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Educational Spillovers at the Firm Level:

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Abstract:

This paper examines spillover effects from education at the firm level, separating the effects for different levels and types of education and allowing for a curvilinear relationship. Modeling a Cobb-Douglas production function, we show that wages of tertiary-educated workers depend positively on the number of workers with an apprenticeship degree. These effects are the result of informational spillovers between differently educated workers. We estimate an aggregated Mincerian earnings equation using data from a large employer-employee survey and account for firm fixed effects as well as endogeneous workforce composition. Our results are highly significant and robust throughout our specifications and show that the number of workers with an apprenticeship degree has a positive impact on average wages of tertiary-educated workers but with a decreasing rate.

Keywords: Education, Informational Spillovers, Wages

JEL-Classification: I20, J24, J30

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Introduction

Increasing investment in tertiary education is the main factor for sustainable growth in high technology countries (Aghion and Howitt 2006). An empirical study by Vandenbussche et al. (2004), using cross-country data, shows, that the importance of tertiary education for the growth of countries becomes higher with countries' increasing proximity to the technological frontier. Therefore, national growth rates depend both on this proximity and on a country's workforce composition. As the educational composition of a firm's workforce is a major determinant of firm productivity, a change in the educational composition of the labor force has an impact on the educational composition of a firm's workforce and as a result on firm's productivity.

A growing literature investigates the impact of an increase in average or tertiary education (i.e., the external or spillover effect) on productivity of firms or workers (e.g., Barth 2002, Battu et al. 2003, Bratti and Leombruni 2009, Martins and Jin 2010). These spillover effects are the result of worker interactions that lead to the sharing of knowledge and skills, thereby influencing both firm and worker productivity. While spillover effects at the firm level[1] are significant, they vary substantially depending on the education of the workers they affect. For example, Martins and Jin (2010) find that spillover effects vary by level of education. Similarly, Wirz (2008) shows different effects by type of education. However, all these studies focus on the impact of average schooling within a firm or the average schooling of one part of the workforce.

As the workforce of a firm usually represents a lot of different levels and types of education, the purpose of this study is to investigate spillover effects between these educational categories. In particular, given Aghion and Howitt's (2006) findings, we aim at answering the question of whether the productivity effects of tertiary-educated workers depend on the educational composition of a firm workforce. Moreover, we consider the functional form of the spillover effects, which previous studies usually assume to be linear. One notable exception is Battu et al. (2003), who find a positive but decreasing return to co-workers' education but do not consider spillovers from different educational categories.

As spillover effects are the result of worker interactions, we use a Cobb-Douglas production technology to model the wages of tertiary-educated workers. These wages reflect their

[1] Further evidence for the existence of spillover effects can be found in studies using higher aggregation levels such as region (e.g., Ciccone and Peri 2006, Moretti 2004b, Rauch 1993) or industry (e.g., Kirby and Riley 2008, Sakellariou and Maysami 2004).

productivity, dependent on the educational composition of the workforce. Interaction and differences in knowledge are the main prerequisites for the occurrence of spillover effects. We allow for spillovers between both different levels and different types of education, an approach consistent with Jovanovic and Rob's (1989) model on informational spillovers. Given that discussions on countries' different educational systems inevitably include the question of whether a high percentage of workers with completed tertiary education or instead, a high percentage of workers with completed secondary vocational education[2] (apprenticeship graduates) is the main goal, we focus on these two educational categories in deriving our hypothesis. We hypothesize that tertiary-educated workers benefit from interacting with workers with apprenticeship degrees. This positive effect is the result of the differences in both the level and type of education that both categories of workers have.

Furthermore, we test for a curvilinear relationship between the wages of tertiary-educated workers and the number of workers with apprenticeship degrees. We hypothesize that the return to an increase in the number of workers with apprenticeship degrees is positive but declining. Thus we extend the literature on spillover effects by considering spillover effects from lower to high levels of education and by allowing for a curvilinear relationship.

To test our hypotheses, we aggregate worker data from the Swiss Earnings Structure Survey (ESS), a large employer-employee survey, to the firm level and estimate Mincerian earnings equations (Mincer 1974). The ESS is a perfect match for our empirical analysis, as the data set contains information on workers' education and wages, and allows us to measure education by using educational degrees instead of years of schooling. An additional advantage of the data is the panel structure from the period 1998 to 2004 at the firm level. We use this panel structure to account for unobserved firm-specific effects that are potentially correlated with wages of tertiary-educated workers. These effects might bias OLS estimations. Furthermore we take the endogeneity of the number of workers with apprenticeship degrees into account by using a variable reflecting the tradition to train apprentices. As apprenticeship training is more widespread in German-speaking regions, we use the percentage of the German-speaking population in a region as instrument.

