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Backes-Gellner, Uschi ; Rupietta, Christian ; Tuor Sartore, Simone N

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Reverse educational spillovers at the firm level

Uschi Backes-Gellner
Department of Business Administration, University of Zurich, Zurich, Switzerland
Christian Rupietta
Department of Business Administration, University of Zurich, Zurich, Switzerland and Schumpeter School of Business and Economics, University of Wuppertal, Wuppertal, Germany, and
Simone N. Tuor Sartore
Department of Business Administration, University of Zurich, Zurich, Switzerland

Abstract

Purpose – The purpose of this paper is to examine spillover effects across differently educated workers. For the first time, the authors consider "reverse" spillover effects, i.e. spillover effects from secondary-educated workers with dual vocational education and training (VET) to tertiary-educated workers with academic education. The authors argue that, due to structural differences in training methodology and content, secondary-educated workers with VET degrees have knowledge that tertiary academically educated workers do not have.

Design/methodology/approach – The authors use data from a large employer-employee data set: the Swiss Earnings Structure Survey. The authors estimate ordinary least squares and fixed effects panel-data models to identify such "reverse" spillover effects. Moreover, the authors consider the endogenous workforce composition.

Findings – The authors find that tertiary-educated workers have higher productivity when working together with secondary-educated workers with VET degrees. The instrumental variable estimations support this finding. The functional form of the reverse spillover effect is inverted-*U*-shaped. This means that at first the reverse spillover effect from an additional secondary-educated worker is positive but diminishing.

Research limitations/implications – The results imply that firms need to combine different types of workers because their different kinds of knowledge produce spillover effects and thereby lead to overall higher productivity.

Originality/value – The traditional view of spillover effects assumes that tertiary-educated workers create spillover effects toward secondary-educated workers. However, the authors show that workers who differ in their type of education (academic vs vocational) may also create reverse spillover effects.

Keywords Earnings, Education, Informational spillovers

Paper type Research paper

1. Introduction

Educational 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 and Peri, 2006; Moretti, 2004a; Rauch, 1993), industry (e.g. Kirby and Riley, 2008; Sakellariou and Maysami, 2004), and firms or workers (e.g. Barth, 2002; Battu *et al.*, 2003; Bratti and Leombruni, 2009; Wirz, 2008). The common underlying assumption in research on spillover effects is that spillovers flow "down" to lower-educated workers from either the highest-educated individuals (e.g. Moretti, 2004b) or from the firm's average education level measured in number of years (e.g. Rauch, 1993). This assumption neglects that educational spillovers can also arise from having different types of knowledge regardless of the level or the length of education.

If individuals are heterogeneous in terms of the type of their education, we expect that this will also cause educational spillovers due to complementary heterogeneous knowledge.

JEL Classification — I20, J24, J30

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In such cases, distinction only by educational level would not cover all relevant educational dimensions. Especially in countries that have a vocational education and training (VET) system offering high quality training at the secondary level such as Austria, Germany, Switzerland, or Denmark, distinction by educational level might prove insufficient[1]. Therefore analyzing educational spillover effects not only by level but also by 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 present a new type of spillover effects, which we call "reverse spillovers." We discuss a conceptual background that establishes differences in knowledge as the underlying mechanism for spillovers. Thereby we define a new type of spillovers that goes in the opposite direction as the "traditional" spillover. "Traditional" spillovers go from highly educated workers to lower-educated workers and assume that lower-educated workers have no additional skills or knowledge that could be relevant for higher-educated workers (Moretti, 2004b). We define a new type of spillover that is distinct from the "traditional" view on spillovers: reverse spillovers. Reverse spillovers occur if a formally lower-educated workers has skills and knowledge that is different from but relevant for a formally higher-educated worker. Thus, we assume that lower-educated workers can have a different rather than a reduced skill set than higher-educated workers. We extend the traditional view on spillover effects by arguing that not only the level of education (i.e. secondary vs tertiary education) but also the educational type (i.e. academic vs vocational education) causes differences in knowledge and thus spillover effects.

Second, we include predictions on the functional form of reverse spillovers in our hypotheses. In line with Battu *et al.* (2003), we expect a non-linear relationship. They find a positive but diminishing return from an increase in the overall educational level of a workplace. We empirically analyze the spillovers to tertiary education from co-workers with secondary vocational education like VET.

To test our hypotheses, we use data from the Swiss Earnings Structure Survey (ESS), a large firm panel that also contains information on worker characteristics. We estimate Mincer (1974) earnings equations[2]. The ESS is a very good match for our empirical analysis, as the data set contains information on workers' education and earnings and allows us to measure education by using educational degrees instead of years of schooling. In our estimation strategy we consider the potential endogeneity of a firm's workforce composition and use two instruments 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, we use a firm's location as an instrument for the employment of workers with VET degrees. Moreover, we use the number of higher vocational diplomas awarded in each major region as a second instrument. Higher vocational diplomas are tertiary degrees that instructors of apprentices often hold. Thus, the number of higher vocational diplomas reflects the supply of instructors in VET.

