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Educational Spillovers at the Firm Level: Who Benefits from Whom?

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Educational Spillovers at the Firm Level:

Who Benefits from Whom?

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Abstract:

This paper examines spillover effects across differently educated workers at the firm level. For the first time, we also consider spillover effects from secondary education to tertiary education, so the reverse that is usually looked at. Modeling a Cobb-Douglas production function, we hypothesize that due to informational spillovers between differently educated workers the productivity of tertiary-educated workers also depends positively on the number of workers with apprenticeship degrees. Using data from a large employer-employee survey, we account for both firm fixed effects and endogenous workforce composition. We find that the number of workers with an apprenticeship degree has a positive impact on the productivity of their tertiary-educated fellow workers. The effect is inversely U-shaped, highly significant, and stable through a large number of robustness checks.

Keywords: Education, Informational Spillovers, Wages

JEL-Classification: I20, J24, J30

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1. Introduction

Educational or human capital spillover effects have been of increasing interest to economists over the past three decades. Studies focus on educational spillover effects at different aggregation levels such as region (e.g., Ciccone & Peri, 2006; Moretti, 2004a; Rauch, 1993), industry (e.g., Kirby & Riley, 2008; Sakellariou & Maysami, 2004), and firms or workers (e.g., Barth, 2002; Battu, Belfield, & Sloane, 2003; Bratti & Leombruni, 2009). The common underlying assumption in research on spillover effects is that spillovers arise either from the individuals with the highest education level (e.g., Moretti, 2004b) or from the average education level (measured in number of years) of a community (e.g., Rauch, 1993). This assumption neglects that educational spillovers can also arise from having different types of knowledge even if the level or length of education is the same.

If individuals are heterogeneous in terms of their education, educational spillovers can also arise from such heterogeneous knowledge. In such cases, the mere distinction by educational level would not cover all educational differences. Especially in countries that have a Vocational Education and Training (VET) system that offers high quality training at the secondary level, such as Austria, Germany, Switzerland, and Denmark, a mere distinction by educational level might prove insufficient.[2] The interaction of workers with different types and levels of education, and therefore different knowledge, causes spillover effects. Therefore analyzing educational spillover effects, not only by the level but also by the type of education is important to catch the whole range of possible spillovers.

This paper contributes to the spillover literature in two ways. First, we develop a model that establishes informational spillovers as the underlying concept of educational spillovers. Following Jovanovic and Robs' (1989) model on informational spillover, we integrate educational type as an additional dimension in the spillover literature. By applying the informational spillover model, we also include predictions on the functional form in our hypotheses, i.e. we expect a non-linear relationship. Second, we empirically analyze the spillovers to tertiary education from the presence of co-workers with secondary vocational education (i.e., dual-track VET).

To test our hypotheses, we use data from the Swiss Earnings Structure Survey (ESS), a large panel of employer-employee data, and estimate Mincerian earnings equations (Mincer,

[2] Secondary vocational education in Austria, Germany, and Switzerland primarily consists of a combination of extensive workplace training and vocational schooling. The training programs typically last 3-4 years and convey general and occupation-specific skills.

1974)[3]. 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.

Our results show that the effect from an increase in the number of workers with VET degrees on the productivity of workers with tertiary education is positive but diminishing. The effect is robust against the inclusion of regional, year, and sector controls, as well as firm controls. Furthermore, the results remain robust with fixed effects estimation.

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 robustness checks. Section 6 concludes.

2. Theory

From a traditional spillover perspective highly skilled or educated workers generate positive spillover effects to lower educated workers (Ciccone & Peri, 2006; Moretti, 2004a, 2004b). This perspective neglects that education differs not only by level but also by type and that spillovers could thus go in both directions. In their model on informational spillover effects, Jovanovic and Rob (1989) argue that a difference in knowledge between two workers can cause a spillover effect if these workers interact. They argue that the exchange of different ideas between workers leads to an improvement of ideas or to imitation of the more valuable ideas, depending on the degree of differences in knowledge of the interacting workers. In their model the differences in knowledge stems from differences in workers' level of education. We argue that differences in knowledge might also result from differences in educational types and that spillover effects can also flow from VET workers to academic workers (independent of their level of education).

