the agglomeration of college graduates.

All this literature is focused on the existence and size of human capital externalities, not addressing the mechanisms that make these externalities to arise. The goal of this work is to assess the sources of human capital externalities in two ways: 1. How the concentration of skilled workers in a given region affects the returns on different inputs within the firm; 2. How the size of the human capital externality is affected by industry and firms characteristics. Particularly we measure how the allocation of certain firms and industries to regions affect the size of the human capital externality.

In order to assess the first goal we explore the richness of the firm level data, to evaluate how the marginal productivity of labour and capital benefit differently from the regional concentration of skilled workers. When assessing the impact on the labour returns we study if the externality effect has different effects in workers with different education levels within the firm.

To tackle the second goal of this paper, we exploit the Gelbach decomposition methodology, [Gelbach, 2016]. The size of the human capital externalities may depend on the allocation of firms and industries to regions where the concentration of skilled workers is higher. The Gelbach decomposition allows us to decompose how the estimation on the size of the human capital externalities is affected by the matching between firms, industries and concentration of skills. This way we study how the agglomeration of skilled workers operate through the estimated firms and industries effects.

To study these questions we use longitudinal data on firms and workers for Portugal between 2005 and 2013, the data comprises detailed information on workers' characteristics and on the firms' accounts.[1]

In section 2 we propose a theoretical framework to assess how the regional concentration of skilled workers may impact the firm's problem. Then, in section 3 we present the data and in section 4 we present the results of the empirical methodology. Finally, section 5 concludes.

2 A baseline intertemporal Model

We start by building a theoretical model to study how the regional concentration of skilled workers impact the firm. Consider that each firm j maximizes the following profit function, $\pi_{j,t}$, at each moment, t in a certain region, c:

$$\pi_{j,c,t} = P_{j,c,t}Y_{j,c,t} - r_{j,c,t}K_{j,c,t} - w^H_{j,c,t}H_{j,c,t} - w^L_{j,c,t}L_{j,c,t} - \tau_{j,c,t}M_{j,c,t} - AC_{j,c,t} \tag{1}$$

$Y_{j,c,t}$ is the production function of the firm which is a function of high skilled labour, $H_{j,c,t}$, low skilled labour, $L_{c,t}$, physical capital, $K_{j,c,t}$, materials, $M_{j,c,t}$, and a exogenous

[1] [Martins and Jin, 2010] and [Sousa et al., 2015]assessed the size of human capital externalities. The first evaluates the spillovers from the firm skill concentration, the second studied the impact of county skill concentration on individual wages.

technology term, $A_{c,t}$. $P_{c,t}$ stands for the price level and $AC_{j,c,t}$ for the adjustment cost function of labour and capital.
The unit costs of high skilled labour, low skilled labour, physical capital and materials, are respectively given by $w^H_{j,c,t}$,$w^L_{j,c,t}$, $r_{j,c,t}$ and $\tau_{j,c,t}$
We assume that the production function, $Y_{j,c,t}$ is given by a two stage production function. η is the elasticity between $K_{j,c,t}$, $H_{j,c,t}$ and $L_{j,c,t}$, and a elasticity equal equal to one is assumed between these inputs and materials. λ stands for the share of materials, $M_{j,c,t}$, in the output.

$$Y_{j,c,t,K} = A_{j,c,t}[\alpha_K(K_{j,c,t})^\eta + \alpha_H(H_{j,c,t})^\eta + \alpha_L(L_{j,c,t})^\eta]^{\frac{1-\lambda}{\eta}} M^\lambda_{j,c,t} \tag{2}$$

The intertemporal component is given by the adjustment costs of labour and physical capital, which follow a simple quadratic function:

$$\begin{aligned} AC_{j,c,t} = \theta_{1,K}(I_{j,c,t}) + \theta_{2,K}(I_{j,c,t})^2 + \theta_{1,H}(\Delta H_{j,c,t}) + \theta_{2,H}(\Delta H_{j,c,t})^2 \\ + \theta_{1,L}(\Delta L_{j,c,t}) + \theta_{2,L}(\Delta L_{j,c,t})^2 \end{aligned} \tag{3}$$

$I_{j,c,t}$ stands as net investment and $\Delta H_{j,c,t}$ and $\Delta L_{j,c,t}$ are the net hiring of high and low skilled workers. These variables enter in the law of motions of labour and capital given as:

$$\begin{aligned} K_{j,c,t} &= I_{j,c,t} + K_{j,c,t-1} \\ H_{j,c,t} &= \Delta H_{j,c,t} + H_{j,c,t-1} \\ L_{j,c,t} &= \Delta L_{j,c,t} + H_{j,c,t-1} \end{aligned} \tag{4}$$

Prices in equilibrium equal the iso-elastic demand function:

$$P_{j,c,t} = P_0 Y^{-g}_{j,c,t} \tag{5}$$

g stands for the negative inverse of the elasticity of demand and it can be taken as the market power of the firm.

2.1 Incorporating externalities in the firm's problem

We now assess how we can use the previous baseline model to measure the size of human capital externalities. One of the main methodological issues in the identification of human capital externalities concerns the disentangle between the externality effect and the neo-classical effects related with the imperfect substitutability between inputs. For example, consider an increase in the supply of high skilled workers in a given region. Due to the shape of labour demand for high skilled workers this makes these workers' wage to decrease. By the opposite, given the positive cross marginal products between inputs, it makes the demand for physical capital and low skilled workers to increase and consequently their marginal returns. These effects clearly create a confounding effect which bias the estimation of externalities. To tackle this issue our theoretical approach builds on [Ciccone and Peri, 2006] allowing for the disentangle between what are the expected market effects. Thus, we consider that the concentration of skilled workers in a given region,c, as:

$$S_{c,t} = \frac{H_{c,t}}{L_{c,t}} \tag{6}$$

$H_{c,t}$ and $L_{c,t}$ stand for the level of high and low skill workers at the region level. In each period, the concentration of skills in the region affects the firm's productivity factor, which can be rewritten as:

$$A_{j,c,t} = A^{*}_{j,c,t} S^{x}_{c,t} \tag{7}$$

x is the impact of the human capital in productivity and it can be interpreted as the size of the human capital externalities.

Three of the inputs, high skilled labour, low skilled labour and physical capital are taken as technologically augmented and the the impact of the human capital level is different according to the respective input:

$$\begin{aligned} A^{K}_{j,c,t} &= A^{*}_{j,c,t} S^{x_K}_{c,t} \\ A^{H}_{J,c,t} &= A^{*}_{j,c,t} S^{x_H}_{c,t} \\ A^{L}_{J,c,t} &= A^{*}_{j,c,t} S^{x_L}_{c,t} \end{aligned} \tag{8}$$

The terms x_K, x_H and x_L are the measures of the human capital externality in the productivity terms of high skilled labour, low skilled labour and physical capital.

Proposition 1: The human capital externality is the impact of regional concentration of skilled workers on a firm's production function and it is given as:

$$\text{Human Capital Externalities}=[(1-g)(1-\lambda)](\phi_K x_K+\phi_H x_H+\phi_L x_L)+g(\phi_K x_K+\phi_H x_H+\phi_L x_L) \tag{9}$$

To prove such proposition we solve the intertemporal firm's problem:

$$\begin{gathered} \text{Max}\pi_{Y_{j,c,t}} = E_0 \sum_{t=0}^{\infty} \beta^t \pi_{j,c,t} \\ \text{s.to} \\ K_{j,c,t} = I_{j,c,t} + K_{j,c,t-1} \\ H_{j,c,t} = \Delta H_{j,c,t} + H_{j,c,t-1} \\ L_{j,c,t} = \Delta L_{j,c,t} + H_{j,c,t-1} \end{gathered} \tag{10}$$

Deriving the FOC we arrive to the following conditions for capital, high skilled and low skilled labour:

$$r^*_{j,c,t} = P_0 A_{j,c,t*} M_{j,c,t}^{(1-\lambda)} \alpha_K (1-\lambda)(1-g) \left[\alpha_K + \alpha_H S_{c,t}^{\eta(x_H - x_K)} \left(\frac{H_{j,c,t}}{K_{j,c,t}}\right)^{\eta} + \alpha_L S_{c,t}^{\eta(x_L - x_K)} \left(\frac{L_{j,c,t}}{K_{j,c,t}}\right)^{\eta}\right]^{\frac{\rho(1-\lambda)}{\eta}} (S_{c,t}^{x_K})^{\upsilon} (K_{j,c,t})^{\psi} \tag{11}$$

$$w^H_{j,c,t} = P_0 A_{j,c,t*} M_{j,c,t}^{(1-\lambda)} (1-\lambda)(1-g)\alpha_H \left[\alpha_K S_{c,t}^{\eta(x_K - x_H)} \left(\frac{K_{j,c,t}}{H_{j,c,t}}\right)^{\eta} + \alpha_H + \alpha_L S_{c,t}^{\eta(x_L - x_H)} \left(\frac{L_{j,c,t}}{H_{j,c,t}}\right)^{\eta}\right]^{\frac{\rho(1-\lambda)}{\eta}} (S_{c,t}^{x_H})^{\upsilon} (H_{j,c,t})^{\psi} \tag{12}$$

$$w^L_{j,c,t} = P_0 A_{j,c,t*} M_{j,c,t}^{(1-\lambda)} (1-\lambda)(1-g)\alpha_L \left[\alpha_K S_{c,t}^{\eta(x_K - x_L)} \left(\frac{K_{j,c,t}}{L_{j,c,t}}\right)^{\eta} + \alpha_H S_{c,t}^{\eta(x_H - x_L)} \left(\frac{H_{j,c,t}}{L_{j,c,t}}\right)^{\eta} + \alpha_L\right]^{\frac{\rho(1-\lambda)}{\eta}} (S_{c,t}^{x_L})^{\upsilon} (L_{j,c,t})^{\psi} \tag{13}$$

We consider that the total income generated by each firm, j, per worker is given as:

$$W_{j,c,t} = w^{H}_{j,c,t}{}^{*} \frac{H_{j,c,t}}{N_{j,c,t}} + w^{L}_{j,c,t}{}^{*} \frac{L_{j,c,t}}{N_{j,c,t}} + r_{j,c,t} \frac{K_{j,c,t}}{N_{j,c,t}} + \frac{\pi_{j,c,t}}{N_{j,c,t}} \tag{14}$$