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

2.1 Conceptual background

From a classical spillover perspective, educational spillovers occur when higher-educated workers transfer their knowledge and skills to lower-educated workers and thereby increase their productivity (Battu *et al.*, 2003; Martins and Jin, 2010; Wirz, 2008). Researchers assume that spillover effects are unidirectional (i.e. from higher to lower education levels). For example, Martins and Jin (2010) model education as a determinant of productivity and expect low productive workers to learn from high productive workers. Similarly, Battu *et al.* (2003) expect a worker who collaborates with a higher-educated colleague to learn from such a collaboration and thus to increase productivity and earnings. Thus educational spillover effects have a clear direction that goes from high to low education levels.

The assumption of unidirectional spillovers implies that workers who have a lower education level than their colleagues have no skills that they can offer to their higher-educated colleagues. In terms of skill sets the assumption of unidirectional spillovers means that the skill set of lower-educated workers is part of the skill set of higher-educated workers.

This typical assumption of unidirectional spillovers might be perfectly reasonable in countries with an educational setting that consists of a strong single pathway to one predominant type of education. For example, we can plausibly assume that workers with a college degree have the same knowledge as workers with a high school degree plus the knowledge that they have learnt in college. In this context we observe unidirectional spillovers and a perfect overlap of skill sets. However, some countries' education systems offer different types of education of similar quality, like Germany and Switzerland with their vocational and academic education. In those cases, assuming unidirectional spillovers might not be correct. For example, workers with vocational degrees have other rather than fewer skills than workers with tertiary degrees.

We illustrate the difference between unidirectional spillover effects and so-called "reverse" spillover effects in Figure 1. The left side of Figure 1 demonstrates the traditional spillover. In this situation, the skills and knowledge of individuals with tertiary education perfectly covers the skills and knowledge of individuals with secondary education. Here, spillover effects are unidirectional. The right side of the same figure contrasts this concept with a situation where skill sets between secondary and tertiary education overlap but only partly. Thus we have two effects: first, a traditional spillover effect that occurs because workers with secondary education can learn from workers with tertiary education. Second a "reverse" spillover effect that occurs because workers with secondary education possess skills and knowledge that workers with tertiary education do not have. In this case, workers with tertiary education learn from workers with secondary education. We call this latter situation "reverse spillover" as it goes in the opposite direction as the traditional spillover effect.

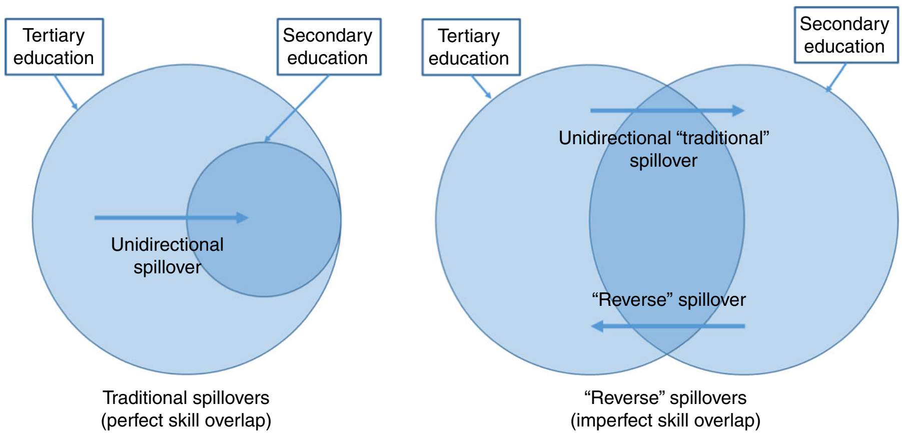

Figure 1.
Spillover effects between skill sets

2.2 Different skill sets in Swiss vocational and academic education

Reverse spillover effects require skill sets that are substantially distinct. Switzerland is an ideal case to study reverse spillovers because it has an education system with two distinct educational pathways that are of comparable quality: vocational and academic education (Wolter *et al.*, 2014). The pathways are structured differently and have a different educational content (Wolter *et al.*, 2014). Thus, workers who graduate from one track have different skills and knowledge than workers who graduate from the other track. This difference in skills and knowledge then fulfills the requirement for the analysis of reverse spillover effects.

Secondary vocational education in Switzerland comprises three- to four-year programs that combine theoretical education in vocational schools and on-the-job training in companies. Typically students learn in vocational schools one to two days a week and spend three to four days on the job. These training programs are part of upper secondary education and follow directly after mandatory schooling. Each of these programs follows a nationally standardized curriculum that regulates training in schools and on the job (Wolter and Ryan, 2011; The Federal Assembly of the Swiss Confederation, 2012). Students in this educational type learn theoretical and practical skills that are relevant for their occupation. After, students have the option to continue their education in higher VET or at a university of applied sciences.

Secondary academic education in Switzerland prepares students for tertiary education at a university. Like vocational education, these programs follow directly after mandatory schooling. They typically last four years and end with a university entrance certificate. Typically these programs contain general education and are not specific to any occupation. They also do not include occupation-relevant practical skills.

Tertiary education includes educational degrees from a university, university of applied sciences, or higher vocational education. Typically, students in tertiary education learn more theoretical skills than occupation-specific and applied skills, especially compared to secondary vocational education students. In sum, vocational education conveys practical skills that are relevant for a specific occupation, while tertiary education conveys theoretical skills that are more general.