We follow Moretti (2004a, 2004b), who models city-level productivity using a Cobb-Douglas technology and specifies two types of labor.[4] We model the productivity of tertiary-educated workers depending on the educational composition of a firm's workforce, i.e., the number of workers with a different knowledge set generated by VET degrees. We start with the model of Moretti but omit physical capital in the production function for simplicity (because the implications from the model remain unchanged and because our main interest lies in the

[3] This procedure is based on Martins and Jin (2010).

[4] As we use aggregated firm-level measures, we exclude individual human capital from our model.

composition of the workforce). Unlike Moretti, we use two types of workers T and S and model firm-level productivity as follows:

$$Q = AT^{\alpha}S^{\beta} \quad (1)$$

where A is a productivity shifter, and T and S denote the number of workers with a tertiary education and the number of workers with a secondary vocational education (VET degree), respectively. We assume that firms 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:

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

The first order conditions are given by:

$$\frac{\delta L}{\delta T} = W_T - \lambda \alpha A T^{\alpha-1} S^{\beta} = 0 \quad (3)$$

$$\frac{\delta L}{\delta S} = W_S - \lambda \beta A T^{\alpha} S^{\beta-1} = 0 \quad (4)$$

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 VET degrees:

$$\frac{W_T}{W_S} = \frac{\alpha S}{\beta T} \quad (5)$$

Thus, an increase in the number of workers with VET degrees is associated with an increase in the productivity of tertiary-educated workers and thus an increase in output. With an increase in the number of workers with VET degrees, productivity of tertiary-educated workers rise.

In line with the derived marginal rate of substitution and the model on informational spillovers—spillover effects occur if the type of education, and thus the ideas that the workers possess, differs. As tertiary educated-workers and workers with VET degrees differ in their level and type of education. We derive our first hypothesis:

H1: An increase in the number of workers with VET degrees has a positive effect on the productivity of workers with tertiary education.

As an increase in the number of co-workers with a given education might have a different impact depending on the initial number of these co-workers, we expect a nonlinear effect of educational spillovers. We model this effect in analogy to nonlinear forms of individual returns to education (Card, 1999). We argue that the return to an increase in the number of workers with VET degrees is positive but declining. An initial increase in the percentage of workers with VET degrees has a stronger impact than an additional increase.

H2: The positive effect from workers with VET degrees on the productivity of workers with tertiary education diminishes with the number of workers with VET degrees.

3. Data and descriptive statistics

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 set 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, sector, and region). To generate a firm panel that allows us to control for time and firm-specific fixed effects, we aggregate the data to the firm level. We use data from 1998 through 2004.

Table 1 Descriptive statistics (firm level)

Variable	Obs	Mean	Std. Dev.	Min	Max
Log average gross monthly wages	22,846	8.799	0.236	8.019	9.829
Log average gross monthly wages of tert. educ.	22,846	9.054	0.275	7.956	9.929
Number of tertiary-educated workers	22,846	14.07	72.17	1	2,679
Number of workers with VET degrees	22,846	30.09	128.1	0	6,388
Number of workers with other education	22,846	18.09	111.5	0	5,667
Firm size	22,846	62.25	262.5	5	9,973
Male	22,846	0.600	0.259	0	1
Tenure	22,846	8.197	4.034	0	34.80
Age	22,846	41.00	4.733	22.27	63.20
Part-time	22,846	0.257	0.264	0	1

Source: Swiss Earning Structure Survey 1998-2004; authors' calculations

Before aggregating the data, we restrict our sample in the following way we restrict our sample to companies in the private sector.[5] For the calculation of the firm-average wages of workers with a tertiary education, we focus on workers aged 25 to 60.[6] Given the estimation of a fixed time and a firm-specific effect, all firms observed only once during the observation period, as well as firms switching to another sector, are excluded. Because we are interested

[5] The aggregation of the data results from the estimation strategy we choose in the following section.