Our results show that the effect from an increase in the number of workers with apprenticeship degrees on the wages of workers with tertiary education is positive but

[2] A brief description of the quality and duration of secondary and tertiary education in Switzerland appears in the appendix.

declining. The effect is robust against the inclusion of regional, year, and industry controls, as well as firm controls.

The remainder of the paper is structured as follows. Section 2 presents the theoretical considerations and derives our hypotheses. Section 3 explains our estimation strategy, and Section 4 introduces the data set. Section 5 presents our empirical results, and Section 6 concludes.

Theory

The productivity of highly educated workers depends on physical capital and the human capital of co-workers. Therefore, we model the productivity of tertiary-educated workers, as reflected by their wages, depending on the educational composition of a firm's workforce, i.e., the number of workers with apprenticeship degrees. For simplicity, we omit physical capital in the production function, because the results remain unchanged and because our main interest lies in the workforce composition. We follow Moretti (2004a,b), who models city-level productivity using a Cobb-Douglas technology and who specifies two types of labor. Accordingly, we model firm-level productivity and use a similar specification:

$$Q = AT^{\alpha}S^{\beta} \tag{1}$$

Where A is a productivity shifter, T and S denote the number of workers with a tertiary education and secondary vocational education (apprenticeship degree) respectively. We expect firms to have a linear labor cost function. For the minimization of labor costs (or equivalently the maximization of output) we calculate the partial derivatives $\frac{\delta L}{\delta T}$ and $\frac{\delta L}{\delta S}$ of:

$$L = W_T T + W_S S + \lambda(Q - AT^{\alpha}S^{\beta}) \tag{2}$$

The first order conditions are given by:

$$\frac{\delta L}{\delta T} = W_T - \lambda\alpha AT^{\alpha-1}S^{\beta} = 0 \tag{3}$$

$$\frac{\delta L}{\delta S} = W_S - \lambda\beta AT^{\alpha}S^{\beta-1} = 0 \tag{4}$$

Solving (3) and (4) for λ and substituting (4) into (3) leads to the marginal rate of substitution of tertiary-educated workers and workers with apprenticeship degrees:

$$\frac{W_T}{W_S} = \frac{\alpha S}{\beta T} \tag{5}$$

Thus an increase in the number of workers with an apprenticeship degree increases the wages of tertiary-educated workers.

As the Cobb-Douglas technology models firm productivity dependent on a firm's workforce, interaction among co-workers is implicitly assumed. One explanation for the influence of the number of apprenticeship graduates on the productivity of workers with a tertiary education is the existence of spillover effects.[3] The main prerequisite for the existence of spillover effects is that workers interact and possess different knowledge (Jovanovic and Rob 1989). In their model on informational spillovers, Jovanovic and Rob (1989) argue that the exchange of different ideas between workers leads to an improvement of ideas or to imitation of the more valuable idea, depending on the degree of differences in knowledge of the interacting workers. The value of an idea is then measured as the return to the implementation. As differences in education reflect workers' different sets of knowledge, we expect the existence of spillover effects between tertiary-educated workers and apprenticeship graduates.

Without changing the generality of the model, we assume that education, and thus the amount of general human capital that workers have, reflects the quality of ideas they possess, and we assume ideas to vary by both level and type of education. Given this assumption, we derive two directions of spillover effects. First, spillover effects occur if lower educated workers interact with higher educated workers and learn during the interaction. As a result, lower educated workers' productivity increases. This case is the one usually discussed as a spillover effect in the existing literature. Second—both in line with the derived marginal rate of substitution and the model on informational spillovers—spillover effects also occur in either direction if the type of education differs. As tertiary educated-workers and apprenticeship graduates in Switzerland differ in both level and type of education, they provide an ideal setting for testing whether higher-educated workers benefit from working with lower educated workers. Thus we derive our first hypothesis:

H1: Workers with tertiary education benefit from interacting with workers with apprenticeship degrees.