2.3 Hypotheses

Differences in skill sets between vocational and academic education are a prerequisite for the occurrence of reverse spillover effects. Skill sets of workers with vocational education comprise more practical skills than those of workers with academic skills. We therefore expect not only that workers with vocational education will benefit from collaboration with academically qualified workers, but also that academically qualified workers will benefit from collaborating with workers who completed vocational education.

To show that these reverse spillover effects are a matter of different skill sets and not only workers collaborating at the same education level, we examine reverse spillovers up from workers with VET degrees to workers with tertiary degrees. This setting is an even stronger test for the presence of reverse spillovers, as there exists a difference in levels of education:

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 an individual's 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 non-linear effect of educational spillovers. We model this effect in analogy to non-linear 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 diminishing.

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 ESS, a representative data set collected biennially by the Swiss Federal Statistical Office. This data set is well suited for our analysis because it contains information on individual characteristics like earnings, education, and tenure; and firm-level attributes like firm size, sector, and region. Before we run our estimation, we aggregate the individual data to the firm level. First, this aggregation step is in line with our theory, because we expect the same spillover effect for each worker in a firm. Second, aggregating the data helps us to overcome potential endogeneity problems that might bias the estimation at the individual level. As the firm identifier remains the same throughout all waves, we can generate a firm panel that allows us to include firm fixed effects and thus to eliminate time-invariant endogeneity at the firm level[3]. We use data from 1998 through 2004.

Before aggregating the data, we restrict our sample in the following ways. First, we restrict it to companies in the private sector[4]. For the calculation of firm-average earnings of workers with tertiary education, we focus on workers aged 25-60[5]. Given the estimation of a fixed time and a firm-specific effect, we exclude all firms that are observed only once during the observation period as well as firms switching to another sector. Because we are interested in how the earnings of tertiary-educated workers are affected by workers with VET degrees, we restrict our data set to firms employing at least five workers, of which at least one has tertiary education. After these restrictions, we aggregate our data set to the firm level. Table I shows the descriptive statistics.

Variables	Obs.	Mean	SD	Min.	Max.
Dependent variables					
Log average gross monthly earnings	22,837	8.799	0.236	8.019	9.829
Log average gross monthly earnings of workers with tert. educ.	22,837	9.055	0.275	7.956	9.929
Log average gross monthly earnings of workers with tert. ac. educ.	10,050	9.177	0.320	7.990	9.926
Independent variables					
Share of workers with tert. ac. degrees	22,837	0.088	0.164	0	1
Share of workers with tert. voc. degrees	22,837	0.215	0.197	0	1
Share of workers with high school degrees	22,837	0.026	0.069	0	0.947
Share of workers with VET degrees	22,837	0.475	0.255	0	0.992
Share of workers with obligatory schooling	22,837	0.164	0.205	0	0.963
Share of workers with other education	22,837	0.032	0.100	0	0.998
Number of tertiary-educated workers	22,837	14.08	72.19	1	2,679
Number of workers with VET degrees	22,837	30.14	128.2	0	6,388
Number of workers with other education	22,837	18.10	111.5	0	5,667
Ratio VET/tertiary	22,837	4.539	10.37	0	745
Controls					
Firm size	22,837	62.33	262.6	5	9,973
Male	22,837	0.600	0.259	0	1
Tenure	22,837	8.197	4.034	0	34.800
Age	22,837	41.00	4.734	22.270	63.200
Part-time	22,837	0.257	0.264	0	1

Notes: Earnings are adjusted for inflation. The reference year is 2005

Table I.
Descriptive statistics (firm level)

To investigate the relationship between the productivity of tertiary-educated workers and the educational composition of the workforce, we use monthly gross earnings as a measure for productivity assuming that earnings reflect productivity sufficiently well. Thereby, we follow previous studies on spillover effects in firms. Martins and Jin (2010) estimate the effect of co-workers' education on workers' productivity. They argue that earnings are proportional to workers' productivity. Wirz (2008) analyzes the effect of co-workers' education on productivity using the 1996 wave of the Swiss ESS, the same data set that we use in our study. She argues that learning from higher-educated co-workers increases workers' productivity and thus earnings. Earnings 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 earnings as a proxy for workers' productivity.

Our dependent variable is the log of average monthly gross earnings for workers with tertiary education. We use real earnings (2005 = 100) for our analysis. The ESS contains information on the highest educational degree of each worker, which we categorize into three categories: "tertiary education" includes workers who are graduates of one of the federal institutes of technology, a university, a university of applied sciences[6], a pedagogical university, or a higher vocational school; "VET degrees" includes workers who have completed dual VET at the upper secondary level; "other education" includes workers who have completed only high school or lower, or with an unclassifiable foreign education[7].

Additionally, we include several control variables aggregated at the firm level. We aggregate these for each firm and year. The individual variables at the firm level are: 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 controls for sector, region, and year (all categorical). The regional controls consist of dummy variables that represent major regions in Switzerland. Major regions consist of one or more cantons. The seven major regions in Switzerland are Lake Geneva Region, Espace Mittelland, North-Western Switzerland, Zurich, Eastern Switzerland, Central Switzerland, and Ticino. For the year controls, we use dummies for each observation year.