$N_{j,c,t}$ stands as the total amount of workers, (i.e $N_{j,c,t} = H_{j,c,t} + L_{j,c,t}$). The average wealth generated by the firm, $W_{j,c,t}$ is a function of the wages paid to the high skilled workers, ${w^H_{j,c,t}}^* H_{j,c,t}$ and to the low skilled workers, ${w^L_{j,c,t}}^* L_{j,c,t}$. In what concerns the return on capital we consider two types of return: the pure profit, $\pi_{j,c,t}$, and the payments to capital, $r_{j,c,t}K_{j,c,t}$. Following [Keane, 2009] we use the two types of return on capital to recover the price of capital, $r_{j,c,t}$, without the need to use accounting data.[2]

$$W_{j,c,t} = {w^H_{j,c,t}}^* \frac{H_{j,c,t}}{N_{j,c,t}} + {w^L_{j,c,t}}^* \frac{L_{j,c,t}}{N_{j,c,t}} + r_{j,c,t}\frac{K_{j,c,t}}{N_{j,c,t}} + r_{j,c,t}R_{j,c,t}\frac{K_{j,c,t}}{N_{j,c,t}} \tag{15}$$

Using the constant composition approach we consider Human Capital Externalities given as:

$$\text{Human Capital Externalities=}$$
$$\frac{\partial \left[{w^H_{j,c,t}}^* \frac{H}{N} + {w^L_{j,c,t}}^* \frac{L}{N} + r^*_{j,c,t}\frac{K}{N} + r^*_{j,c,t}R_{j,c,t}\frac{K}{N} \right]}{\partial S_{c,t}} \frac{S_{c,t}}{{w^H_{j,c,t}}^* \frac{H}{N} + {w^L_{j,c,t}}^* \frac{L}{N} + r_{j,c,t}\frac{K}{N} + r_{j,c,t}R_{j,c,t}\frac{K}{N}} | H_t,\ L_t \text{ and } K_t \text{ are constant} \tag{16}$$

Developing this expression we then arrive to the size of human capital externalities, which is given as [3]:

$$\text{Human Capital Externalities}=[(1-g)(1-\lambda)](\phi_K x_K+\phi_H x_H+\phi_L x_L)+g(\phi_K x_K+\phi_H x_H+\phi_L x_L) \tag{17}$$

Where ϕ_K, ϕ_L and ϕ_H stand for the share of capital, low skilled and high skilled labour respectively.
The expression is composed by two terms; the first is the externalities generated over the inputs, high skilled labour, $H_{j,c,t}$, low skilled labour, $L_{j,c,t}$ and capital $K_{j,c,t}$. The last term stands for the effect of the externality on the economic profits for the owner of the firm.
As expected, the size of human capital externalities depend on x_K, x_L and x_H, which correspond to the parameters on the skill concentration, $S_{c,t}$ in the firm's augmented technology, $A_{j,c,t}$. However the size of human capital externalities also depend on the share of the materials inputs, λ and on the market power g. Under perfect competition, e.g $g \approx 0$, the last term regarding the impact on externalities on economic profits vanishes.

[2]In Appendix 1 we show the steps behind this methodology.
[3]The detailed steps of the derivation are shown in Appendix 2.

3 Data

To assess the proposed research questions, we make use of two different databases covering portuguese firms between 2005 and 2013. The first one, *Quadros de Pessoal*, a longitudinal database which comprises information from firms and workers across time. From this database we collect information on firms' and workers' characteristics. The second database, *IES (Informação Empresarial Simplificada)*, regards balance sheet information. From this we recover information on the firms' assets and physical capital, as well as expenditures in materials and sales.

An important issue concerns the distinction between firms and establishments. In *Quadros de Pessoal* we observe the distribution of workers not just across the firms' headquarters but also across establishments. For Portugal, during the period studied, 12.06% of firms report to have more than one establishment. However in the merged balance sheet dataset, data is only reported at the firm level. In this work we exploit the richness of the data and our unit of observation is at the establishment level.[4]

In table 1 we present the descriptive statistics on our data, which covers 366,106 firms during a period of 9 years.

Since we focus our analysis on the skill concentration at the regional level, it is important to define the regional unit we are working with. We consider the skill concentration in 28 different regions in the portuguese mailand. These correspond to the smallest administrative region in Portugal after county level (NUTS III). We prefer to consider the regional concentration at this level, rather than at the county level, since in Portugal, particularly in the north part of the country, the county concentration of college graduates, is relatively small, and concentrated in few firms.[5]

[4]In Appendix 2 we elaborate on the data treatment.

[5]NUTS stand for the portuguese acronym for *Nomenclatura das Unidades Territoriais para Fins Estatísticos* (Methodology for territorial units for statistical purposes). This methodology divides the country into different partitions. When we consider the skill concentration we assume NUTS III. In all the empirical specification we use NUTS II level as a control variable. In appendix 6.4 we show maps of the portuguese mainland displaying these administrative divisions.

Table 1: Descriptive statistics

	Mean	S.d	Min	Max
Firm level (N=2,024,609)				
% workers not high school graduated	46.39	39.96	0	100
% workers high school graduated - academic track	12.69	24.81	0	100
% workers high school graduated - vocational track	3.37	13.2	0	100
% workers college graduated	8.12	20.73	0	100
Hourly wages not high school graduated (€)	4.71	15.91	1.7	12,747.01
Hourly wages high school graduated - academic track (€)	5.41	5.78	1.7	1,624.39
Hourly wages high school graduated - vocational track (€)	6.22	8.99	1.7	1,987.46
Hourly wages college graduated (€)	8.52	16.13	1.7	5,023.33
Price of capital	10.35	34.58	0	499.98
Mean workers' age	40.12	8.33	16	78
Number of workers	10.14	45.24	1	6,295
Sales (hundreds of €)	12,460.7	15,523.5	0	-
Capital (hundreds of €)	45.79	954.54	0.01	359,657.4
% female	42.53	37.07	0	100
% long-term contracts	57.46	37.01	0	100
Mean workers' tenure	6.34	5.76	0	50
Region Level (NUTS III level - 28 regions)				
Mean sales (hundreds of €)	11,858.29	4,431.52	1,529.517	192,757.7
Number of firms (hundreds)	219.27	197.95	15.02	6,145.38
% workers not high school graduated	63.07	10.25	0.2	85.75
% workers high school graduated - academic track	41.58	28.53	0.8	100
% workers high school graduated - vocational track	30.35	27.35	0.04	100
% workers college graduated	45.79	29.76	0.035	100

4 Empirical Strategy

Based on the theoretical framework, in the empirical strategy we assume that markets work in perfect competition (e.g $g \approx 0$) and the production function takes a Cobb Douglas functional form (e.g $\rho \approx 0$).

Under these assumptions, we consider that the return on the different inputs equal their marginal productivity and estimate how they are impacted by the concentration of skilled workers. Considering the return on different inputs separately we try to identify the externality effect filtered from the composition effect. As addressed in the theoretical part, these two may act together confounding the externality estimation. Thus, following [Moretti, 2004b] we estimate the impacts of externalities on the returns of different inputs. Particularly, within the firms, we split the returns on different production factors, namely: 1. Wages of workers without high school graduation; 2. Wages of high school graduated workers who followed a standard academic track; 3. Wages of high school graduated workers who followed a vocational track; 5. Wages of college graduated workers; 4. Price of capital:

$$ln(w^{C}_{j,c,I,t}) = X_{j,c,t}\beta_1 + Z_{c,t}\phi_1 + S_{c,t}\gamma_1 + \Phi_{1t} + \epsilon_{1j,c,I,t} \quad (18)$$

$$ln(w^{HA}_{j,c,I,t}) = X_{j,c,t}\beta_2 + Z_{c,t}\phi_2 + S_{c,t}\gamma_2 + \Phi_{2t} + \epsilon_{2j,c,I,t} \quad (19)$$

$$ln(w^{HV}_{j,c,I,t}) = X_{j,c,t}\beta_3 + Z_{c,t}\phi_3 + S_{c,t}\gamma_3 + \Phi_{3t} + \epsilon_{3j,c,I,t} \quad (20)$$

$$ln(w^{LH}_{j,c,I,t}) = X_{j,c,t}\beta_4 + Z_{c,t}\phi_4 + S_{c,t}\gamma_4 + \Phi_{4t} + \epsilon_{4j,c,I,t} \quad (21)$$

$$ln(r_{j,c,I,t}) = X_{j,c,t}\beta_5 + Z_{c,t}\phi_5 + S_{c,t}\gamma_5 + \Phi_{5t} + \epsilon_{5j,c,I,t} \quad (22)$$

$X_{j,c,t}$ stands for a set of controls at the firm level; $Z_{j,c,t}$ is a set of controls at the region level, Φ_t correspond to time fixed effect and $\epsilon_{j,c,t}$ is the error term. w^C, w^{AC}, w^{HV}, w^{LH} stand for the firm's average hourly wages for college graduated workers, high school graduated under the academic track, high school graduated under the vocational track and no high school graduated workers, respectively. $r_{j,c,I,t}$ corresponds to the price of capital, considering the specification given in (47).
$S_{c,t}$ stands for the share of skilled workers. We consider the concentration of two types of workers: 1. College graduated workers; 2. High school graduated workers under an academic track. This way we test how the size of the externality is different according to the type of education considered.
The different coefficients, γ, measure the size of human capital externality. As stated before, it is relevant to distinguish what part of this corresponds to the externality effect, and what part corresponds to composition effects. Consider that there is an increase in the share of college graduated workers in a given region, c. Over γ_1-γ_5 we may have two distinguish effects: 1. The externality effect due to concentration of skilled workers; 2. The market effect which may depress the wages of the college graduated workers due to the higher supply and increase the returns on the remaining inputs due to the cross elasticity effect. In this example if the coefficient γ_1 is positive, it means that the externality exists and it is able to overcome the potential negative effect due to a higher labour supply.
The specifications presented before does not control for an important component that may bias the estimation of human capital externality: selection. If the allocation of firms and industries to regions where the concentration of skills is higher is not random, then the human capital externalities estimate may be biased. Particularity if firms and industries which are more productive match to regions where the workers' skill level is

higher, this may create an upward bias of the externalities estimation. To take this into account, fixed effects at the industry level, π_I, and industry level, α_j are included:

$$ln(w^{C}_{j,c,I,t}) = X_{j,c,t}\beta_1 + Z_{c,t}\phi_1 + S_{c,t}\gamma_1 + \Phi_{1t} + \alpha_{1j} + \alpha_{1I} + \epsilon_{1j,c,I,t} \quad (23)$$

$$ln(w^{HA}_{j,c,I,t}) = X_{j,c,t}\beta_2 + Z_{c,t}\phi_2 + S_{c,t}\gamma_2 + \Phi_{2t} + \alpha_{2j} + \alpha_{2I} + \epsilon_{2j,c,I,t} \quad (24)$$

$$ln(w^{HV}_{j,c,I,t}) = X_{j,c,t}\beta_3 + Z_{c,t}\phi_3 + S_{c,t}\gamma_3 + \Phi_{3t} + \alpha_{3j} + \alpha_{3I} + \epsilon_{3j,c,I,t} \quad (25)$$

$$ln(w^{LH}_{j,c,I,t}) = X_{j,c,t}\beta_4 + Z_{c,t}\phi_4 + S_{c,t}\gamma_4 + \Phi_{4t} + \alpha_{4j} + \alpha_{4I} + \epsilon_{4j,c,I,t} \quad (26)$$

$$ln(r_{j,c,I,t}) = X_{j,c,t}\beta_5 + Z_{c,t}\phi_5 + S_{c,t}\gamma_5 + \Phi_{5t} + \alpha_{5j} + \alpha_{5I} + \epsilon_{5j,c,I,t} \quad (27)$$

This estimation is performed using an OLS approach. However, there maybe an endogenous relation between the concentration of workers in the region and the returns on the different firm inputs. To tackle this issue, and in line, with previous approaches in the literature [[Moretti, 2004a], [Ciccone and Peri, 2006], [Iranzo and Peri, 2009] and [Shapiro, 2006]] we adopt a an Instrumental Variable methodology. We detail this IV methodology ahead.