[6] In Switzerland, workers younger than 25 are unlikely to be university graduates, whereas workers older than 60 have the possibility of retiring up to two years before reaching the official retirement age of 65 for males and 64 for females. Workers older than 60 are assumed to be a heterogeneous group, as some stop working before reaching retirement age or continue working after it (Die Bundesversammlung der Schweizerischen Eidgenossenschaft 2012). Therefore, we use only the wages of workers aged 25 to 60. To calculate the educational composition of the workforce, we release the prior restriction to obtain a more precise number for the working environment of the workers in our sample.

in how the wages of tertiary-educated workers are affected by workers with other types of education, 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 data set to the firm level. Table 1 shows the descriptive statistics.

To investigate the relationship between the productivity of tertiary-educated workers and the educational composition of the workforce, we use monthly gross wages as a measure for measuring productivity assuming that wages reflect productivity sufficiently well. Wages in the ESS contain, in addition to time-based components, also performance-based components such as: bonus pay, commissions, and piece rates. Thus we are confident to use wages as a proxy for workers' productivity.

Our dependent variable is the log of 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 of each worker, which we categorize in three categories: firstly, tertiary education, including workers who are graduates of one of the federal institutes of technology, a university, a university of applied science,[7] a pedagogical university, or a higher vocational school, secondly VET education including workers who have completed dual-track VET, thirdly other education including workers who have completed only high school or lower, or with a not classifiable foreign education.

Additionally, we include several control variables aggregated at the firm level. We aggregate for each firm and year the following individual variables at 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 sector, region, and year (all categorical).

4. Estimation strategy

We follow earlier work by Martins and Jin (2010) and aggregate a Mincerian earnings equation on the firm level, because we are interested in spillover effects on the firm level. Because of the aggregation of the data at the firm level, we can include firm fixed effects that control strategic human resource management decisions affecting the education and ability distribution of the workforce. In addition, a Mincerian earnings equation allows the inclusion of the squared number of workers with VET degrees in our analysis, so that we can test for a

[7] A university of applied science offers 3-year bachelors and 2-year masters programs containing more practical education, in comparison to universities or federal institutes of technology, which offer more theoretical education.

nonlinear relationship. Doing so would not be possible if we derived our estimation equation directly from the Cobb-Douglas production function that we presented in the theory section.

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

$$y_{jt} = \sum_{k=1}^{3} \beta_k e_{kjt} + \sum_{k=1}^{3} \gamma_k e_{kjt}^2 + X_{jt}\delta + \varepsilon_{jt} \tag{6}$$

We further add controls, denoted X_{jt}, for average firm-specific characteristics, such as average age, average tenure (and their squares), the percentage of male workers, and the percentage of part-time workers. Furthermore, we add controls for region, sector, and year. Our first specification does not take into account factors that are time-invariant and potentially correlated with the educational composition of the firm, such as the average ability of the workforce. If these fixed 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. The inclusion of firm fixed effects controls for factors such as high wage level, high tech firm, and a broad firm size class. Equation (7) shows our second specification, which includes firm fixed effects:

$$y_{jt} = \alpha_j + \sum_{k=1}^{3} \beta_k e_{kjt} + \sum_{k=1}^{3} \gamma_k e_{kjt}^2 + X_{jt}\delta + \varepsilon_{jt} \tag{7}$$

To overcome potential endogeneity problems, we use an instrument for the number of workers with VET degrees. Since the tradition of training apprentices is more widespread in the German-speaking regions of Switzerland than in the non-German-speaking regions,[8] a firm located in a German-speaking region is more likely to employ workers with VET degrees and region can be used as an instrument.