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 non-linear relationships.

In our first specification, shown in Equation (1), we use the logarithm of average earnings w_{jt} of tertiary-educated workers as a dependent variable. This equation contains an intercept β_0 that measures the average earnings level. 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. The first sum in Equation (1) ($\sum_{k=1}^{3} \beta_k e_{kjt}$) contains the three education variables e_{kjt}. The second sum ($\sum_{k=1}^{3} \gamma_k e_{kjt}^2$) contains the squared education variables to test for a non-linear reverse spillover effect. We use these three variables as our explanatory variables. The main explanatory variable in our equation is the number of workers with VET degrees:

$$\ln(w_{jt}) = \beta_0 + \sum_{k=1}^{3} \beta_k e_{kjt} + \sum_{k=1}^{3} \gamma_k e_{kjt}^2 + X_{jt}\delta + \varepsilon_{jt} \tag{1}$$

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 earnings of tertiary-educated workers, Equation (1) will 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 earnings level, high tech firm, and a class for broad firm size. Following equation shows our second specification, which includes firm fixed effects (α_j):

$$\ln(w_{jt}) = \beta_0 + \sum_{k=1}^{3} \beta_k e_{kjt} + \sum_{k=1}^{3} \gamma_k e_{kjt}^2 + X_{jt}\delta + \alpha_j + \varepsilon_{jt} \tag{2}$$

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 (see Tables AII and AIII for descriptive results). By choosing languages as an instrument for tradition and culture, we follow Eugster *et al.* (2011), who argue that the linguistic border in Switzerland is also a cultural border. We argue that this cultural difference is also reflected in the tradition of training apprentices and employing workers who completed apprenticeships.

The applicability of the instrument not only depends on its influence on the endogenous variables but also on the exclusion restriction. An instrument fulfills the exclusion restriction if its effect goes only through the channel of the endogenous variable. In our case the language of a canton must influence productivity only through the number or share of workers with VET degrees. Before we discuss potential threats to the validity of our instrument, we introduce its measurement.

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 percent of the population speaks German. For this classification, we use data from the 2,000 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 (Angrist and Krueger, 2001).

As our instrumental variable uses information on language at the cantonal level, we have to exclude a direct effect of cantons on earnings. Otherwise the exclusion restriction will not hold. In our estimation we include a control for major region and thereby exclude regional information at a higher level than cantons as explanation for earnings. As six of seven major regions are homogenous in terms of language, the potential threat to our exclusion restriction comes from within one major region (Espace Mittelland).

One potential threat to the validity of our instrument might be that firms chose their geographical location strategically dependent of the available human capital in a canton. The majority of companies in our data are SMEs. For such firm we would expect a lower mobility because once they made a location decision relocation comes with additional costs. Moreover, some SMEs depend heavily on their location (e.g. firms in the crafts and tourism sector) and cannot relocate without losing customers. Thus, we expect a low mobility for the majority of our sample, SMEs.

A further point that might threaten the validity of our instrument is the composition of a firms' workforce. As firms in the non-German-speaking part of Switzerland hire more workers with tertiary degrees, there might be a penalty for workers with tertiary degrees in firms who employed a large share of these workers simply due to market forces. In Table AV, we show that earnings for workers with tertiary degrees decrease if the share of such workers increases, however, we also show that the firm size also decreases. Thus, firms that employ a large share of workers with tertiary degrees have obviously fewer economics of scale due to their limited size than firms not doing so. However, we control for firm size in our regression and thereby exclude this alternative explanation.

As we cannot assess the validity of our instrument in the case just described, we include an additional instrument to conduct overidentification tests. As a second instrumental variable we use the number of graduates with a higher vocational diploma at the regional level for each year. Higher vocational diplomas are tertiary degrees. Workers who have these degrees often work as instructors and train apprentices in firms. Thus the availability of workers with higher vocational diplomas supports firms in their tradition to train apprentices and enables them to offer more apprenticeships and consequently to employ more workers with VET degrees.

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 Pooled ordinary least squares (OLS) estimates

According to *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 *H2*, we expect that the return to an increase in the number of workers with VET degrees is positive but diminishing. Table II provides the pooled OLS estimates for testing our hypotheses. 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 II).

The coefficient for the number of workers with VET degrees is positive and statistically significant at the 1 percent level. Using the coefficients from specification (5) for the squared coefficient we calculate that the maximum effect is reached at 2,050 workers with VET degrees. This indicates that for the average firm – one with 30 workers with VET degrees – an increase in the number of VET workers results in higher productivity for workers with tertiary education. This result changes only for very large firms, those exceeding the maximum of 2,050 VET workers. For these firms, additional VET workers will no longer have 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*)[9].