Although we expect tertiary-educated workers to benefit from interacting with apprenticeship graduates, we take a potential curvilinear effect into account. An increase in the number of

[3] An alternative explanation for the positive impact of an increase in the number of apprenticeship graduates on the wages of workers with a tertiary education is imperfect substitution between workers with apprenticeship degrees and workers with tertiary education as shown in equation (5). However our analysis remains unchanged as we are interested in the impact on earnings an interaction with apprenticeship graduates has for tertiary educated workers.

similarly educated co-workers might have a different impact depending on the initial number of these co-workers. Therefore, drawing on the literature on private returns to education, we analyze the functional form of the external return to education. For private returns to education, the introduction of individual heterogeneity in the optimal schooling choice leads to a curvilinear functional form (which includes the linear relationship as a special case) (Card 1999). For the external return to education, investigations of the functional form are quite rare and the assumption of strict linearity has hardly been challenged. However, we argue that the return to an increase in the number of workers with apprenticeship degrees is positive but declining. The reason is that an initial increase in the percentage of workers with apprenticeship degrees, which reflects the probability of an interaction with this category of workers, has a stronger impact on the growth rate of the percentage than any additional increase in the percentage of workers with apprenticeship degrees.

Therefore, we expect the acquisition of new knowledge that improves ideas (in the sense of Jovanovic and Rob, 1989) to be positive but declining. We thus derive our second hypothesis:

H2: The positive effects from workers with apprenticeship degrees on the wages of workers with tertiary education are declining.

Estimation Strategy

To investigate the relationship between wages and the educational composition of the workforce, we follow Martins and Jin (2010) and aggregate a Mincerian earnings equation to the firm-level. The reason is that we estimate the effect of an increase in the number of workers with apprenticeship degrees on the average wages of workers with tertiary education. Moreover a Mincerian earnings equation allows the inclusion of the squared number of apprenticeship graduates, so that we can test for a curvilinear relationship, that would not be possible if we directly derive our estimation equation from the Cobb-Douglas production function.

In our first specification, shown in equation (6), we use the logarithm of firm average wages of tertiary-educated workers as dependent variable. After sorting workers into three categories (tertiary education, apprenticeship training, and other education), we calculate the number of workers belonging to each category for every firm. We use these three variables as our explanatory variables. The main explanatory variable in our equation is the number of workers with apprenticeship degrees. To test for a curvilinear relationship, we calculate the squared number of workers in each category.

$$y_{jt} = \alpha_{jt} + \sum_{k=1}^{3} \beta_{kjt} e_{kjt} + \sum_{k=1}^{3} \gamma_{kjt} e_{kjt}^{2} + X_{jt}\delta + \varphi_r + \varphi_i + \varphi_t + \varepsilon_{jt} \quad (6)$$

We further add controls for average firm-specific characteristics denoted X_{jt}, such as average age, average tenure (and their squares), the percentage of male workers, and the percentage of part-time workers. φ_r, φ_i and φ_t are controls for region, industry, and year, respectively. Our first specification does not take into account factors that are time-invariant and potentially correlated with the educational composition of the firm. If these factors affect the wages of tertiary-educated workers, equation (6) would be inconsistent. The panel structure of our data set allows us to include firm fixed effects to overcome this problem. Equation (7) shows our second specification which includes firm fixed effects.

$$y_{jt} = \alpha_{jt} + \sum_{k=1}^{3} \beta_{kjt} e_{kjt} + \sum_{k=1}^{3} \gamma_{kjt} e_{kjt}^{2} + X_{jt}\delta + \varphi_j + \varphi_t + \varepsilon_{jt} \quad (7)$$

To overcome potential endogeneity problems we use an instrument for the number of workers with apprenticeship degrees. The decision of a firm to train apprentices or to employ apprenticeship graduates is, besides economic factors, strongly related to tradition. The tradition to train apprentices is more widespread in German-speaking major regions than in non-German-speaking major regions.[4] Being located in a German-speaking major region is therefore related to the employment of apprenticeship graduates. However the performance of tertiary educated workers does not depend on the language of the major region.

For the IV estimation we use the percentage of the German-speaking population in the first stage to obtain predictions for the number of workers with apprenticeship degrees, we can include in the second stage. To avoid specification error, we only use a linear specification for our IV estimation. Regardless of the functional form, linear IV estimates contains an average effect analogous to the local average treatment effect (LATE) (Angrist and Krueger 2001).

[4] The categorization of being German-speaking is unambiguously possible for six out of seven major regions in Switzerland. One major region, Espace Mittelland, has a high language heterogeneity (three French-speaking and two German-speaking cantons). As our sample has no information on the location of firms in 2002 and 2004 on cantonal level, we use observation from 1994 and the panel structure of our data set to categorize firms in 2002 and 2004. This procedure is rather reliable because of the low mobility of firms in Switzerland. We assign the cantonal percentage of the German-speaking population to firms which have observations in 1994, 1998 or 2000. We assign the percentage of the German-speaking population of Espace Mittelland to firms which do not have observations in 1994, 1998 or 2000.