4.1 OLS Results

In this section we present the results of the OLS estimates of the returns of different production factors following the specifications (18)-(22); (23)-(27).

$X_{j,c,t}$ is the set of firm control variables which include: mean age of the firms' workers, total number of workers, proportion of female workers, proportion of long-term contracts, mean tenure of firm's workers, share of workers with different types of education, physical capital stock and firm's sales. $Z_{j,c,t}$ corresponds to two time varying regional variables, mean value of firms' sales and total number of firms. These two variables aim to control for the regional economic cycle across time. We present results for two specification with and without the variables in $Z_{j,c,t}$. Additionally we present results with and without firm and industry fixed effects. For all cases we control for a regional fixed effect, which correspond to the larger regional division of the country (NUTSII - 5 regions as the ones depicted in figure 6 of Appendix 6.4).

We start by reporting the results considering that the skills concentration, $S_{c,t}$, is given as the concentration of high school graduated workers who followed an academic track:

Table 2: OlS γ estimations - concentration of high school graduated workers - academic track.

	(1)	(2)	(3)	(4)
$ln(w^{LH}_{j.c.I.t})$	0.010***	0.009***	0***	0.001**
	(0.0002)	(0.0001)	(0.0006)	(0.0006)
$ln(w^{HA}_{j.c.I.t})$	0.011***	0.018***	0.001	0.002
	(0.0003)	(0.0002)	(0.0011)	(0.0012)
$ln(w^{HV}_{j.c.I.t})$	0.013***	0.020***	0.001	0.001
	(0.0006)	(0.0004)	(0.0021)	(0.0020)
$ln(w^{C}_{j.c.I.t})$	0.009***	0.016***	0.001	0.003*
	(0.0005)	(0.0003)	(0.0015)	(0.0015)
$ln(r_{j.c.I.t})$	-0.008***	0.038***	-0.014***	-0.016***
	(0.0006)	(0.0004)	(0.0016)	(0.0016)

(1) No industry and firm fixed effects, $Z_{j,c,t}$ included; (2) No industry and firm fixed effects, $Z_{j,c,t}$ not included (3) With industry and firm fixed effects, $Z_{j,c,t}$ included; (4) With industry and firm fixed effects, $Z_{j,c,t}$ not included
* $p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

Table 2 shows the OLS estimates of equations (18)-(22) considering $S_{c,t}$ as the regional concentration of high school graduated workers under an academic track. Generally, on the labour returns, we observe how the estimators are very different whether we include firm and industry fixed effects. When fixed effects are not included the estimators on the externalities effects are higher and generally significant. In this case an increase of one percentage point in the concentration of high school graduates in the region increases the wages between 0.09% and 2.00%. These effects fade way when the fixed effects are included. Additionally when we control for cyclical regional economic effects (e.g the number of firms and firm sales), the estimators tend to be lower. The only coefficients which remain significant in all specifications are the ones regarding the price of capital. These last estimators are a bit unstable with estimations which are both positive and negative. However in specifications which include firm and industry fixed effects we find that an increase of one percentage point in the regional share of high school graduates who followed an academic track decreases the return on capital between 1.4% and 1.6%.

Table 3: OlS γ estimations - concentration of college graduated workers

	(1)	(2)	(3)	(4)
$ln(w^{LH}_{j.c.I.t})$	0.004***	0.005***	-0.001**	-0.001***
	(0.0002)	(0.0000)	(0.0003)	(0.0003)
$ln(w^{HA}_{j.c.I.t})$	0.008***	0.011***	-0.001	-0.001
	(0.0004)	(0.0001)	(0.0007)	(0.0007)
$ln(w^{HV}_{j.c.I.t})$	0.008***	0.012***	0.001	0.001
	(0.0005)	(0.0002)	(0.0012)	(0.0011)
$ln(w^{C}_{j.c.I.t})$	0.006***	0.009***	-0.001*	-0.002*
	(0.0004)	(0.0002)	(0.0009)	(0.0008)
$ln(r_{j.c.I.t})$	-0.007***	0.029***	0.004***	0.006***
	(0.0006)	(0.0003)	(0.0009)	(0.0009)

(1) No industry and firm fixed effects, $Z_{j,c,t}$ included; (2) No industry and firm fixed effects, $Z_{j,c,t}$ not included (3) With industry and firm fixed effects, $Z_{j,c,t}$ included; (4) With industry and firm fixed effects, $Z_{j,c,t}$ not included
* $p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

In table 3 we report the OLS estimations regarding the externalities of the regional concentration of college graduated workers. Like in the previous case, the coefficients, without including fixed effects are higher and more significant than in the specifications where fixed effects are included. In the most complete specifications (with firm and industry fixed effects) the impact of the concentration of the most skilled workers is insignificant for the cases of the wages of the high school graduated workers (academic and vocational track). Negative and small impacts are found to be significant for the case of the workers who are not high school graduated and for the college graduated workers. For this last case, together with the externality effect the market effect must be also responsible for depressing the wages. In these most complete specifications the coefficient on capital is found to be positive and significant, implying that an increase of 1 p.p in the share of regional college graduated workers leads to an increase between 0.04% and 0.06% in the price of capital. This positive effect may reveal not just the positive externality of college graduated workers on capital but also a higher degree of complementarity between the regional concentration of college graduates and the firm's physical capital stock.

4.2 IV Results

In the previous specifications we showed the impact of the regional concentration of skilled workers on the firms' returns. However these specifications do not rule out the possibility that these impacts are driven by other regional factors which are correlated with the concentration of skilled workers. To mitigate this hypothesis, we follow an IV approach to estimate the causal effect between the firms' wages and returns on capital and the regional share of skilled workers.

To build the IV we take advantage of some institutional changes that happened in the portuguese educational system. Since the 1980's, the portuguese educational system has been suffering important changes, namely with policies to increase the mandatory education and the education supply. In 1986 it was decided to extend the mandatory education in Portugal from 6 to 9 years. This extension made that more students wanted to pursue an upper secondary education, reaching the 12 years of schooling. This increase in the enrolment rate at this level is visible in the figure 1. However the school supply across the country was short for the demand, and during this time period, it was needed to build new high schools across the country. Combining information collected in the archives of the portuguese ministry of education and in contacts directly with the schools we gathered the dates of construction of the 467 high schools in Portugal. Using this information, we constructed figures 1 and 2, which show that the number of high schools increased particularly during the 70's and 80's across the 28 regions of the country considered.

Figure 1

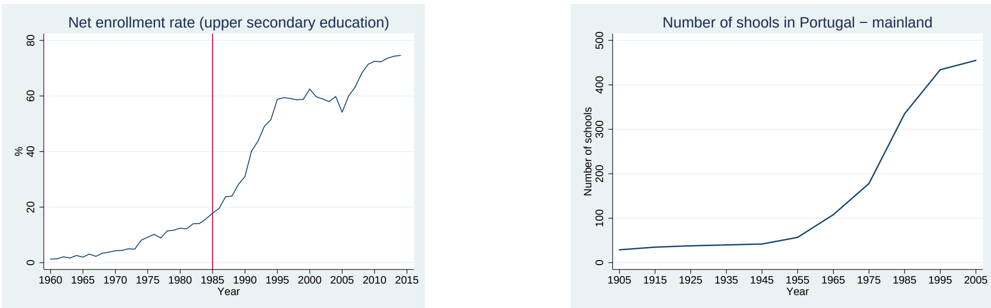
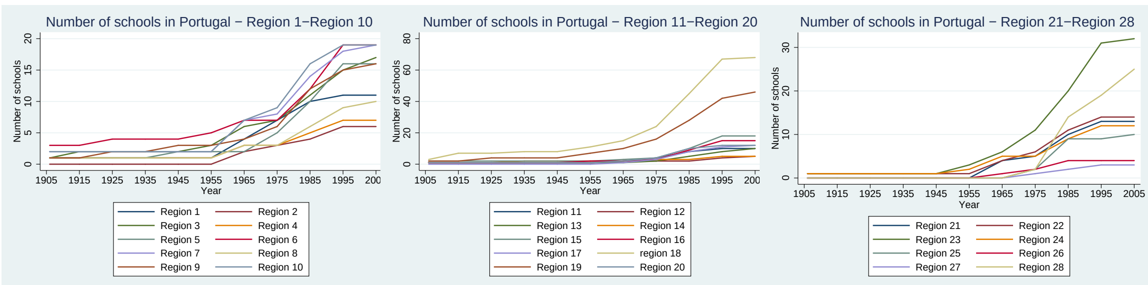


Figure 2



Region 1-Alentejo Central; Region 2-Alentejo Litoral; Region 3-Algarve; Region 4-Alto Alentejo; Region 5-Alto do Minho; Region 6-Alto Trás-os-Montes; Region 7-Ave; Region 8- Baixo Alentejo; Region 9-Baixo Mondego; Region 10-Baixo Vouga; Region 11-Beira Interior Norte; Region 12- Beira Interior Sul; Region 13- Cávado; Region 14-Cova da Beira; Region 15- Dão Lafões; Region 16-Douro; Region 17-Entre Douro e Vouga; Region 18- Grande Lisboa; Region 19- Grande Porto; Region 20- Lezíria do Tejo; Region 21-Médio Tejo; Region 22- Oeste; Region 24- Península de Setúbal; Region 25- Pinhal Litoral; Region 26- Pinhal Interior Norte; Region 27- Pinhal Interior Sul; Region 28- Tâmega e Sousa

This policy created an exogenous shock over the education supply which we use as a possible instrumental variable.This way, we construct an instrumental variable based on the number of schools in each region across time. Since our firm level data starts in 2005 we decided to consider the 100 years before, from 1905, and see in each year how many high schools were in each region. Then we average the number of schools in each region across this 100 years:

$$schools_c = \frac{\sum_{1905}^{2004} schools_t}{100} \tag{28}$$

This instrument is able to capture different trends in the evolution of the school supply in the country's regions across time. As it can be observed in figure 2 between 1905 and 2005 there is much of variation in the number of schools both within region and across regions.