[8] The categorization of being German-speaking is unambiguously possible for six of the seven major regions in Switzerland. One major region, Espace Mittelland, has a high linguistic heterogeneity (three French-speaking and two German-speaking cantons). For this major region, we use cantonal data to calculate our instrument. As our sample has no information on the location of firms in 2002 and 2004 at the cantonal level, we use observations from 1994 and the panel structure of our data set to categorize firms in 2002 and 2004. This procedure is reliable because of the low mobility of firms in Switzerland. (For example, Bodenmann & Axhausen, 2012, show that in the St. Gallen region, 1.77% of the companies within a period of 15 years starting in 1991 relocated; furthermore, most of the relocations occurred within the St. Gallen region.) Given this categorization and data on the linguistic distribution for each canton (2000 Swiss Federal Population Census), we calculate a dummy variable indicating German-speaking and non-German-speaking regions.

For the IV estimation, we use a dummy variable that indicates whether the majority of the population of a region speaks German. We define a region as German-speaking if at least 50% of the population speaks German. For this classification, we use data from the 2000 Swiss Federal Population Census. We include the dummy variable in the first stage to obtain predictions for the number of workers with VET degrees, which we can include in the second stage. To avoid specification error, we use a linear specification for our IV estimation. Regardless of the functional form, linear IV estimates contain an average effect analogous to the local average treatment effect (LATE) (Angrist & Krueger, 2001).

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.

5. Results

5.1 Ordinary least squares (OLS) 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 VET degrees on the productivity of workers with tertiary education. Moreover, according to hypothesis 2 (H2), we expect that the return to an increase in the number of workers with VET degrees is positive but diminishing. As the results for the number of workers with VET degrees are robust throughout the different specifications, we focus on specification 5, which includes the full set of control variables (table 2).

The coefficient for the number of workers with VET degrees is positive and statistically significant at the 1% level. Using the coefficients from specification 5 for the squared coefficient we calculate that the maximum effect is reached at 2105 workers with VET degrees. This indicates that for the average firm (i.e., 30 workers with VET degrees) an increase in the number of VET workers results in a higher productivity of workers with tertiary education. This result changes only for very large firms, i.e., only for firms exceeding the maximum of 2105 VET workers additional VET workers will have no longer positive effects on tertiary educated workers. Thus, for the majority of firms, we find support for both hypotheses: Tertiary-educated workers benefit from interacting with workers with VET degrees (H1), and the returns diminish as the number of workers with VET degrees increases (H2).

Table 2 OLS Regressions

OLS Regressions	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. Var.: Log average gross monthly wages of tert. educ.					
Number of workers with:					
Tertiary Education	0.02614***	0.03226***	0.02931***	0.00534	0.00518
	(3.47)	(4.29)	(4.19)	(0.80)	(0.78)
VET	0.02748***	0.02176***	0.01233***	0.01179***	0.01179***
	(5.85)	(4.93)	(3.05)	(2.83)	(2.83)
Other	-0.02104***	-0.02210***	-0.01774***	-0.00122	-0.00121
	(-4.04)	(-3.85)	(-3.33)	(-0.29)	(-0.29)
Sq. number of workers with:					
Tertiary Education	-0.00128***	-0.00152***	-0.00134***	-0.00041	-0.00040
	(-4.35)	(-5.15)	(-4.96)	(-1.43)	(-1.41)
VET	-0.00051***	-0.00039***	-0.00022**	-0.00028***	-0.00028***
	(-3.39)	(-3.16)	(-2.51)	(-3.13)	(-3.13)
Other	0.00035**	0.00043**	0.00037**	-0.00004	-0.00004
	(2.26)	(2.28)	(2.17)	(-0.41)	(-0.41)
Controls:					
Firm characteristics	no	yes	yes	yes	yes
Regional controls	no	no	yes	yes	yes
Sector controls	no	no	no	yes	yes
Year controls	no	no	no	no	yes
R-squared	0.01	0.06	0.10	0.19	0.19
N	22,846	22,846	22,846	22,846	22,846

Note: Cluster-robust t-statistics in parentheses (Cluster level: Firm). Number of workers was divided by 100.
* Statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

In contrast to workers with VET degrees, the number of workers with other qualifications is negatively associated with the productivity of tertiary-educated workers. This result is in line with Jovanovic and Robs' (1989) model: During an interaction, workers' knowledge can never be reduced but may only be increased as a result of additional information. In this case, we expect that the knowledge set of workers with other qualifications is largely a part of the knowledge set that tertiary-educated workers have. Those parts that do not overlap might not have any influence on the productivity of tertiary-educated workers.