Furthermore the use of firm-level data requires a correction of the standard errors for clustering at the firm-level. Therefore we use cluster-robust standard errors (Moulton 1990) in our estimations.

Data

For our empirical analysis, we use the Swiss Earning Structure Survey (ESS), a representative data set conducted biennially by the Swiss Federal Statistical Office. This data is well-suited for our analysis because it contains information on individual characteristics (e.g., wages, education, tenure) and firm-level attributes (e.g., firm size, industry, and region). We aggregate the data to the firm level to generate a firm panel that allows us to control for time and firm-specific fixed effects. We use data from 1998 through 2004.

Table 1: Descriptive statistics (firm level)

Variable	Obs	Mean	Std. Dev.	Min	Max
Log average gross monthly wage	25519	8.794	0.233	8.019	9.829
Log average gross monthly wage of tert. educ.	25519	9.050	0.275	7.956	9.929
Tertiary educated workers	25519	13.507	68.566	1	2679
Workers with apprenticship degree	25519	28.966	122.166	0	6388
Workers with other education	25519	17.045	105.749	0	5667
Firm size	25519	59.518	249.525	5	9973
Male	25519	0.599	0.261	0	1
Tenure	25519	8.208	4.026	0	34.800
Tenure squared	25519	83.572	80.811	0	1211.040
Age	25519	40.999	4.732	22.273	63.200
Age sqared	25519	1703.335	387.991	496.074	3994.240
Parttime	25519	0.265	0.268	0	1
Region	25519	3.392	1.907	1	7
Industry	25519	8.444	3.800	3	15
Year	25519	2002.235	1.776	1998	2004

Source: Swiss Earning Structure Survey 1998-2004; own calculations.

Before aggregating the data we restrict our sample in the following way: As we assume that wages in the public sector are both less flexible than in the private sector and dependent on cantonal wage contracts, we restrict our sample to companies in the private sector. For the calculation of the firm-average wages of workers with a tertiary education, we focus on workers aged 25 to 60.[5] Given the estimation with a fixed time and firm-specific effect, all

[5] Workers younger than 25 are unlikely to be university graduates, whereas workers older than 60 are likely to receive retirement offers before reaching the retirement age of 65. Workers older than 60 are assumed to be a heterogeneous group as some workers continue working even if they receive offers for early retirement. Therefore we use only the wages of workers aged 25 to 60. To calculate the educational composition of the

firms observed only once during the observation period, are excluded, as well as firms switching the industry. As we are interested in the wages of tertiary-educated workers, we restrict our data set to firms employing at least five workers and at least one worker with a tertiary education. After these restrictions, we aggregate our dataset. Table 1 shows the descriptive statistics.

Our dependent variable is the log of firm average monthly gross wages of workers with tertiary education. We use real wages (2005 = 100) for our analysis. The ESS contains information on the highest educational degree, which we summarize in these three educational categories as follows: Workers belong to the first category (tertiary education) if they are graduates of one of the federal institutes of technology, a university, a university of applied science[6], a pedagogical university, or a higher vocational school. Workers belong to the second category (apprenticeship) if they have completed apprenticeship training. Workers belong to the third category (other education) if they have completed only high school, have a foreign–not classifiable–education, or have only a middle school education.

Additionally, we include several control variables aggregated at the firm level. We aggregate for each firm and year the following individual variables to the firm level: being male (dummy), age and age squared (in years), tenure and tenure squared (in years), and working part-time (dummy). At this level we also include industry, region, and year (all categorial).

Results

To test our hypotheses, we first estimate equation (6). Then we add firm fixed effects to control for omitted time-invariant variables possibly correlated with the education of the workforce and the average wages of tertiary-educated workers and estimate equation (7). For each estimation model we include the control variables stepwise. Furthermore, we provide some robustness checks by using an instrumental variable approach.

Ordinary least squares estimates

Table 2 provides the OLS estimates for testing our hypotheses. According to hypothesis 1 (H1), we expect a positive effect from an increase in the number of workers with apprenticeship degrees on the wages of workers with tertiary education. Moreover, according

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workforce, we release the prior restriction to obtain a more precise number for the working environment of the workers in our sample.