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

5.2 OLS estimates with firm fixed effects

Table III shows the estimation results of Equation (7). Due to the inclusion of fixed effects, we must interpret the coefficients as deviations from firm averages[10]. In the first column, we include no control variables at the firm level. We focus on specification (4), because the

Table II. Non-linear spillover effects of workers with VET on workers with tertiary education (pooled OLS estimation)

Pooled OLS regression	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. var.: log average gross monthly earnings of tert. educ.					
Number of workers with					
Tertiary education	0.02588 (3.43)***	0.03204 (4.25)***	0.02854 (4.04)***	0.00485 (0.73)	0.00472 (0.71)
VET	0.02788 (5.90)***	0.02213 (4.98)***	0.01302 (3.20)***	0.01231 (2.97)***	0.01230 (2.97)***
Other	−0.02113 (−4.04)***	−0.02215 (−3.84)***	−0.01794 (−3.34)***	−0.00131 (−0.31)	−0.00133 (−0.32)
Sq. number of workers with					
Tertiary education	−0.00128 (−4.33)***	−0.00152 (−5.14)***	−0.00132 (−4.84)***	−0.00039 (−1.37)	−0.00038 (−1.34)
VET	−0.00052 (−3.40)***	−0.00039 (−3.18)***	−0.00024 (−2.69)***	−0.00030 (−3.32)***	−0.00030 (−3.33)***
Other	0.00035 (2.26)**	0.00043 (2.28)**	0.00037 (2.18)**	−0.00004 (−0.41)	−0.00004 (−0.40)
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
Cluster	9,855	9,855	9,855	9,855	9,855
Observations	22,837	22,837	22,837	22,837	22,837
R^2	0.01	0.06	0.10	0.19	0.19

Notes: Cluster-robust *t*-statistics in parentheses (cluster level: firm). Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Fixed-effects model	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)
Dep. var.: log average gross monthly earnings of tert. educ.				
Number of workers with				
Tertiary education	−0.05517 (−6.66)***	−0.05652 (−6.71)***	−0.05646 (−6.73)***	−0.05724 (−6.75)***
VET	0.02283 (4.73)***	0.02297 (4.73)***	0.02276 (4.72)***	0.02249 (4.65)***
Other	0.00073 (0.16)	0.00116 (0.25)	0.00122 (0.26)	0.00121 (0.26)
Sq. number of workers with				
Tertiary education	0.00175 (4.55)***	0.00181 (4.46)***	0.00181 (4.48)***	0.00184 (4.54)***
VET	−0.00029 (−3.63)***	−0.00029 (−3.62)***	−0.00029 (−3.61)***	−0.00029 (−3.58)***
Other	0.00008 (0.95)	0.00008 (0.96)	0.00008 (0.95)	0.00008 (0.98)
Controls				
Firm characteristics	No	Yes	Yes	Yes
Regional controls	No	No	Yes	Yes
Year controls	No	No	No	Yes
Cluster	9,855	9,855	9,855	9,855
Observations	22,837	22,837	22,837	22,837
R^2	0.00	0.02	0.02	0.02

Notes: Robust *t*-statistics in parentheses. Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Table III. Non-linear spillover effects of workers with VET on workers with tertiary education (fixed-effects estimation)

results are robust against the inclusion of the full set of control variables. The results confirm the results of Table II: 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 3,878 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*). These returns diminish with the number of workers with VET degrees employed (*H2*)[11].

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 pooled OLS regressions (Table II) with the results of the FE estimations (Table III), 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. We find a positive but diminishing return of the number of workers with tertiary education on their average productivity when using OLS regressions, and a negative but increasing return when using FE estimations. The negative effect in the FE estimation could result from different characteristics of workers that enter the firm. A new hire typically has lower work experience than workers who are employed by the firm for a long time. Moreover, new workers need some time to work at their full productivity because they must acquire firm-specific knowledge. In this time incumbent workers might spend more effort in teaching newly hired workers necessary skills than receiving valuable knowledge from them. Thus new hires can temporarily reduce the productivity of incumbents.

5.3 Model extensions and robustness checks

To strengthen our findings we conduct a series of robustness tests. These tests include alternative model specifications and consider heterogeneous reverse spillover effects.

5.3.1 Alternative measures for workforce composition. In our original specification we classify educational degrees in three categories, use the number of workers of each category as explanatory variable and allow firm size to vary. Thus, holding all other variables constant, an increase in the number of workers with VET degrees means that also firm size increases by one. This allows to directly measuring the effect of an additional VET graduate holding the current workforce composition constant.

However, with this approach we are unable to control for the effect of firm size on our outcome variable (earnings of tertiary-educated workers). Thus we modify our initial specification and use the ratio between workers with VET degrees and tertiary-educated workers as an explanatory variable. This specification assumes that the workforce remains constant and thus allows keeping firm size constant. The new specifications thus have a different interpretation. In this new framework employing an additional worker with VET degrees means that another worker leaves the firm. An increase in the ratio means that the firm either hires workers with a VET degree or lays off workers with a tertiary degree. For our testing our hypothesis, this measure does not make a difference because a higher number and a higher ratio lead to reverse spillovers.

In the next step, to control for the entire workforce composition, we include the share of each educational category and keep firm size constant. The inclusion of additional ratios (e.g. the ratio between workers with VET degrees and workers with other degrees) would not be possible, because the assumption that all other ratios remain constant if one ratio increase would not hold. For example, hiring a worker with a VET degree and laying off a worker with a tertiary degree automatically results in a change in the ratio between workers with VET degrees and workers with other degrees.

Table IV shows the results for this new specification. This table contains the results of a fixed-effects regression that contains the ratio (and its squared term) between workers with VET degrees and workers with tertiary degrees. The results show within-firm effects. An increase of the ratio results in a higher productivity of tertiary-educated workers. This relationship is positive but declining and thus supports both *H1* and *H2*.