Table 4: IV - concentration of high school graduated workers

		(1)	(2)	(3)	(4)
$ln(w^{LS}_{j,c,I,t})$	1st stage	0.67***	0.39***	0.29***	0.41***
		(0.0011)	(0.0003)	(0.0018)	(0.0017)
	2nd stage	0.002***	0.009***	-0.016***	0
		(0.0004)	(0.0001)	(0.0034)	(0.0022)
$ln(w^{HA}_{j,c,I,t})$	1st stage	0.74***	0.39***	0.35***	0.41***
		(0.0017)	(0.0001)	(0.0029)	(0.0026)
	2nd stage	0.009***	0.022***	-0.014***	-0.004
		(0.0006)	(0.0003)	(0.0053)	(0.004)
$ln(w^{HV}_{j,c,I,t})$	1st stage	0.59***	0.38***	0.25***	0.39***
		(0.0025)	(0.0006)	(0.0042)	(0.0009)
	2nd stage	0.013***	0.020***	0.008	0.006
		(0.0013)	(0.0003)	(0.0121)	(0.007)
$ln(w^{C}_{j,c,I,t})$	1st stage	0.60***	0.37***	0.24***	0.38***
		(0.0018)	(0.0004)	(0.0028)	(0.0026)
	2nd stage	0.019***	0.022***	-0.004	0.003
		(0.0010)	(0.0004)	(0.0088)	(0.005)
$ln(r_{j,c,I,t})$	1st stage	0.65***	0.39***	0.25***	0.41***
		(0.0008)	(0.0002)	(0.0013)	(0.0012)
	2nd stage	-0.019	0.068***	0.082***	0.027***
		(0.0014)	(0.0006)	(0.0010)	(0.0059)

(1) No industry and firm fixed effects, $Z_{j,c,t}$ included; (2) No industry and firm fixed effects, $Z_{j,c,t}$ not included (3) With industry and firm fixed effects, $Z_{j,c,t}$ included; (4) With industry and firm fixed effects, $Z_{j,c,t}$ not included
* $p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

Regarding the first stage of the IV estimations the coefficients have the expected sign and are significant. Namely, the increase in one unit of the average number of high schools in the region between 1905 and 2005 results in an increase between 0.24 and 0.74 p.p in the share of high school graduates under an academic track after 2005. The F-statistics on exclusion of the instrument are sufficiently high, fulfilling the rule of thumb of 10 for non-weak instruments. The results from the previous table must be compared with the ones from Table 2, the correspondent OLS estimation. For the cases of the workers' wages the IV results are in line with the OLS ones, with slightly lower estimations in the IV case for the workers without high school graduation in specifications (1) and (3). The estimation on the impact for the high school graduated workers who followed an academic track have also a lower return on the skill concentration in specification (3). In what concerns the return on capital, the IV estimations bring some differences in relation to the previous OLS one (Table 2 vs Table 4). The coefficients in the specifications which include firm and industry fixed effects, (3) and (4), are now positive in the IV specification. Then, when we use the instrumental variable, the impact of the concentration off high school graduated workers has a positive externality over the returns on capital in all significant specifications. Like in the OLS estimation great part of the externality effect ends up being absorbed when firm and industry fixed effects are included.

Table 5: IV - concentration of college graduated workers

		(1)	(2)	(3)	(4)
$ln(w^{LS}_{j,c,I,t})$	1st stage	0.27***	0.30***	0.51***	0.52***
		(0.0004)	(0.0001)	(0.0006)	(0.0006)
	2nd stage	0.010***	0.005***	-0.003***	-0.003
		(0.0003)	(0.0001)	(0.0005)	(0.0005)
$ln(w^{HA}_{j,c,I,t})$	1st stage	0.64***	0.74***	0.97***	0.70***
		(0.0017)	(0.0004)	(0.0046)	(0.0043)
	2nd stage	0.011***	0.011***	-0.005***	-0.002
		(0.0007)	(0.0001)	(0.0019)	(0.0024)
$ln(w^{HV}_{j,c,I,t})$	1st stage	0.25***	0.29***	1.19***	0.77***
		(0.0009)	(0.0003)	(0.0067)	(0.0068)
	2nd stage	0.012***	0.013***	0.0016	0.003
		(0.0011)	(0.0002)	(0.0025)	(0.0014)
$ln(w^{C}_{j,c,I,t})$	1st stage	0.27***	0.29***	1.19***	0.75***
		(0.0007)	(0.0002)	(0.0044)	(0.0045)
	2nd stage	0.007***	0.010***	0	0.0017
		(0.0008)	(0.0002)	(0.0018)	(0.0025)
$ln(r_{j,c,I,t})$	1st stage	0.28***	0.30***	0.50***	0.52***
		(0.0003)	(0.0001)	(0.0005)	(0.0005)
	2nd stage	-0.028***	0.033***	0.015***	0.015***
		(0.0011)	(0.0003)	(0.0014)	(0.0014)

(1) No industry and firm fixed effects, $Z_{j,c,t}$ included; (2) No industry and firm fixed effects, $Z_{j,c,t}$ not included (3) With industry and firm fixed effects, $Z_{j,c,t}$ included; (4) With industry and firm fixed effects, $Z_{j,c,t}$ not included
* $p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

Table 5 shows the IV estimation considering the regional concentration of college graduated workers. The first stage results show that the instrumental variable has the expected sign and it is significant for all the cases.
In terms of the results they are aligned with the OLS ones in Table 3. This implies that in the most complete specifications the only positive impact due to the concentration of college graduated students is on the return on capital, around 1.5%. As before the fixed effects at the industry and firm level absorb great part of the externality effect.
Overall from the OLS and IV estimations four important conclusions are taken: 1. In the specifications without controlling for firm and industry fixed efects, the impact on wages is higher in the case of the concentration of high school graduated workers than the case of the concentration of college graduated workers. This finding contradicts [Iranzo and Peri, 2009], which finds the opposite results with US data at the state level; 2. Regarding the wages, the size of human capital externalities becomes non significant when firm and industry and fixed effects are included; 3. The coefficients on capital are the ones which remain significant in the most complete specifications (with firm and industry fixed effects). For the OLS case, these are negative for the concentration of high school graduated workers and positive for the concentration of college workers. However, when we follow an IV estimation the impact on the price of capital is positive both due to the concentration of high school graduated workers and college graduated workers.

4.3 Decomposition

The results show how the size of the externalities effect are very sensitive to the inclusion of firm and industry effects The goal of this section is to understand if the potential bias in the externality estimation is driven by the non random allocation of firms and industries to regions with higher concentration of skills. In order to do so we apply the Gelbach decomposition which allow us to test how the coefficient on the human capital externality changes when industry and firm fixed effects are included in the specification. Examples of recent uses of this decomposition are [Buckles and Hungerman, 2013] which addresses the validity of the birth month as an exogenous variable to assess later outcomes and [Cardoso et al., 2016] which apply this methodology to decompose the gender wage gap.
To exemplify how this decomposition works, we come back to our specification of the firms' wages of the college graduated workers, given in (23):

$$ln(w^C_{j,c,I,t}) = X_{j,c,t}\beta_1 + Z_{c,t}\phi_1 + S_{c,t}\gamma_1 + \Phi_{1t} + \alpha_{1j} + \pi_{1I} + \epsilon_{1j,c,I,t} \tag{29}$$

Now consider this same specification, but without the industry and firm fixed effects, like in (18):

$$ln(w^C_{j,c,I,t}) = X_{j,c,t}\beta_1 + Z_{c,t}\phi_1 + S_{c,t}\gamma_1 + \Phi_{1t} + \epsilon_{1j,c,I,t} \tag{30}$$

In this last specification, the term, γ_1, stands for the impact on the average wage of the regional concentration of skilled workers. For γ_1 in (30) to be unbiased, there must be no correlation between the regional skill level and firm and industry constant characteristics. If that's not the case, γ_1 in (31) is different. The Gelbach decomposition allows to understand which part of this bias is due to the firm and industry effect.
We consider now a more generic case in matricial form, in which the explained variable is given as Y. S stands for the vector of the regional concentration of skilled workers. Additionally F the matrix of firm fixed effects, I the matrix of industry fixed effects. Thus, we consider two specifications, one which we call the base one, where fixed effects at firm and industry level are not included, and the full one, which includes F and I:

$$Y = S\gamma_{base} + \epsilon \tag{31}$$

$$Y = S\gamma_{full} + F\alpha_{full} + I\pi_{full} + \epsilon \tag{32}$$

By definition, we have:

$$\widehat{\gamma_{base}} = (S'S)^{-1}S'Y \tag{33}$$

Now, in (33) we multiply the right and left hand-side by part of the expression of γ_{base}, $(S'S)^{-1}S$:

$$(S'S)^{-1}SY = (S'S)^{-1}X\widehat{\gamma_{full}} + (S'S)^{-1}SF\widehat{\alpha_{full}} + (S'S)^{-1}SI + (S'S)^{-1}S\epsilon \tag{34}$$

Assuming the orthogonality condition between S and ϵ we have that $(S'S)^{-1}S\epsilon = 0$:

$$\widehat{\gamma_{base}} - \widehat{\gamma_{full}} = (S'S)^{-1}SF\widehat{\alpha_{full}} + (S'S)^{-1}SI\widehat{\pi_{full}} \tag{35}$$

$$\begin{aligned} \widehat{\gamma_{base}} - \widehat{\gamma_{full}} &= \widehat{\delta^F} + \widehat{\delta^I} \\ \widehat{\delta^F} &= (S'S)^{-1}SF\widehat{\alpha_{full}} \\ \widehat{\delta^I} &= (S'S)^{-1}SI\widehat{\pi_{full}} \end{aligned} \tag{36}$$

In this final expression we have on the left hand-side the difference between γ_{base} and γ_{full}, meaning the difference between the estimation on the externality effect, before and after controlling for firm and industry effects. The Gelbach decomposition allows us to observe how this difference depends on these variables.
When the estimation is done using an IV approach, the Gelbach decomposition can still be used. As pointed by Gelbach (2016), the expression (35) in that case becomes:

$$\widehat{\gamma_{base}} - \widehat{\gamma_{full}} = (\widehat{S}'\widehat{S})^{-1}\widehat{S}F\widehat{\alpha_{full}} + (\widehat{S}'\widehat{S})^{-1}\widehat{S}I\widehat{\pi_{full}} \tag{37}$$

Where $\widehat{S}$ corresponds to the OLS estimation of the projection of S in the instrumental variable. Thus, for the OLS and IV specifications, through the Gelbach decomposition we observe how the endogenous relation between the skill concentration and the firm and industry characteristics. If this endogenous relation exists, then firms and industries are not randomly allocated across the regions with different skill concentration.
When reporting the results for the Gelbach decomposition we must compare similar specifications with and without fixed effects, which means decompose the results between columns (1) and (3) and (2) and (4) in tables 2,3,4 and 5.