[6] A University of applied science offers 3-year Bachelor and 5-year Master-programms containing more practical education in comparison to universities or Federal institutes of Technology which offer more theoretical education.

to hypothesis 2 (H2), we expect that the return to an increase in the number of workers with apprenticeship degrees is positive but declining. As the results are robust throughout the different specifications, we focus on specification 5, which includes the full set of control variables (table 2).

Table 2: OLS Regressions

OLS Regressions	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. Var.: Log firm av. Monthly wages tertiary educated					
Number of workers with:					
Tertiary Education	0.0002***	0.0003***	0.0003***	0.0000	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Apprenticeship	0.0003***	0.0002***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Other	-0.0002***	-0.0002***	-0.0002***	-0.0000	-0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0000)
Sq. number of workers with:					
Tertiary Education	-0.0000***	-0.0000***	-0.0000***	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Apprenticeship	-0.0000***	-0.0000***	-0.0000***	-0.0000***	-0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Other	0.0000**	0.0000**	0.0000**	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Controls:					
Firm characteristics	No	yes	yes	yes	yes
Regional controls	No	no	yes	yes	yes
Industry controls	No	no	no	yes	yes
Year controls	No	no	no	no	yes
R-squared	0.006	0.060	0.097	0.186	0.186
N	25519	25519	25519	25519	25519

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%, OLS Regressions with cluster corrected standard errors. Standard errors are in parentheses.

The number of workers with apprenticeship degrees shows a positive and statistically significant value. The wages of workers with tertiary education rise as the number of workers with apprenticeship degrees rise. This finding confirms our first hypothesis (H1) and shows that the productivity, measured as wages, of a tertiary educated worker depends positively on the number of differently educated workers. Learning not only takes place from higher levels of education to lower levels but also depends on the difference in the types of education between co-workers. As workers with apprenticeship degrees are highly qualified workers, we assume that workers with a tertiary education learn from suggestions or feedback from apprenticeship graduates on how to implement new ideas. In contrast, an increase in the number of workers with other education shows a negative effect on the wages of workers with tertiary education.

To investigate whether the positive effect of apprenticeship graduates on the wages of workers with tertiary education is linear, we include the squared number of apprenticeship graduates in a firm in our estimation equation. The results show a negative and statistically significant value of the squared number of apprenticeship graduates on the wages of workers with tertiary education. These results are in line with our second hypothesis (H2).

In addition to the effect of apprenticeship graduates on the wages of workers with tertiary education, we investigate whether apprenticeship graduates have a positive effect on the total firm productivity measured as average wages of a firm. Considering the theoretical predictions by Aghion and Howitt (2006), we expect a negative effect of all primary- and secondary-educated workers on firm productivity, whereas workers with tertiary education are predicted to have a positive impact on overall firm productivity. As Switzerland is close to the technological frontier and thus has a rather low rate of tertiary-educated workers compared to other European countries, an increase in the employment of tertiary-educated workers reflects an increasing innovative power and thus a productivity increase (Bildungsbericht Schweiz 2010, World Bank 2009). The results from this estimation appear in the appendix in Table B.1. The estimation results show, that an increase in the number of tertiary-educated workers results in a higher overall firm productivity, whereas an increase in the number of workers with apprenticeship degrees results in a lower overall firm productivity. Combining the results of both regressions, we note that while tertiary-educated workers have a positive impact on firm productivity, their wage depends strongly on the number of highly qualified apprenticeship graduates employed within a firm.

Although we include a full set of control variables in specification (5) in Table 2, our results could be biased due to omitted time-invariant variables correlated with both average wages of tertiary-educated workers and the educational composition of a firm. In the next section, to capture unobserved time-invariant variables at the firm level, we include a firm-level fixed effect in our equations.

Ordinary least squares estimates with firm-fixed effects

Table 3 shows the estimation results of equation (7). In the first column we include no control variables at the firm level. As the results are robust against the inclusion of firm-level control variables, we focus on specification 2. The results confirm the results of Table 2, i.e., the results where we do not control for firm fixed effects. The impact of an increase in the number of workers with apprenticeship degrees on wages of workers with tertiary education is positive and statistically significant. These findings support our first hypothesis (H1).