As all our results provide strong support for tertiary-educated workers to benefit from spillover effects from workers with VET degrees, we are now interested in analyzing whether these spillover effects are similar for workers with different types of tertiary education. Therefore, we use a more narrowly defined classification of tertiary educational degrees. We distinguish between academic and vocational degrees and in tertiary education. We thus decompose the category tertiary education into two sub-categories: first, tertiary academic degrees include tertiary degrees from Federal Institutes of Technology,

Table IV. Fixed-effects model with VET/tertiary education ratio

Fixed-effects model	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)
Dep. var.: log average gross monthly earnings of tert. educ.				
Ratio (VET/tertiary)	0.00386 (7.95)***	0.00397 (8.07)***	0.00397 (8.06)***	0.00397 (8.04)***
Squared ratio (VET/tertiary)	−0.00001 (−4.87)***	−0.00001 (−4.79)***	−0.00001 (−4.79)***	−0.00001 (−4.77)***
Constant	9.03797 (4,309.77)***	8.34224 (55.92)***	8.35248 (55.64)***	8.35242 (55.42)***
Controls				
Firm characteristics	No	Yes	Yes	Yes
Regional controls	No	No	Yes	Yes
Year controls	No	No	No	Yes
Cluster	9,855	9,855	9,855	9,855
Observations	22,837	22,837	22,837	22,837
R^2	0.01	0.03	0.03	0.03

Notes: Robust *t*-statistics in parentheses. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively universities, and pedagogical universities[12]. Second, tertiary vocational degrees including tertiary degrees in higher VET (professional degrees) and from universities of applied sciences. At the upper secondary level, we distinguish between high school degrees and VET degrees[13]. Moreover, we include a category for compulsory schooling and a category for other degrees that also contains unclassified foreign education degrees[14].

Table V provides the results for this augmented specification that contains education-type shares and a more detailed classification of degrees. The results show that university graduates have a higher productivity if the share of workers with VET degrees increases. As in our main results tables (Tables II and III), the squared term of the share of workers with VET degrees is statistically significant up to specification (3). However, this squared term is only marginally significant in specifications (4) and (5) but still in line with our *H2*. After the inclusion of sector and year controls, we still find a positive association between an increase in the share of workers with VET degrees and the productivity of university graduates. One reason for this change in functional form might be that the share of university graduates differs largely between sectors, resulting in different functional forms of reverse spillover effects. Furthermore, the distinction between academic and vocational tertiary education reduces the number of observations and leads to less statistical power (we lose more than half of our observations). In sum, we again find strong support for *H1* and the results are also in line with *H2*.

5.3.2 Professional status and occupation. So far our specifications do not include the occupation or professional status of workers. Including occupation and professional status is important to the robustness of our results for two reasons: first, workers that have the same occupation perform, independent of their respective education, similar tasks and problems and share similar knowledge. We expect workers of a given occupation to interact more frequently and to have more common knowledge than workers of different occupations. Communication within an occupational group might be easier and simpler than communication between different occupational groups (Wirz, 2008). Wirz (2008) indeed provides evidence for strong spillover effects within occupational groups. As workers within an occupation have similar tasks and tasks determine earnings (the proxy for our productivity measure), we use occupations as additional controls.

Second, we control for professional status as higher responsibility is typically associated with an earnings premium. However, professional status might not be equally distributed across education levels. We expect that workers with a tertiary education are also likely to have higher professional status. Some firms have more positions that require tertiary degrees than others (e.g. banks, insurance companies, pharmaceutical companies, and consultancies). In such companies, not all workers with tertiary degrees also have high professional status. We therefore check whether professional status and thus higher earnings depend on the share of workers with tertiary degrees[15].

For including professional status and occupation into our estimations, we use the disaggregated data set. Without disaggregated data we cannot link occupation and professional status to university graduates. Having this information linked is crucial as we must control for these variables directly and not via an average.

In Table VI, we show the results of a pooled OLS regression that uses individual earnings data and controls for professional status and occupation. As in our main equation, we find a positive but diminishing reverse spillover effect. Once we include professional status and occupation (Specification (4)), we observe a drastic increase in the explanatory power of our model. The R^2 increases by 0.14 from specifications (3) to (4). This result highlights that both professional status and occupation are important control variables in our model. However, we still find support for our hypotheses (*H1* and *H2*).