Table 6: Gelbach Decomposition - OLS estimation on the concentration of high school graduates - academic track

	(1)/(3)		(2)/(4)	
	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)
$ln(w^{LS}_{j,c,I,t})$	0.0011***	0.0090***	0***	0.0076***
	(0.0002)	(0.0002)	(0.0002)	(0.0001)
$ln(w^{HA}_{j,c,I,t})$	0.001***	0.0098***	0***	0.0150***
	(0.0001)	(0.0003)	(0.0001)	(0.0002)
$ln(w^{HV}_{j,c,I,t})$	-0.001***	0.0210***	-0.0005***	0.0201***
	(0.0004)	(0.0019)	(0.0001)	(0.0004)
$ln(w^{C}_{j,c,I,t})$	0***	0.0078***	0.0002***	0.0138***
	(0.0001)	(0.0005)	(0.0001)	(0.0003)
$ln(r_{j,c,I,t})$	0.0018***	0.0034***	0.0022***	0.0523***
	(0.0001)	(0.0006)	(0.0001)	(0.0004)

$p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

Table 7: Gelbach Decomposition - OLS estimation on the concentration of college graduated workers

	(1)/(3)		(2)/(4)	
	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)
$ln(w^{LS}_{j,c,I,t})$	0.0007***	0.0048**	0****	0.0006***
	(0.0001)	(0.0002)	(0.0000)	(0.0001)
$ln(w^{HA}_{j,c,I,t})$	0.0005***	0.0087***	0***	0.0117***
	(0.0001)	(0.0001)	(0.0002)	(0.0001)
$ln(w^{HV}_{j,c,I,t})$	0***	0.0079***	0***	0.0115***
	(0.0001)	(0.0002)	(0.0000)	(0.0001)
$ln(w^{C}_{j,c,I,t})$	0***	0.0077***	0***	0.0112***
	(0.0002)	(0.0004)	(0.0002)	(0.0002)
$ln(r_{j,c,I,t})$	0.0010***	-0.0130***	0.0012***	0.0219***
	(0.0002)	(0.0002)	(0.0002)	(0.0001)

$p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

Tables 6 and 7 report the Gelbach decomposition for the OLS estimations considering the concentration of high school and college graduated workers. For both cases we observe similar results. The difference between the estimations on externalities with and without industry and firm fixed effects is due to the firm effect. The positive sign in the industry effect, δ^F, shows that the inclusion of firms effects is the one responsible for the sensitiveness of the estimations on the externality effect. This implies that the most productive firms are allocated in the places where the concentration of skilled workers is higher, leading then to higher returns of the inputs. This gives a relevant input on how the human capital externality is built within each region. The concentration of skilled workers makes that the most productive firms match in these same regions, making that the wages go up. The only result that seems to challenge this pattern is the impact of college gradates concentration on capital, which in the case that compares (1)/(3) shows a negative sign for the firm effect. This matches the more floaty results on capital showed previously in tables 2-5. We now show the results of this this same decomposition for the case of the IV estimation:

Table 8: Gelbach Decomposition - IV estimation on the concentration of high school graduates - academic track

	(1)/(3)		(2)/(4)	
	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)
$ln(w^{LS}_{j,c,I,t})$	0.0010***	0.0178***	0.0004****	0.0086***
	(0.0001)	(0.0003)	(0.0000)	(0.0001)
$ln(w^{HA}_{j,c,I,t})$	0.0013***	0.0271***	0.0009***	0.0266***
	(0.0001)	(0.0007)	(0.0000)	(0.0002)
$ln(w^{HV}_{j,c,I,t})$	0.0010***	0.0045***	0***	0.0204***
	(0.0001)	(0.0007)	(0.0000)	(0.0005)
$ln(w^{C}_{j,c,I,t})$	0.0009***	0.0242***	0.0002***	0.0184***
	(0.0001)	(0.0009)	(0.0000)	(0.0004)
$ln(r_{j,c,I,t})$	0.0012 ***	-0.1032***	0.0024	0.039***
	(0.0000)	(0.00123)	(0.0000)	(0.0001)

$p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

Table 9: Gelbach Decomposition - IV estimation on the concentration of college graduated workers

	(1)/(3)		(2)/(4)	
	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)	industry ($\widehat{\delta^I}$)	firm ($\widehat{\delta^F}$)
$ln(w^{LS}_{j,c,I,t})$	0.0010***	0.0039***	0.0001***	0.0075***
	(0.0000)	(0.0003)	(0.0000)	(0.0001)
$ln(w^{HA}_{j,c,I,t})$	0.0011***	0.0112**	0.0005***	0.0129***
	(0.0000)	(0.0005)	(0.0000)	(0.0001)
$ln(w^{HV}_{j,c,I,t})$	0.0007	0.0073***	-0.0003***	0.0098***
	(0.0002)	(0.0008)	(0.0000)	(0.0002)
$ln(w^{C}_{j,c,I,t})$	0.0007	0.0151***	0.0000****	0.0088***
	(0.0001)	(0.0007)	(0.0000)	(0.0002)
$ln(r_{j,c,I,t})$	0.0008	-0.032***	0.0012***	0.018***
	(0.0001)	(0.0009)	(0.0000)	(0.0001)

$p < 0.1$; ** $p < 0.05$; ***$p < 0.001$. Standard errors in parentheses.

The Gelbach decomposition on the IV estimates shows result similar to those ones of the OLS case. Again the firm effect is the one responsible for absorbing the externality effect. The industry effect is never higher than 0.001 meaning that it explains at most 1 p.p of the effect of the skill concentration on wages. Again, the case for which results are more sensitive are the ones for capital, whose firm effect, $\widehat{\delta^F}$, does not show to be robustly positive.

5 Conclusion

This works intends to enlarge the literature on human capital externalities addressing the sources and mechanisms responsible for these same externalities at the firm level. Particularity, we assess: 1. How the externalities affect the marginal productivity of different inputs within the firm; 2. How the Human Capital externalities are affected by the allocation of firms and industries to regions with higher concentration of skills.
On the first research question we found non significant impacts on wages due to the regional concentration of high school graduated workers and college graduated workers. This is true for the wages of workers with different education levels within the firm. However in terms of the return on capital, particularly when we use the number of high schools built across time as an instrumental variable, the impact of skills concentration is positive and statistically significant. This result is more robust when we consider the regional concentration of college graduates. This shows how human capital externalities can affect differently the marginal productivity on different inputs, helping to explain how the firm reacts to the regional concentration of skills.
We also observed that the results on the estimation of the externality effect are substantially reduced when we account for firm and industry fixed effects, arising the question about the endogenous relation between firm and industry characteristics and the regional concentration of human capital. Using the methodology proposed by Gelbach (2016) we note that the industry effect plays the major role in cancelling the externality effect. This result is particularly robust when we address the returns on labour. This allows us to understand that the concentration of skilled workers in a region makes the most productivity firms to locate in this same region, being the firms' productivity the one responsible for higher wages.

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6 Appendix

6.1 Appendix 1

The price of capital is estimated structurally, without exploiting the use of accounting data. We now show how we estimate the price of capital, $r_{j,c,t}$, following Keane (2009). In order to arrive to the price of capital, $r_{j,c,t}$, we first need to recover the profit rate, $R_{j,c,t}$:

$$R_{j,c,t} = \frac{\pi_{j,c,t}}{r_{j,c,t} K_{j,c,t}} \tag{38}$$

To identify $R_{j,c,t}$ we assume the firm's maximization problem without considering the adjustments costs:

$$\pi_{j,c,t} = P_{j,c,t} Y_{j,c,t} - w_{H,j,c,t} H_{j,c,t} - w_{L,j,c,t} L_{j,c,t} - r_{j,c,t} K_{j,c,t} \tag{39}$$

We consider as before that prices are given as:

$$P_{j,c,t} = P_0 Y_{j,c,t}^{-g} \tag{40}$$

Considering the marginal product of capital:

$$r_{j,c,t} = \frac{P_0 A_{j,c,t}{}_{*}^{\pi} M_{j,c,t}^{\omega} (1-\lambda)(1-g)\alpha_K (S_{c,t}^{x_K})^{\eta} Y_{j,c,t}^{\rho}}{(K_{j,c,t})^{1-\eta}} \tag{41}$$

Coming back to the profit function we have:

$$\pi_{j,c,t} = P_{j,c,t} Y_{j,c,t} - w_{H,j,c,t} H_{j,c,t} - w_{L,j,c,t} L_{j,c,t} - r_{j,c,t} K_{j,c,t} \tag{42}$$

Remembering that:

$$R_{j,c,t} = \frac{\pi_{j,c,t}}{r_{j,c,t} K_{j,c,t}} \tag{43}$$

$$R_{j,c,t} r_{j,c,t} K_{j,c,t} = \pi_{j,c,t} \tag{44}$$

$$R_{j,c,t} r_{j,c,t} K_{j,c,t} = P_{j,c,t} Y_{j,c,t} - w_{H,j,c,t} H_{j,c,t} - w_{L,j,c,t} L_{j,c,t} - r_{j,c,t} K_{j,c,t} \tag{45}$$

$$r_{j,c,t}(R_{j,c,t}K_{j,c,t} + K_{j,c,t}) = P_{j,c,t}Y_{j,c,t} - w_{H,j,c,t}H_{j,c,t} - w_{L,j,c,t}L_{j,c,t} \tag{46}$$

$$r_{j,c,t} = \frac{P_{j,c,t}Y_{j,c,t} - w_{H,j,c,t}H_{j,c,t} - w_{L,j,c,t}L_{j,c,t}}{(R_{j,c,t}K_{j,c,t} + K_{j,c,t})} \tag{47}$$