Although we include a full set of control variables in specification (5) in Table 2, our results could be biased as a result of 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.

5.2 OLS 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. We focus on specification 4, because the results are robust against the inclusion of the full set of control variables. The results confirm the results of Table 2: positive but diminishing spillover effects from VET workers to tertiary educated workers.

We again calculate the number of workers with VET degrees where the effect is maximized from specification 4. The maximum is at 3948 workers with VET degrees. This again shows that for the majority of firms, tertiary-educated workers benefit from interacting with workers with VET training (H1) and that these returns diminish with the number of workers with VET degrees employed (H2).[9]

Table 3 FE Model

FE Model	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)
Dep. Var.: Log average gross monthly wages of tert. educ.				
Number of workers with:				
Tertiary Education	-0.05477***	-0.05623***	-0.05633***	-0.05726***
	(-6.63)	(-6.70)	(-6.69)	(-6.72)
VET	0.02244***	0.02254***	0.02245***	0.02211***
	(4.66)	(4.66)	(4.67)	(4.59)
Other	0.00111	0.00154	0.00135	0.00133
	(0.24)	(0.33)	(0.29)	(0.29)
Sq. number of workers with:				
Tertiary Education	0.00173***	0.00180***	0.00180***	0.00184***
	(4.54)	(4.46)	(4.43)	(4.49)
VET	-0.00028***	-0.00029***	-0.00028***	-0.00028***
	(-3.60)	(-3.59)	(-3.54)	(-3.50)
Other	0.00007	0.00007	0.00008	0.00008
	(0.87)	(0.88)	(0.91)	(0.93)
Controls:				
Firm characteristics	no	yes	yes	yes
Regional controls	no	no	yes	yes
Year controls	no	no	no	yes
R-squared	0.00	0.02	0.02	0.02
N	22,846	22,846	22,846	22,846

Note: Cluster robust t-statistics in parentheses (Cluster level: Firm). Number of workers was divided by 100.
* Statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

[9] The calculated turning points should not be interpreted as constituting a target value that firms should achieve. Instead, they show that the productivity of workers with tertiary education improves due to an increase in the number of workers with VET degrees.

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' productivity. As we expected from the theory on informational spillovers, workers with tertiary education benefit from interacting with workers with VET degrees.

Comparing the results of the OLS regressions (table 2) with the results of the FE estimations (table 3), we find that while the results for the number of workers with VET degrees remains stable, the results for the number of workers with tertiary education are different. For the effect of the number of workers with tertiary education on their average productivity, we find an inverted u-shaped relationship when using OLS regressions and a u-shaped relationship when using FE estimations. This change in the functional form can be explained by the inclusion of sector dummies and fixed effects, respectively. While the diversity of qualifications within tertiary education might differ across sectors and firms, tertiary-educated workers learn from other tertiary-educated workers if this diversity is high. After the inclusion of sector dummies, a change in the statistical significance of the coefficients causing the inverted u-shaped relationship occurs. While the coefficients remain positive, the significance level indicates that they are not different from zero.

The fixed effects estimator controls for factors such as high average wage level, use of high technology, and broad firm-size classes. These effects do not influence the estimates we report in table 3.

5.3 Robustness check: Instrumental variable estimates

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 workers with VET degrees within a firm might bias the OLS and fixed effects estimations. We use a dummy indicating a German-speaking region as defined in the estimation strategy section as the instrument for the number of workers with VET degrees.

Table 4 shows the mean value comparison between firms located in German-speaking regions and non-German-speaking regions. As expected, the percentage of workers with VET degrees is higher in firms in German-speaking regions than in firms in non-German-speaking regions. These findings are in line with official statistics by the Federal Office for Professional Education and Technology (OPET) on the provision of dual-track VET: Firms in German-speaking regions offer more dual-track VET than firms in non-German-speaking regions (OPET 2010).