Table 3: FE-Estimates

FE Model	Spec. (1)	Spec. (2)
Dep. Var.: Log firm av. Monthly wages tertiary educated		
Number of workers with:		
Tertiary Education	-0.0006***	-0.0006***
	(0.0001)	(0.0001)
Apprenticeship	0.0002***	0.0002***
	(0.0000)	(0.0000)
Other	0.0000	0.0000
	(0.0000)	(0.0000)
Sq. number of workers with:		
Tertiary Education	0.0000***	0.0000***
	(0.0000)	(0.0000)
Apprenticeship	-0.0000***	-0.0000***
	(0.0000)	(0.0000)
Other	0.0000	0.0000
	(0.0000)	(0.0000)
Controls		
Firm characteristics	No	yes
R-squared	0.004	0.018
N	25519	25519

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%, OLS Regressions with firm fixed effects and cluster corrected standard errors. Standard errors are in parentheses.

Furthermore the results show that the coefficient of the squared number of apprenticeship graduates within a firm remains negative and highly significant. These results support the robustness of the previous specifications against time invariant factors, which are potentially correlated with firm-specific educational composition and tertiary-educated workers' wages. As we expected from the theory on informational spillovers, workers with tertiary education benefit from interacting with workers with apprenticeship degrees. While tertiary-educated workers have a high theoretical knowledge, the knowledge of workers with apprenticeship degrees is more practical. Both categories of workers have completed a high quality education and are specialists in their fields. Suggestions and feedback from workers with an apprenticeship degree enhance the wage of tertiary educated workers.

Furthermore we test whether the effect of workers with apprenticeship degrees on total firm productivity remains robust to the inclusion of a firm fixed effect. The results from the previous section show that an increase in the number of tertiary educated workers results in a higher overall firm productivity, while an increase in the number of workers with apprenticeship degrees results in a lower overall firm productivity. Table B.2 in the appendix shows, that an increase in the number of tertiary educated workers has still a positive impact on overall firm productivity, whereas the impact of an increase in the number of workers with apprenticeship degrees is insignificant. These results support the findings of the previous section: Workers with tertiary education have a positive impact on total firm productivity, but their wages depend on the number of workers with apprenticeship degrees.

Robustness check: Instrumental variable estimate.

As a robustness check we conduct an instrumental variable estimation. Unobservable variables correlated with both the log average wage of tertiary educated workers and the number of apprenticeship graduates within a firm might bias the OLS and fixed effects estimations. We use the percentage of the German-speaking population as defined in the Estimation Strategy section as instrument for the number of workers with apprenticeship degrees.

Table 4: IV Estimation

IV Estimation	First Stage	Second Stage
Dep var:	Number of workers with apprenticeship	Log firm av. monthly wages tertiary educated
Number of workers with:		
Tertiary Education	1.0901***	-0.0023
	(0.1634)	(0.0015)
Apprenticeship		0.0021
		(0.0013)
Other	0.3858***	-0.0008
	(0.0637)	(0.0005)
Instrument:		
German-speaking region	19.5546***	
	(6.1623)	
Controls:		
Firm characteristics	yes	yes
Regional controls	yes	yes
Industry controls	yes	yes
Year controls	yes	yes
N	25519	25519
F-statistic: First stage	37.47	37.47

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%, IV Regressions with cluster corrected standard errors. Standard errors are in parentheses.

Table 4 shows the first and second stage results from our IV estimation. The problem of weak instruments does not occur in our estimation, because the value of the F-statistic of the first stage is above 10 (Stock et al. 2002). Moreover the results of the first stage show, that the effect of the percentage of the German-speaking population on the number of workers with apprenticeship degrees is positive and highly significant. Firms being located in German-speaking major regions employ more workers with apprenticeship degrees than firms being located in non-German-speaking major regions. Although this effect does not arise from a change in a dummy variable as in the case of the LATE, the interpretation is analogous (Angrist and Krueger 2001). Only those firms which would change their employment behavior dependent on language and traditional influences of the location are represented by the IV estimates.

The second stage estimation results show, as expected from theory, a positive effect for the number of workers with apprenticeship degrees on wages of workers with tertiary education. This estimate has a p-value, which is slightly above the 10 percent level and is therefore insignificant. Nevertheless the positive sign and the proximity of the p-value to the 10 percent level of the IV estimate indicate together with the results from the OLS and FE estimations that we still can support our first hypothesis.

Discussion

This paper analyzes the impact of the educational composition of the workforce on wages of workers with tertiary education. Our results show that an increase in the number of workers with apprenticeship degrees has a positive effect on the wage of workers with tertiary education but with a decreasing rate. The results remain robust against the inclusion of several control variables such as regional, industry and year controls. Furthermore, the results are stable if we include a firm fixed effect. Thus we conclude that workers who are university graduates not only serve but also benefit from the knowledge of workers with different qualifications.