Considering the equivalence between (47) and (41) we have:

$$\frac{P_{j,c,t}Y_{j,c,t} - w_{H,j,c,t}H_{j,c,t} - w_{L,j,c,t}L_{j,c,t}}{(R_{j,c,t}K_{j,c,t} + K_{j,c,t})} = \frac{P_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K (S_{c,t}^{x_K})^{\eta} Y_{j,c,t}^{\rho}}{(K_{j,c,t})^{1-\eta}} \tag{48}$$

$$\frac{P_{j,c,t}Y_{j,c,t} - w_{H,j,c,t}H_{j,c,t} - w_{L,j,c,t}L_{j,c,t}}{(R_{j,c,t} + 1)} = \frac{P_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K (S_{c,t}^{x_K})^{\eta} Y_{j,c,t}^{\rho}}{(K_{j,c,t})^{-\eta}} \tag{49}$$

$$\left(\frac{1}{S_{c,t}^{x_K} K_{j,c,t}}\right)^{\eta} \frac{Y_{j,c,t}^{\frac{\eta}{1-\lambda}}}{A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K} \frac{P_{j,c,t}Y_{j,c,t} - w_{H,j,c,t}H_{j,c,t} - w_{L,j,c,t}L_{j,c,t}}{P_{j,c,t}Y_{j,c,t}} = (1+R_{j,c,t}) \tag{50}$$

Now we remember that g is given as a Lerner markup index:

$$g = \frac{P_{j,c,t}Y_{j,c,t} - w_{H,j,c,t}H_{j,c,t} - w_{L,j,c,t}L_{j,c,t} - r_{j,c,t}K_{j,c,t}}{P_{j,c,t}Y_{j,c,t}} \tag{51}$$

Then we can rewrite (51) as:

$$\left(\frac{1}{S_{c,t}^{x_K} K_{j,c,t}}\right)^{\eta} \frac{Y_{j,c,t}^{\frac{\eta}{1-\lambda}}}{A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K} \left\{g + \frac{r_{j,c,t}K_{j,c,t}}{P_{j,c,t}Y_{j,c,t}}\right\} - 1 = R_{j,c,t} \tag{52}$$

$$\left(\frac{1}{S_{c,t}^{x_K} K_{j,c,t}}\right)^{\eta} \frac{Y_{j,c,t}^{\frac{\eta}{1-\lambda}}}{A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K} \left\{g + \frac{P_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K (S_{c,t}^{x_K})^{\eta} Y_{j,c,t}^{\rho}}{(K_{j,c,t})^{1-\eta}} \frac{K_{j,c,t}}{P_{j,c,t}Y_{j,c,t}}\right\} - 1 = R_{j,c,t} \tag{53}$$

$$\left(\frac{1}{S_{c,t}^{x_K} K_{j,c,t}}\right)^{\eta} \frac{Y_{j,c,t}^{\frac{\eta}{1-\lambda}}}{A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K} \left\{g + A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}\alpha_K(1-\lambda)(1-g)(Y_{j,c,t})^{(1-\lambda)} \left[\frac{S_{c,t}^{x_K} K_{j,c,t}}{Y_{j,c,t}}\right]^{\eta}\right\} - 1 = R_{j,c,t} \tag{54}$$

$$R_{j,c,t} = \left(\frac{1}{S_{c,t}^{x_K} K_{j,c,t}}\right)^{\eta} \frac{Y_{j,c,t}^{\frac{\eta}{1-\lambda}} g}{A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K} \tag{55}$$

Then, after identifying $R_{j,c,t}$ we can then recover the price of capital, $r_{j,c,t}$.

6.2 Appendix 2

In this section we provide a detailed proof on the derivation of human externalities presented in the theoretical framework section. Before proceeding we define the following parameters:

$$\rho = (1-g) - \frac{\eta}{(1-\lambda)} \tag{56}$$

$$\rho_2 = (1-g) - \frac{2\eta}{(1-\lambda)} \tag{57}$$

$$\upsilon = (1-g)(1-\lambda) \tag{58}$$

$$\psi = (1-g)(1-\lambda) - 1 \tag{59}$$

$$\pi = \frac{\eta}{(1-\lambda)} - (1-g) \tag{60}$$

$$\pi_2 = \frac{2\eta}{(1-\lambda)} - (1-g) \tag{61}$$

$$\omega = \eta - (1-\lambda)(1-g) \tag{62}$$

$$\omega_2 = 2\eta - (1-\lambda)(1-g) \tag{63}$$

Developing the first order conditions of the problem in relation to physical capital, $K_{j,c,t}$,

$$\frac{\partial \Pi_{j,c,t}}{\partial K_{j,c,t}} = \frac{P_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K (S_{c,t}^{xK})^{\eta} Y_{j,c,t}^{\rho}}{K_{j,c,t}^{1-\eta}} - r_{j,c,t} - \theta_{1,K} - 2\theta_{2,K}[K_{j,c,t} - K_{j,c,t-1}] + \beta E[\theta_{1,K} + 2\theta_{2,K}(K_{j,c,t+1} - K_{j,c,t})] = 0 \tag{64}$$

$$r_{j,c,t}^{*} = r_{j,c,t} + \theta_{1,K} + 2\theta_{2,K}[K_{j,c,t} - K_{j,c,t-1}] - \beta E_t[\theta_{1,K} + 2\theta_{2,K}(K_{c,t+1} - K_{c,t})] \tag{65}$$

$$r_{j,c,t}^{*} = \frac{P_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\alpha_K (S_{c,t}^{xK})^{\eta} Y_{j,c,t}^{\rho}}{(K_{j,c,t})^{1-\eta}} \tag{66}$$

$$r_{j,c,t}^{*} = P_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega} \alpha_K (1-\lambda)(1-g) \left(\frac{Y_{j,c,t}}{(S_{c,t}^{xK} K_{j,c,t})^{(1-\lambda)}} \right)^{\rho} (S_{c,t}^{xK})^{\upsilon} (K_{j,c,t})^{\psi} \tag{67}$$

$$r^*_{j,c,t} = P_0 A_{j,c,t*} M^{(1-\lambda)}_{j,c,t} \alpha_K (1-\lambda)(1-g) \left[\frac{[\alpha_K (S^{x_K}_{c,t} K_{j,c,t})^\eta + \alpha_H (S^{x_H}_{c,t} H_{j,c,t})^\eta + \alpha_L (S^{x_H}_{c,t} L_{j,c,t})^\eta]^{\frac{1-\lambda}{\eta}}}{(S^{x_K}_{c,t} K_{j,c,t})^{(1-\lambda)}} \right]^\rho (S^{x_K}_{c,t})^\upsilon (K_{j,c,t})^\psi \tag{68}$$

$$r^*_{j,c,t} = P_0 A_{j,c,t*} M^{(1-\lambda)}_{j,c,t} \alpha_K (1-\lambda)(1-g) \left[\alpha_K \left(\frac{S^{x_K}_{c,t} K_{j,c,t}}{S^{x_K}_{c,t} K_{j,c,t}} \right)^\eta + \alpha_H \left(\frac{S^{x_H}_{c,t} H_{j,c,t}}{S^{x_K}_{c,t} K_{j,c,t}} \right)^\eta + \alpha_L \left(\frac{(S^{x_L}_{c,t} L_{j,c,t}}{S^{x_K}_{c,t} K_{j,c,t}} \right)^\eta \right]^{\frac{\rho(1-\lambda)}{\eta}} (S^{x_K}_{c,t})^\upsilon (K_{j,c,t})^\psi \tag{69}$$

$$r^*_{j,c,t} = P_0 A_{j,c,t*} M^{(1-\lambda)}_{j,c,t} \alpha_K (1-\lambda)(1-g) \left[\alpha_K + \alpha_H S^{\eta(x_H - x_K)}_{c,t} \left(\frac{H_{j,c,t}}{K_{j,c,t}} \right)^\eta + \alpha_L S^{\eta(x_L - x_K)}_{c,t} \left(\frac{L_{j,c,t}}{K_{j,c,t}} \right)^\eta \right]^{\frac{\rho(1-\lambda)}{\eta}} (S^{x_K}_{c,t})^\upsilon (K_{j,c,t})^\psi \tag{70}$$

In a similar fashion for the other inputs, low skilled labour, $L_{j,c,t}$ and $H_{j,c,t}$, we arrive to the following expressions:

$$w^H_{j,c,t} = P_0 A_{j,c,t*} M^{(1-\lambda)}_{j,c,t} (1-\lambda)(1-g) \alpha_H \left[\alpha_K S^{\eta(x_K - x_H)}_{c,t} \left(\frac{K_{j,c,t}}{H_{j,c,t}} \right)^\eta + \alpha_H + \alpha_L S^{\eta(x_L - x_H)}_{c,t} \left(\frac{L_{j,c,t}}{H_{j,c,t}} \right)^\eta \right]^{\frac{\rho(1-\lambda)}{\eta}} (S^{x_H}_{c,t})^\upsilon (H_{j,c,t})^\psi \tag{71}$$

$$w^L_{j,c,t} = P_0 A_{j,c,t*} M^{(1-\lambda)}_{j,c,t} (1-\lambda)(1-g) \alpha_L \left[\alpha_K S^{\eta(x_K - x_L)}_{c,t} \left(\frac{K_{j,c,t}}{L_{j,c,t}} \right)^\eta + \alpha_H S^{\eta(x_H - x_L)}_{c,t} \left(\frac{H_{j,c,t}}{L_{j,c,t}} \right)^\eta + \alpha_L \right]^{\frac{\rho(1-\lambda)}{\eta}} (S^{x_L}_{c,t})^\upsilon (L_{j,c,t})^\psi \tag{72}$$

Like stated in the theoretical framework we then use this equilibrium wages and return on capital to assess the impact of regional skill concentration on the income generated by the firm. We assume that the total remuneration of the firms' production factors is given as:

$$W_{j,c,t} = {w^H_{j,c,t}}^* \frac{H_{j,c,t}}{N_{j,c,t}} + {w^L_{j,c,t}}^* \frac{L_{j,c,t}}{N_{j,c,t}} + r_{j,c,t} \frac{K_{j,c,t}}{N_{j,c,t}} + \frac{\pi_{j,c,t}}{N_{j,c,t}} \tag{73}$$

This corresponds to the average income per worker generated by the firm, composed by the wages of the high and low skilled workers, the return on the owners of capital and on the owners of the firm. Replacing for the conditions found in Appendix 1 for the returns on capital, we have:

$$W_{j,c,t} = {w^H_{j,c,t}}^* \frac{H_{j,c,t}}{N_{j,c,t}} + {w^L_{j,c,t}}^* \frac{L_{j,c,t}}{N_{j,c,t}} + r_{j,c,t} \frac{K_{j,c,t}}{N_{j,c,t}} + r_{j,c,t} R_{j,c,t} \frac{K_{j,c,t}}{N_{j,c,t}} \tag{74}$$