Table 4 Mean value comparison by linguistic region

Variable	Mean		p-value
	German-speaking region	Non-German-speaking region	(Difference equal to 0)
Log average gross monthly wages	8.8101	8.7789	0.0000
Log average gross monthly wages of tert. educ.	9.0834	9.0014	0.0000
Percentage of workers with VET degree	0.5312	0.3728	0.0000
Firm size	123.7275	80.9336	0.0000
Male	0.6183	0.5663	0.0000
Tenure	8.2857	8.0342	0.0000
Age	41.1377	40.7388	0.0000
Part-time	0.2589	0.2545	0.2272

Source: Swiss Earning Structure Survey 1998-2004; authors' calculations

We also investigate the relationship between the instrument and the dependent variable by estimating the reduced form. The results from this estimation appear in Table A1 in the Appendix. In the reduced form, the instrument has a positive and statistically significant effect on the average productivity of tertiary-educated workers. Thus both the mean value comparison (table 2) and the results from the reduced form support the credibility of our instrument.

Table 5 shows the first- and second-stage results from our IV estimation. A comparison of the F-statistic with the critical values reported in Stock and Yogo (2002) show that the hypothesis of a 5% bias of the IV estimation is rejected not more than 15% of the time. Moreover, the results of the first stage show that the effect of the dummy indicating a German-speaking region on the number of workers with VET degrees is positive and highly significant (at the 1% level). Both results indicate a strong instrument. Firms in German-speaking major regions employ more workers with VET degrees than firms in non-German-speaking major regions. The instrument captures those firms that would change their training behavior according to the culture that the region indicates.

Table 5 IV Estimation

IV Estimation	First Stage	Second Stage
Dep. Var.:	Number of workers with VET degree	Log average gross monthly wages of tert. educ.
Number of workers with:		
Tertiary Education	1.09066***	-0.23004
	(6.63)	(-1.57)
VET		0.21350*
		(1.65)
Other	0.38367***	-0.08101
	(6.03)	(-1.59)
Instrument:		
German-speaking region	0.13934***	
	(3.10)	
Controls		
Firm characteristics	yes	yes
Regional controls	yes	yes
Sector controls	yes	yes
Year controls	yes	yes
F Statistic	9'612	
N	22,846	22,846

Note: Cluster-robust t-statistics in parentheses (Cluster level: Firm). Number of workers was divided by 100.
* Statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

As hypothesized, the second stage estimation results show a positive effect for the number of workers with VET degrees on the productivity of workers with tertiary education. This estimate is statistically significant at the 10% level. The positive sign shows, together with the results from the OLS and FE estimations, that we still can support our first hypothesis.

5.4 Robustness check: Industry level estimation

The benefit received by tertiary-educated workers from interacting with workers with VET degrees might differ across industries. First the industry-specific educational distribution might differ. Second, knowledge differences between tertiary-educated workers and workers with VET degrees might be industry-specific. Thus the spillover effect depends on whether tertiary-educated workers and workers with VET degrees work in related occupations and whether the workers with VET degrees have knowledge relevant for the productivity of tertiary-educated workers. As the number of occupations differs across industries, spillover effects between workers with different sets of knowledge might also differ across industries.

To analyze industry-specific differences in the relationship between the productivity of tertiary-educated workers and the number of workers with VET degrees, we divide our sample by sector into different subsamples. For each subsample, we calculate the average number of workers with tertiary education per firm and divide this number by the average firm size of the sector. Table 6 shows the calculated values for the education sector (highest value), the hotel and restaurant sector (lowest value), and the manufacturing sector and the health and social work sector (two sectors representing values very close to the overall mean).

Table 6 Distribution of the percentage of tertiary educated workers within selected sectors

Sectors	Percentage of tertiary educated
Manufacturing	20.08
Hotel and restaurants	9.56
Education	70.87
Health and social work	21.23

Source: Swiss Earning Structure Survey 1998-2004; authors' calculations

Table 7 shows the estimation results for equation (6). For all of the selected sectors, we find similar results, which are in line with our main findings: The coefficient for the number of workers with VET degrees is positive and statistically significant for all sectors. The coefficient of the corresponding squared term is negative and statistically significant for all sectors Comparable to our main results, we observe positive but diminishing returns for tertiary-educated workers from the employment of workers with VET degrees. This result changes only for very large firms i.e., for those firm with more than 2287 VET workers. Thus, for the majority of firms, we find support for hypotheses H1 and H2.