Our findings are in line with the theoretical predictions derived from a Cobb-Douglas technology and Jovanovic and Rob’s (1989) model on informational spillover effects. One possible explanation for the dependence of the wages of tertiary-educated workers on the number of apprenticeship graduates is the presence of spillover effects. Differences not only in the level of education but also in the type of education determine the spillover effect. Tertiary-educated workers and apprenticeship graduates differ in type and level of education.

Both categories of workers are highly qualified to perform their tasks. While workers with tertiary educations are assumed to possess rather theoretical knowledge, workers with apprenticeship training—in contrast—possess more practical and operative knowledge. For example tertiary-educated workers might learn from apprenticeship graduates how to enhance the implementation of a new technology into the existing one. Our results thus indicate that a combination of the knowledge sets is very useful.

Our results lead to several policy implications. An increase in the employment of tertiary educated workers, as recommended by Aghion and Howitt (2006), requires at the same time the employment of highly qualified workers with a secondary education. Any stronger emphasis on tertiary education should not neglect the importance of investment in the training of workers with secondary education. Workers with an apprenticeship training are not only highly qualified workers with professional knowledge but also contribute to the wage of workers with a tertiary education. Moreover, the goal of increasing the number of workers with a tertiary education is reasonable only as long as the job requirements increase accordingly. Otherwise, these workers might be matched with jobs for which they are inaccurately qualified or even overqualified. A stronger emphasis on secondary vocational education could solve this problem.

Future research on spillover effects should consider both the type and level of education and take into account a curvilinear relationship. Although our method controls for potential endogeneity of the workforce composition, our IV cannot support our first hypothesis at conventional significance levels. Nevertheless, our findings suggest that spillover effects depend not only on the highest or average level of education but also on the difference between workers' and co-workers' educations.

References

Aghion, Phillipe and Peter Howitt. 2006. "Joseph Schumpeter Lecture Appropriate Growth Policy: A Unifying Framework." *Journal of the European Economic Association,* 4(2-3): 269–314.

Angrist, Joshua D. and Alan B. Krueger. 2001. "Instrumental Variables and the Search for Identification: From Supply and Demand to Natural Experiments." *Journal of Economic Perspectives*, 15(4): 69-85

Barth, Erling. 2002. "Spillover Effects of Education on Co-Worker Productivity. Evidence from the wage structure." Paper presented at the European society of population economics annual conference.

Battu, Harminder, Clive R. Belfield, and Peter J. Sloane. 2003. "Human Capital Spillovers within the Workplace: Evidence for Great Britain." *Oxford Bulletin of Economics and Statistics,* 65(5): 575-594.

Bildungsbericht Schweiz. 2010. Chur: Südostschweiz Print

Bratti, Massimiliano and Roberto Leombruni. 2009. "Local Human Capital Externalities and Wages at the Firm Level: The Case of Italian Manufacturing." *IZA Discussion Paper*(4613).

Card, David. 1999. *Handbook of Labor Economics*. Vol. 3. *The Causal Effect of Education on Earnings*. Amsterdam: Elsevier(1): 1802–63.

Ciccone, Antonio and Giovanni Peri. 2006. "Identifying Human Capital Externalities: Theory with Applications." *Review of Economic Studies*, 73(2): 381-412.

Jovanovic, Boyan and Rafael Rob. 1989. "The Growth and Diffusion of Knowledge." *Review of Economic Studies,* 56(4): 569-582.

Kirby, Simon and Rebecca Riley. 2008. "The External Returns to Education: UK Evidence Using Repeated Cross-Sections." *Labour Economics,* 15(4): 619-630.

Martins, Pedro S. and Jim Y. Jin. 2010. "Firm-level social returns to education." *Journal of Population Economics,* 23: 539-558.

Mincer, J. A. 1974. *Schooling, Experience and Earnings*: Columbia University Press.

Moretti, Enrico. 2004a. *Handbook of Regional and Urban Economics*. Vol. 4. *Human Capital Externalities in Cities*. North Holland - Elsevier: 2244–91.

Moretti, Enrico. 2004b . "Workers' Education, Spillovers, and Productivity: Evidence from Plant-Level Production Functions." *American Economic Review*, 94(3): 656-690.

Moulton, Brent R. 1990. "An Illustration of a Pitfall in Estimating the Effects of Aggregate Variables on Micro Units." *The Review of Economics and Statistics*, 72(2): 334–38.