Using the constant composition approach we consider that Human Capital Externalities are given as the marginal change in the total income generated by the firm, when there is an increase in the share of skilled workers, $S_{c,t}$ considering that the distribution on the inputs is kept constant within the firm:

$$\text{Human Capital Externalities}=$$
$$\frac{\partial\left[{w^{H}_{j,c,t}}^{*}\frac{H}{N}+{w^{L}_{j,c,t}}^{*}\frac{L}{N}+r^{*}_{j,c,t}\frac{K}{N}+r^{*}_{j,c,t}R_{j,c,t}\frac{K}{N}\right]}{\partial S_{c,t}}\frac{S_{c,t}}{{w^{H}_{j,c,t}}^{*}\frac{H}{N}+{w^{L}_{j,c,t}}^{*}\frac{L}{N}+r_{j,c,t}\frac{K}{N}+r_{j,c,t}R_{j,c,t}\frac{K}{N}}|H_t,\ L_t \text{ and } K_t \text{ are constant} \tag{75}$$

We develop (75), stating before four parameters that are used below, and which correspond to the share of the four inputs in the total income generated by the firm:

$$r^{*}_{j,c,t}\frac{K_{j,c,t}}{N_{j,c,t}W_{j,c,t}}=\phi_K \tag{76}$$

$${w^{H}_{j,c,t}}^{*}\frac{H_{j,c,t}}{N_{j,c,t}W_{j,c,t}}=\phi_H \tag{77}$$

$${w^{L}_{j,c,t}}^{*}\frac{H_{j,c,t}}{N_{j,c,t}W_{j,c,t}}=\phi_L \tag{78}$$

$$\begin{gathered}\frac{\partial\left[{r^{*}_{j,c,t}}^{*}\frac{K}{N}\right]}{\partial S_{c,t}}\frac{S_{c,t}}{W_{j,c,t}}= \\ \mathrm{P}_0 {A_{j,c,t}}_{*}^{\pi_2}M^{\omega_2}_{j,c,t}(1-\lambda)(1-g)\alpha_K\rho(1-\lambda)(x_H-x_K)\alpha_H S^{\eta(x_H+x_K)}_{c,t}H^{\eta}_{j,c,t}K^{\eta}_{j,c,t}Y^{\rho_2}_{j,c,t}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}+ \\ \mathrm{P}_0 {A_{j,c,t}}_{*}^{\pi_2}M^{\omega_2}_{j,c,t}(1-\lambda)(1-g)\alpha_K\rho(1-\lambda)(x_L-x_K)\alpha_L S^{\eta(x_L+x_K)}_{c,t}L^{\eta}_{j,c,t}K^{\eta}_{j,c,t}Y^{\rho_2}_{j,c,t}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}+ \\ \phi_K x_K \upsilon\end{gathered} \tag{79}$$

$$\begin{gathered}\frac{\partial\left[{w^{H}_{j,c,t}}^{*}\frac{H}{N}\right]}{\partial S_{c,t}}\frac{S_{c,t}}{W_{j,c,t}}= \\ \mathrm{P}_0 {A_{j,c,t}}_{*}^{\pi_2}M^{\omega_2}_{j,c,t}(1-\lambda)(1-g)\alpha_H\rho(1-\lambda)(x_K-x_H)\alpha_K S^{\eta(x_H+x_K)}_{c,t}K^{\eta}_{j,c,t}H^{\eta}_{j,c,t}Y^{\rho_2}_{j,c,t}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}+ \\ \mathrm{P}_0 {A_{j,c,t}}_{*}^{\pi_2}M^{\omega_2}_{j,c,t}(1-\lambda)(1-g)\alpha_H\rho(1-\lambda)(x_L-x_H)\alpha_L S^{\eta(x_L+x_K)}_{c,t}L^{\eta}_{j,c,t}H^{\eta}_{j,c,t}Y^{\rho_2}_{j,c,t}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}+ \\ \phi_H x_H \upsilon\end{gathered} \tag{80}$$

$$
\frac{\partial\left[{w^L_{j,c,t}}^*\frac{L}{N}\right]}{\partial S_{c,t}}\frac{S_{c,t}}{W_{j,c,t}} =
$$
$$
P_0 A_{j,c,t}{}_*^{\pi_2} M_{j,c,t}^{\omega_2}(1-\lambda)(1-g)\alpha_L\rho(1-\lambda)(x_K-x_L)\alpha_K S_{c,t}^{\eta(x_K+x_L)} K_{j,c,t}^{\eta} L_{j,c,t}^{\eta} Y_{j,c,t}^{\rho_2}\tfrac{1}{N_{j,c,t}}\tfrac{S_{c,t}}{W_{j,c,t}}+
$$
$$
P_0 A_{j,c,t}{}_*^{\pi_2} M_{j,c,t}^{\omega_2}(1-\lambda)(1-g)\alpha_L\rho(1-\lambda)(x_H-x_L)\alpha_H S_{c,t}^{\eta(x_H+x_L)} H_{j,c,t}^{\eta} L_{j,c,t}^{\eta} Y_{j,c,t}^{\rho_2}\tfrac{1}{N_{j,c,t}}\tfrac{S_{c,t}}{W_{j,c,t}}+
$$
$$
\phi_L x_L \upsilon \tag{81}
$$

$$
\frac{\partial\left[R_{j,c,t}r^*_{j,c,t}\frac{K}{N}\right]}{\partial S_{c,t}}\frac{S_{c,t}}{W_{j,c,t}} =
$$
$$
\begin{gathered}
\text{g}\phi_K x_K + \\
\text{g}\phi_H x_H + \\
\text{g}\phi_L x_L \Leftrightarrow \\
\text{g}(\phi_K x_K + \phi_H x_H + \phi_L x_L)
\end{gathered} \tag{82}
$$

$$
\begin{gathered}
\text{Human Capital Externalities=} \\
\text{P}_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_K\rho(x_H-x_K)\alpha_H S_{c,t}^{\eta(x_H+x_K)} H_{j,c,t}^{\eta} K_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\tfrac{1}{N_{j,c,t}}\tfrac{1}{W_{j,c,t}}+ \\
\text{P}_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_K\rho(x_L-x_K)\alpha_L S_{c,t}^{\eta(x_L+x_K)} L_{j,c,t}^{\eta} K_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\tfrac{1}{N_{j,c,t}}\tfrac{1}{W_{j,c,t}}+ \\
\phi_K x_K \upsilon + \\
\text{P}_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_K(x_K-x_H)\alpha_H S_{c,t}^{\eta(x_H+x_K)} K_{j,c,t}^{\eta} H_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\tfrac{1}{N_{j,c,t}}\tfrac{1}{W_{j,c,t}}+ \\
\text{P}_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_L(x_L-x_H)\alpha_L S_{c,t}^{\eta(x_L+x_K)} L_{j,c,t}^{\eta} H_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\tfrac{1}{N_{j,c,t}}\tfrac{1}{W_{j,c,t}}+ \\
\phi_H x_H \upsilon + \\
\text{P}_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_L(x_K-x_L)\alpha_K S_{c,t}^{\eta(x_K+x_L)} K_{j,c,t}^{\eta} L_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\tfrac{1}{N_{j,c,t}}\tfrac{S_{c,t}}{W_{j,c,t}}+ \\
\text{P}_0 A_{j,c,t}{}_*^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_L(x_H-x_L)\alpha_H S_{c,t}^{\eta(x_H+x_L)} H_{j,c,t}^{\eta} L_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\tfrac{1}{N_{j,c,t}}\tfrac{S_{c,t}}{W_{j,c,t}}+ \\
\phi_L x_L \upsilon + \\
\text{g}(\phi_K x_K + \phi_H x_H + \phi_L x_L)
\end{gathered} \tag{83}
$$

$$
\begin{gathered}
\text{Human Capital Externalities=}\\
\mathrm{P}_0 A_{j,c,t*}^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_K\rho(x_H-x_K)\alpha_H S_{c,t}^{\eta(x_H+x_K)} H_{j,c,t}^{\eta} K_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}-\\
\mathrm{P}_0 A_{j,c,t*}^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_K(x_H-x_K)\alpha_H S_{c,t}^{\eta(x_H+x_K)} K_{j,c,t}^{\eta} H_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}+\\
\mathrm{P}_0 A_{j,c,t*}^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_K\rho(x_L-x_K)\alpha_L S_{c,t}^{\eta(x_L+x_K)} L_{j,c,t}^{\eta} K_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}-\\
\mathrm{P}_0 A_{j,c,t*}^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_L(x_L-x_K)\alpha_K S_{c,t}^{\eta(x_K+x_L)} K_{j,c,t}^{\eta} L_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\frac{1}{N_{j,c,t}}\frac{S_{c,t}}{W_{j,c,t}}+\\
\mathrm{P}_0 A_{j,c,t*}^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_L(x_L-x_H)\alpha_L S_{c,t}^{\eta(x_L+x_K)} L_{j,c,t}^{\eta} H_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\frac{1}{N_{j,c,t}}\frac{1}{W_{j,c,t}}-\\
\mathrm{P}_0 A_{j,c,t*}^{\pi} M_{j,c,t}^{\omega}(1-\lambda)(1-g)\rho(1-\lambda)\alpha_L(x_L-x_H)\alpha_H S_{c,t}^{\eta(x_H+x_L)} H_{j,c,t}^{\eta} L_{j,c,t}^{\eta} Y_{j,c,t}^{\rho-\eta}\frac{1}{N_{j,c,t}}\frac{S_{c,t}}{W_{j,c,t}}+\\
\phi_K x_K \upsilon+\\
\phi_H x_H \upsilon+\\
\phi_L x_L \upsilon+\\
\mathrm{g}(\phi_K x_K+\phi_H x_H+\phi_L x_L)
\end{gathered} \tag{84}
$$

$$
\begin{gathered}
\text{Human Capital Externalities=}\\
\phi_K x_K[(1-g)(1-\lambda)]+\\
\phi_H x_H[(1-g)(1-\lambda)]+\\
\phi_L x_L[(1-g)(1-\lambda)]+\\
\mathrm{g}(\phi_K x_K+\phi_H x_H+\phi_L x_L)
\end{gathered} \tag{85}
$$

6.3 Appendix 3

As stated in the section regarding the Data, two different databases were merged in this work.

In order to overcome the data limitation that we do not dispose of information on sales, materials and physical capital at the establishment level, we need to adopt a data treatment strategy for such cases.
We start by reporting the number of firms with more than one establishment during the period between 2005 and 2013:

Ano	% firms > 1 estab.	Median # estabs
2005	21.3	4
2006	21.24	4
2007	21.28	4
2008	21.19	4
2009	21.04	4
2010	23.18	4
2011	23.47	4
2012	23.53	4
2013	23.01	4

As we can observe the number of firms with more than one establishments has been fairly constant across time. Those firms whose establishments are located in the same region are treated as a single establishment. Then, we report the number of firms which have establishments in more than one region (considering the NUTS III regional division of the country):

Ano	% firms > 1 estab.	Median # estabs
2005	12.70%	7
2006	12.67%	8
2007	12.76%	7
2008	12.80%	8
2009	12.55%	7
2010	13.61%	7
2011	14.26%	9
2012	14.52%	9
2013	14.18%	9

Then it is for this subset of cases that it is needed a method that splits the measures of materials, physical capital and sales across the different establishments. We chose to divide these variables proportionally according to the number of workers in each establishment. To justify this simple solution we focus on the information on workers, which is detailed at the establishment level. Namely, we test for the possibility that for several workers' characteristics the establishments within the firm are homogeneous. If that's the case, then we assume that the tasks in each establishment are not significantly different, which justifies the solution adopted.