To avoid a potential bias due to the endogenous educational composition of the workforce, we also conduct an instrumental variable estimation (table A2 in the appendix). Again, we use the dummy variable indicating a German-speaking region as an instrument for the number of workers with VET degrees. Our results show a positive and significant impact from the number of workers with VET degrees only in the health and social work sector. The estimation results for the other three sectors suffer either from the weakness of the instrument or do not show a significant impact of the number of workers with VET degrees on the productivity of workers with tertiary education. The rationale for the positive impact in the health and social work sector might depend on the spatial distribution of the instrument. While the presence of the other selected sectors in a region might depend on characteristics such as the availability of resources or infrastructure, the demand for health and social work is independent of regional characteristics. Consequently, the health and social work sector might represent the regional language distribution of Switzerland more precisely than other selected sectors. Thus the instrument is especially well suited for identifying the impact of an increase in the number of workers with dual-track VET on the productivity of workers with tertiary education. These estimation results further support our hypotheses. We show that in sectors with a different educational distribution, the main results remain stable. The positive but diminishing impact of the number of workers with VET degrees on the productivity of workers with tertiary education remains significant in all selected sectors.

Table 7 OLS Estimation in selected sectors

OLS Regressions	Manufacturing	Hotels and restaurants	Education	Health and social work
Dep. Var.: Log average monthly wages of tert. educ.				
Number of workers with:				
Tertiary Education	-0.02028*	-0.70798*	0.01162	-0.16750***
	(-1.85)	(-1.68)	(0.19)	(-3.73)
VET	0.02882***	0.21787***	0.94855***	0.08572***
	(3.26)	(3.12)	(4.93)	(5.87)
Other	-0.00371	0.00788	-0.50825*	0.01697
	(-0.42)	(0.11)	(-1.75)	(0.91)
Sq. number of workers with:				
Tertiary Education	0.00069	0.96087	-0.00083	0.00847
	(1.64)	(0.69)	(-0.06)	(1.30)
VET	-0.00063***	-0.01474**	-0.99173***	-0.00186**
	(-2.81)	(-2.49)	(-4.62)	(-2.09)
Other	-0.00020	-0.00041	1.01163**	-0.00107
	(-0.49)	(-0.19)	(2.46)	(-1.51)
Controls:				
Firm characteristics	yes	yes	yes	yes
Regional controls	yes	yes	yes	yes
Year controls	yes	yes	yes	yes
R-squared	0.11	0.16	0.19	0.10
N	6,661	718	1,321	1,793

Note: Cluster-robust t-statistics in parentheses (Cluster level: Firm). Number of workers was divided by 100.
* Statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

6. Discussion

This paper analyzes the impact of the educational composition of the workforce in a firm on the productivity of workers with tertiary education in the same firm. Such spillover effects are determined not only by the differences in the level of education but also in the type of education While workers with tertiary educations are assumed to possess more theoretical knowledge, workers with dual-track VET possess more practical and operational knowledge. For example, tertiary-educated workers might learn from workers with VET degrees how to enhance the implementation of a new technology into an existing one.

We analyze our hypotheses using a large Swiss employer-employee data set. Our results show that an increase in the number of workers with VET degrees has a positive but declining effect on the productivity (measured in average wages) of workers with tertiary education. The results remain robust against the inclusion of several control variables, such as regional, sector, and year controls and do not depend on firms' location in the educational distribution. Furthermore, the results are stable if we include a firm fixed effect and take potential endogeneity of the employment of workers with VET degrees into account. All specifications are in line with our hypotheses.