Rauch, G. E. 1993. "Productivity gains from geographic concentrtaion of human capital: evidence from the cities." *Journal of Urban Economics*, 34: 380–400.

Sakellariou, Chris N. and Ramin Maysami. 2004. "Lucas Type External Effects of Human Capital: Strong Evidence Using Microdata." *Applied Economics Letters*, 11(6): 343-346.

Stock, James H., Jonathan H. Wright and Motohiro Yogo. 2002. "A Survey of Weak Instruments an Weak Identification in Generalized Method of Moments." *Journal of Business and Economic Statistics*, 20(4): 518-529.

Vandenbussche, Jerome, Phillipe Aghion, and Costas Meghir. 2004. "Growth, Distance to Frontier and the Composition of Human Capital." The Institute for Fiscal Studies WP04/31.

Wirz, Aniela M. 2008. "Private Returns to Education Versus Education Spill-over Effects." *Empirical Economics*, 34(2): 315-342.

World Bank. 2009. World Development Indicators.

Appendix A

Swiss Educational System

In Switzerland, compulsory education ends after 9 years of schooling. Students then have the choice of continuing their education either on an academic or vocational education path. For the academic path, which leads to a university admission certificate, an admissions test is required (Bildungsbericht Schweiz 2010, p.126). The vocational path leads to an apprenticeship degree and combines over 2-4 years of on-the-job training with theoretical education. Apprentices usually have 3-4 days per week of on-the-job training and 1-2 days per week of theoretical education. The structure of the training and the centralized final examination (both theoretical and practical) makes apprenticeship within an occupation comparable across firms.

Completed upper secondary education is the prerequisite for beginning tertiary education. Both tertiary education and upper secondary education have an academic and a vocational path. While switching from an academic upper secondary path to a tertiary vocational path or vice versa is possible, these changes require admissions tests. The tertiary academic path entails education at either a university or at one of the two Federal Institutes of Technology. Graduates from these institutions can continue their education at the doctoral level. Students with an upper secondary academic background enter tertiary academic education without needing to take an admissions test. The tertiary vocational path entails education at either universities of applied sciences (e.g., arts, humanities, etc.), pedagogical universities, or higher vocational schools and takes 3-5 years of studying. Students with an upper secondary vocational background do not have to take the admission test. With certain restrictions graduation from a university of applied science or a pedagogical university entitles the graduate to begin a doctoral program at a university or a Federal Institute of Technology depending on the quality of the completed education.

Appendix B

Table B.1: OLS Regressions

OLS Regressions	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. Var.: Log firm av. Monthly wages					
Number of workers with:					
Tertiary Education	0.0021***	0.0021***	0.0020***	0.0014***	0.0014***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Apprenticeship	-0.0003***	-0.0003***	-0.0003***	-0.0002***	-0.0002***
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Other	-0.0006***	-0.0006***	-0.0006***	-0.0003***	-0.0003***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Sq. number of workers with:					
Tertiary Education	-0.0000***	-0.0000***	-0.0000***	-0.0000***	-0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Apprenticeship	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Other	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Controls:					
Firm characteristics	no	yes	yes	yes	yes
Regional controls	no	no	yes	yes	yes
Industry controls	no	no	no	yes	yes
Year controls	no	no	no	no	yes
R-squared	0.065	0.094	0.157	0.387	0.387
N	25519	25519	25519	25519	25519

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%, OLS Regressions with cluster corrected standard errors. Standard errors are in parentheses.

Table B.2: FE Model

FE Model	Spec. (1)	Spec. (2)
Dep. Var.: Log firm av. Monthly wages		
Number of workers with:		
Tertiary Education	0.0002***	0.0002***
	(0.0000)	(0.0000)
Apprenticeship	-0.0000	-0.0000
	(0.0000)	(0.0000)
Other	-0.0002***	-0.0002***
	(0.0000)	(0.0000)
Sq. number of workers with:		
Tertiary Education	-0.0000***	-0.0000***
	(0.0000)	(0.0000)
Apprenticeship	0.0000*	0.0000
	(0.0000)	(0.0000)
Other	0.0000***	0.0000***
	(0.0000)	(0.0000)
Controls:		
Firm characteristics	no	yes
R-squared	0.007	0.061
N	25519	25519

Notes: * significant at 10%, ** significant at 5%, *** significant at 1%, OLS Regressions with firm fixed effects and cluster corrected standard errors. Standard errors are in parentheses.