Table V. Pooled OLS estimation with shares of differently educated workers

Pooled OLS regression	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. var.: log average gross monthly earnings of workers with tert. ac. education					
Share of workers with					
Tertiary vocational	0.18485 (2.93)***	0.01424 (0.23)	−0.01254 (−0.21)	−0.00208 (−0.04)	0.00248 (0.04)
High school	−0.07003 (−0.68)	−0.02006 (−0.21)	0.07157 (0.75)	0.00091 (0.01)	0.00090 (0.01)
VET	0.47465 (7.82)***	0.29170 (4.97)***	0.19807 (3.35)***	0.18022 (3.13)***	0.18069 (3.14)***
Obligatory schooling	−0.22151 (−3.47)***	−0.33971 (−5.43)***	−0.29472 (−4.75)***	−0.18092 (−2.75)***	−0.18311 (−2.78)***
Other	−0.22591 (−2.27)**	−0.37359 (−3.82)***	−0.35909 (−3.74)***	−0.23554 (−2.49)**	−0.23265 (−2.46)**
Squared share of workers with					
Tertiary vocational	−0.14028 (−1.58)	0.03951 (0.46)	0.05858 (0.69)	0.06566 (0.80)	0.06104 (0.74)
High school	−0.01926 (−0.08)	−0.05696 (−0.26)	−0.15289 (−0.68)	−0.03487 (−0.16)	−0.03373 (−0.16)
VET	−0.28147 (−4.07)***	−0.18640 (−2.80)***	−0.11472 (−1.74)*	−0.10439 (−1.60)	−0.10274 (−1.58)
Obligatory schooling	0.38183 (3.47)***	0.39958 (3.72)***	0.37334 (3.53)***	0.31876 (2.93)***	0.32135 (2.95)***
Other	0.33008 (1.85)*	0.42868 (2.42)**	0.40958 (2.37)**	0.30214 (1.78)*	0.30071 (1.77)*
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
Cluster	5,196	5,196	5,196	5,196	5,196
Observations	10,050	10,050	10,050	10,050	10,050
R^2	0.03	0.11	0.13	0.16	0.16

Notes: Cluster-robust *t*-statistics in parentheses (cluster level: firm); *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Table VI. Pooled OLS estimation with shares of differently educated workers (individual data)

Pooled OLS regression	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)	Spec. (6)	Spec. (7)
Dep. var.: log average gross monthly earnings of workers with tert. ac. education							
Share of workers with							
Tertiary vocational	0.24879 (2.07)**	−0.03284 (−0.30)	−0.03291 (−0.30)	−0.01478 (−0.14)	−0.03388 (−0.36)	−0.16103 (−1.80)*	−0.15448 (−1.74)*
High school	0.43171 (2.04)**	0.57800 (3.14)***	0.57861 (2.88)***	0.33821 (1.93)*	0.44163 (2.88)***	0.42725 (2.94)***	0.42162 (2.93)***
VET	0.64101 (5.28)***	0.39867 (3.84)***	0.39944 (3.88)***	0.42670 (4.60)***	0.36885 (4.38)***	0.31213 (3.98)***	0.31046 (4.04)***
Obligatory schooling	−0.46713 (−3.34)***	−0.49120 (−4.02)***	−0.49066 (−4.35)***	−0.43950 (−4.49)***	−0.31700 (−3.65)***	−0.39056 (−4.36)***	−0.38690 (−4.44)***
Other	0.15932 (0.96)	0.31664 (2.49)**	0.31706 (2.31)**	0.38083 (2.28)**	0.33002 (2.17)**	0.26605 (1.76)*	0.25789 (1.75)*
Squared share of workers with							
Tertiary vocational	−0.15542 (−0.97)	0.06521 (0.46)	0.06532 (0.46)	−0.02913 (−0.22)	−0.03523 (−0.28)	0.09225 (0.78)	0.08565 (0.73)
High school	−0.85133 (−1.79)*	−1.35271 (−3.21)***	−1.35416 (−2.94)***	−1.01012 (−2.66)***	−1.07206 (−3.13)***	−1.11179 (−3.45)***	−1.10508 (−3.46)***
VET	−0.56146 (−3.84)***	−0.39992 (−3.30)***	−0.40056 (−3.25)***	−0.45842 (−4.21)***	−0.41274 (−4.10)***	−0.42864 (−4.64)***	−0.42330 (−4.68)***
Obligatory schooling	0.75996 (3.42)***	0.59931 (3.13)***	0.59834 (3.52)***	0.40558 (3.02)***	0.30561 (2.53)**	0.32708 (2.75)***	0.32311 (2.80)***
Other	−0.22270 (−0.93)	−0.51933 (−2.80)***	−0.51964 (−2.70)***	−0.59701 (−2.70)***	−0.50780 (−2.49)**	−0.51408 (−2.57)**	−0.50622 (−2.59)***
Controls							
Individual characteristics	No	Yes	Yes	Yes	Yes	Yes	Yes
Firm size	No	No	Yes	Yes	Yes	Yes	Yes
Occupation and professional status	No	No	No	Yes	Yes	Yes	Yes
Regional controls	No	No	No	No	Yes	Yes	Yes
Sector controls	No	No	No	No	No	Yes	Yes
Year controls	No	No	No	No	No	No	Yes
Cluster	5,196	5,196	5,196	5,196	5,196	5,196	5,196
Observations	92,302	92,302	92,302	92,302	92,302	92,302	92,302
R^2	0.03	0.29	0.29	0.43	0.45	0.47	0.47

Notes: Cluster-robust t-statistics in parentheses (cluster level: firm). *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

5.3.3 Endogeneity in the estimated reverse spillover effects. As a next robustness check, we conduct an instrumental variable estimation. Unobservable variables correlated with both the average earnings 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 two instrumental variables to estimate a two-stage lease squares model. As a first instrumental variable for the number of workers with VET degrees we use a dummy that indicates a German-speaking region. Information on the linguistic region is available at the cantonal level. Thus, we use more fine-grained regional information than our regional controls, which summarize cantons to seven major regions. This approach allows us to keep regional controls and to include the instrument in our model[16]. As a second instrumental variable we use the number of graduates with a higher vocational diploma at the regional level for each year[17].