Considering the characteristic, θ, of firm j and establishment e, we can state our null hypothesis as:

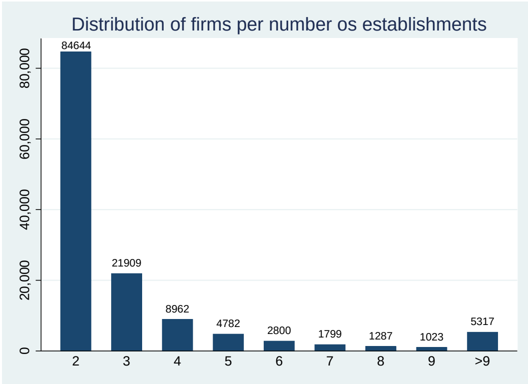
$$H_0 = \theta_{j,1} = \theta_{j,1} = \theta_{j,2} = \theta_{j,3} = ... = \theta_{j,E} \tag{86}$$

$$H_1 = \text{Not all } \theta_{j,i} \text{ are equal}$$

We look at the the following workers' characteristics: 1. Proportion of workers with a given type (9 different types according to the job performed within the firm); 2. Proportion of qualified workers (i.e college graduated). This way we try to assess if the type of workers across the different establishments of the firms is similar. We present the results according to the number of establishments per firm, since it influences the degrees of freedom of the test. Since 90% of the firms have less than 54 establishments that is the upper bound of cases we analyse.

We start by presenting the distribution of the number of establishments per firm.

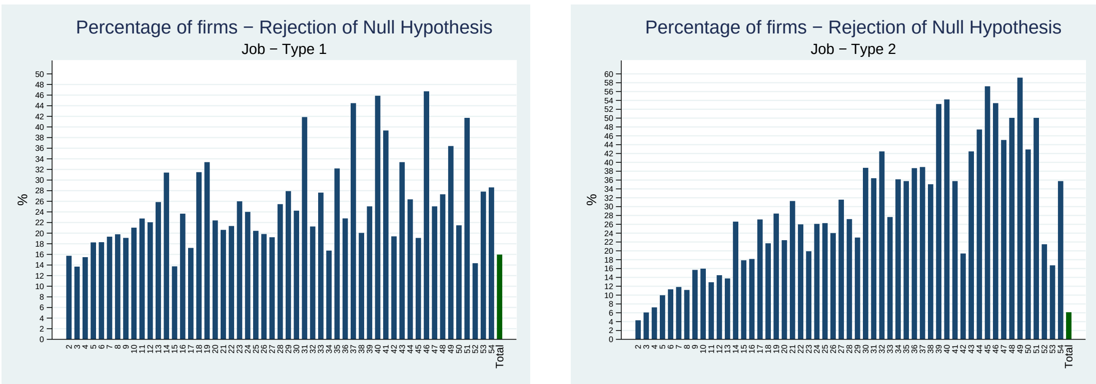
Figure 3

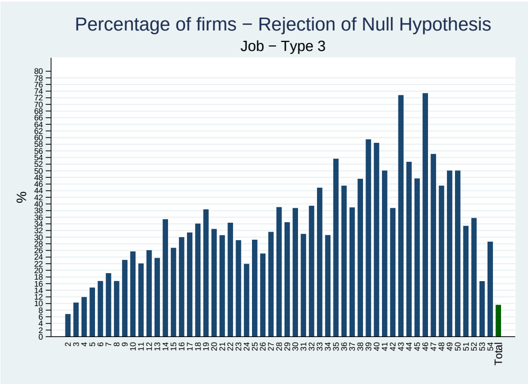


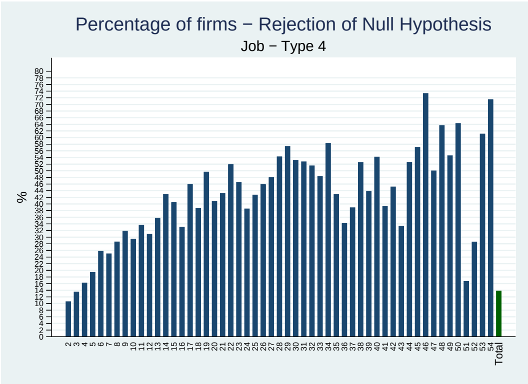
In figure 3 we graph the distribution of establishments per firm, considering those firms which have more than one establishment in different regions. We note that the great majority of these firms have two establishments, corresponding to 64% of the observations.

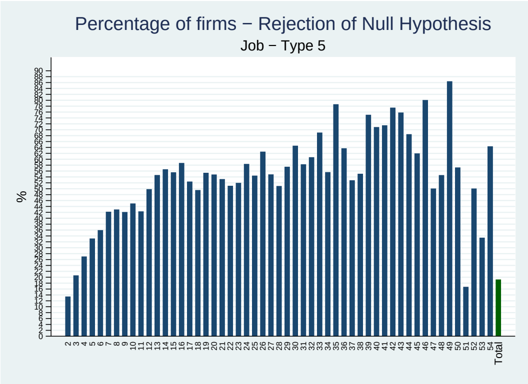
Then we present the graphs regarding the percentage of cases which do not respect the null hypothesis presented above. These results are reported by number of establishments per firm. As pointed above we present this for two different variables: 1. The proportion of workers of 9 different types across establishments; 2. The distribution of high skilled workers across establishments. We start by presenting the graphs of the first, considering each type of workers:

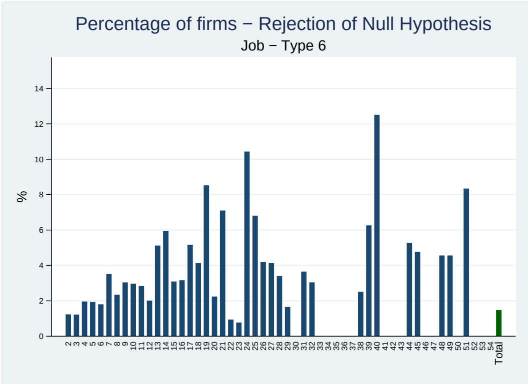
Figure 4

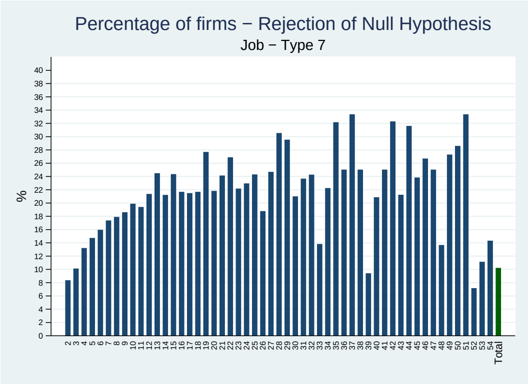


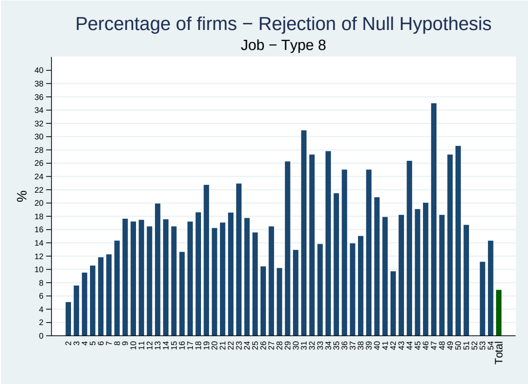

Percentage of firms − Rejection of Null Hypothesis
Job − Type 3

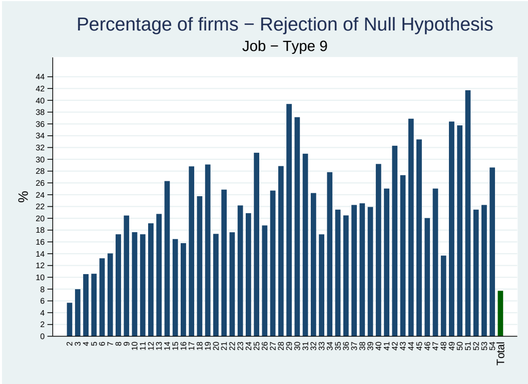

Percentage of firms − Rejection of Null Hypothesis
Job − Type 4


Percentage of firms − Rejection of Null Hypothesis
Job − Type 5


Percentage of firms − Rejection of Null Hypothesis
Job − Type 6

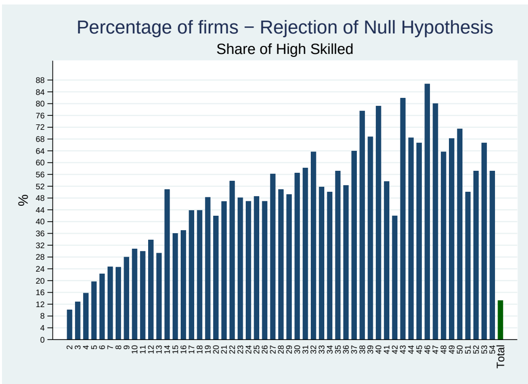

Percentage of firms − Rejection of Null Hypothesis
Job − Type 7


Percentage of firms − Rejection of Null Hypothesis
Job − Type 8



From the above graphs we note that the percentage of firms for which we reject the null hypothesis is quite irregular across firms with different number of establishments. We note that in firms with a lower number of establishments, it corresponds to the cases for which the percentage of rejections of null hypothesis is also lower. This ends up to drive the total result, since the vast majority of the firms do not have a large number of establishments.
The relatively low share of rejections of the null hypothesis in the majority of the firms in our data, strengths our hypothesis of a uniform distribution of the types of workers across the different establishments of the firm, which justifies our hypothesis of proportionally splitting the amount of material costs and capital assets across the different establishments within the firm.
To further justify this decision regarding the treatment of the data, we present the percentage of rejections of the null hypothesis, when we also consider the proportion of high skilled (college graduated) workers across the establishments:

Figure 5



The plot above shows, once again, that there is a lower percentage of rejection of the null hypothesis in firms with few establishments. Overall the total rate of rejection is around 13%.

6.4 Appendix 4

We show in the portuguese mainland divided according to the regions considered in this work. On the left we show the division in larger Regions, NUTII, and on the right the division in small partitions, according to NUTS III:

Figure 6