Our results have several policy implications. Unlike the recommendation by Aghion and Howitt (2006) to increase tertiary educated workers in middle European countries, we argue that it pays to keep a well-balanced mix with vocationally educated workers (as opposed to unqualified workers). Even with stronger emphasis on tertiary education, firms should not neglect the importance of strong investments in the training of workers with vocational skills, particularly on the secondary level. Workers with dual-track VET are highly qualified workers with professional knowledge that contributes to the productivity of workers with a tertiary education. Increasing the number of workers with a tertiary education may be an adequate strategy if jobs require only primarily theoretical work or require workers to perform their own research. As soon as production and implementation of knowledge is involved it pays to also employ a substantial number of highly skilled VET workers. That also asks for a regime shift in human capital investments towards a stronger investment of firms in building the human capital stock in a region or country instead of relying on the schooling/university system and state financing.

Future research on spillover effects should consider both the type and level of education and take into account a nonlinear relationship. Although, we cannot provide evidence for a nonlinear relationship in the IV framework, because of the lack of additional instruments, our results from OLS and FE estimations support our hypothesis of a nonlinear relationship. Our findings clearly suggest that spillover effects depend not only on the highest or average level of education but also on the difference in education between workers and co-workers.

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Appendix 1

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 (Annen et al., 2010; p.126). The vocational path leads to a VET 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 dual-track VET 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 a university of applied sciences (e.g., arts, humanities), a pedagogical university, or higher vocational school, and entails 3-5 years of studies. Students with an upper secondary vocational background do not have to take the admissions test. Depending on the quality of the completed education, graduation from a university of applied sciences or a pedagogical university entitles the graduate to begin a doctoral program at a university or a federal institute of technology.

Appendix 2

Table A1 Reduced Form

OLS Estimation	Spec. (1)
Dep. Var.: Log average gross monthly wages of tert. educ.	
Number of workers with:	
Tertiary Education	0.00281
	(0.98)
Other	0.00090
	(0.54)
Instrument:	
German-speaking region	0.02975*
	(1.86)
Controls	
Firm characteristics	yes
Regional controls	yes
Sector controls	yes
Year controls	yes
R-squared	0.19
N	22,846

Note: Cluster-robust t-statistics in parentheses (Cluster-level: Firm). Number of workers was divided by 100. * Statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.

Table A2 IV Estimation in selected sectors

IV Estimation	Manufacturing		Hotels and restaurants		Education		Health and social work	
	First Stage	Second Stage	First Stage	Second Stage	First Stage	Second Stage	First Stage	Second Stage
Dep var:	Number of workers with apprenticeship	Log average gross monthly wages of tert. educ.	Number of workers with apprenticeship	Log average gross monthly wages of tert. educ.	Number of workers with apprenticeship	Log average gross monthly wages of tert. educ.	Number of workers with apprenticeship	Log average gross monthly wages of tert. educ.
Number of workers with:								
Tertiary Education	0.72503***	-0.19560	7.74453***	-36.99946	0.10492***	-0.11250	2.11588***	-0.51503**
	(3.13)	(-0.76)	(2.61)	(-0.10)	(5.24)	(-0.61)	(8.12)	(-2.21)
VET		0.27459		4.77961		1.52896		0.23456**
		(0.81)		(0.09)		(0.89)		(2.26)
Other	0.54751***	-0.14655	-0.01691	0.09951	0.34958**	-0.49478	0.26018*	-0.04710
	(6.99)	(-0.79)	(-0.10)	(0.10)	(2.41)	(-0.78)	(1.73)	(-1.32)
Instrument:								
German-speaking region	0.07961		-0.00765		0.05980*		0.39852***	
	(1.63)		(-0.10)		(1.72)		(4.65)	
Controls:								
Firm characteristics	yes		yes		yes		yes	
Regional controls	yes		yes		yes		yes	
Year controls	yes		yes		yes		yes	
N	6,661		718		1,321		1,793	

Note: Cluster-robust t-statistics in parentheses (Cluster level: Firm). Number of workers was divided by 100.

* Statistically significant at the 0.1 level; ** at the 0.05 level; *** at the 0.01 level.