We show the results of our IV estimation in Table AV. In the first stage regression we show that the instruments are relevant for the endogenous variable (number of workers with VET degrees). Moreover, weak identification does not seem to be a problem in our estimation as the Kleibergen-Paap Wald rk F-statistic (11.20) is close to the 15 percent maximal IV size threshold. With two instruments and one endogenous variable, we can perform an overidentification test to test the validity of our instrument[18]. The Hansen-J statistic and the accompanying p-values at the bottom of Table AV show that we cannot reject the null hypothesis of a valid instrument. In sum, the tests support the relevance and the validity of our instrumental variables estimation. The findings in Table AV support *H1* and underline that workers with tertiary degrees benefit from working with workers with VET degrees.

5.3.4 Robustness check: industry-level estimation. As a last robustness test we analyze the heterogeneity of the reverse spillover effect. This situation can largely differ by industry. In some industries tertiary-educated workers might require more practical skills, while in other industries tertiary-educated workers might require knowledge from their tertiary-educated colleagues. For example, in R&D, scientists require qualified workers for building precise and functional prototypes. A reverse spillover effect in this case could be that qualified workers can precisely explain where blueprints need to be improved to build a prototype with the desired specifications. In other industries, workers with tertiary degrees and workers with VET degrees work on different problems. For example, in insurance quantitative risk analysts (university graduates) might not collaborate intensively with the sales staff (workers with VET degrees). Thus, the occurrence of reverse spillover effects can strongly depend on the industry-specific need for collaboration between differently qualified workers.

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 VII shows the calculated values for the education sector (highest value), the hotel and restaurant sector (lowest value), the manufacturing sector, and the health and social work sector (two sectors representing values very close to the overall mean).

Table VIII shows the estimation results for Equation (1). 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 – those with more than 2,287 VET workers. Thus, for the majority of firms, we find support for *H1* and *H2*.

6. Discussion

This paper analyzes reverse spillover effects. Reverse spillovers occur if a formally lower-educated worker has skills and knowledge that are relevant for a formally higher-educated worker. Reverse spillovers are conceptually distinct from "traditional" spillover effects: reverse spillovers go in the opposite direction of the "traditional" spillover, from formally lower-educated to formally higher-educated workers. Reverse spillovers base on the assumption that a formally lower-educated worker has skills and knowledge that is relevant for the productivity of a formally higher-educated worker. Thereby the concept of reverse spillovers relaxes the assumption that higher-educated workers have all the skills and knowledge lower-educated workers have.

We argue that such spillover effects occur because knowledge spillovers do not only result from differences in the level of education but also in the type of education. In countries that have two qualitatively equal types of education (academic and vocational), reverse spillovers are likely to occur because both types of education endow a worker with a specific set of knowledge and skills. Thus, even a formally lower-qualified worker might have skills that are relevant for a formally higher-qualified worker with a degree from a different education type. Countries such as Germany, Switzerland, and Austria have both vocational and academic education systems, and are thereby structurally different from countries that have an education system with one strong type (e.g. academic education in the USA). In countries with more than one educational type, reverse spillovers are most likely to occur.

Table VII. 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

Table VIII. Non-linear spillover effects of workers with VET on workers with tertiary education (OLS Estimation in Selected Sectors)

Pooled OLS regressions	Manufacturing	Hotels and restaurants	Education	Health and social work
Dep. var.: log average monthly earnings of tert. educ.				
Number of workers with				
Tertiary education	−0.02048 (−1.86)*	−0.69847 (−1.70)*	0.01162 (0.19)	−0.16774 (−3.74)***
VET	0.02866 (3.20)***	0.19985 (2.79)***	0.94855 (4.93)***	0.08548 (5.86)***
Other	−0.00413 (−0.46)	0.03790 (0.45)	−0.50825 (−1.75)*	0.01719 (0.93)
Sq. number of workers with				
Tertiary education	0.00071 (1.67)*	0.69222 (0.50)	−0.00083 (−0.06)	0.00852 (1.30)
VET	−0.00063 (−2.75)***	−0.01338 (−2.29)**	−0.99173 (−4.62)***	−0.00186 (−2.09)**
Other	−0.00018 (−0.44)	−0.00144 (−0.53)	1.01163 (2.46)**	−0.00108 (−1.52)
Controls				
Firm characteristics	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes
Year controls	Yes	Yes	Yes	Yes
R^2	0.10	0.16	0.19	0.10
n	6,659	717	1,321	1,792

Notes: Cluster-robust t-statistics in parentheses (cluster level: firm). Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

In this paper, we analyze reverse spillover effects from vocational education using Swiss data. Our results show that an increase in the number of workers with VET degrees has a positive but diminishing effect on the productivity (measured in average earnings) 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 important managerial implications. We show that the productivity of workers does not simply depend on their own knowledge and skills but also on the knowledge and skills of their co-workers. Which knowledge and skills a worker acquires during his or her employment depends on the availability of such skills. The composition of a firm's workforce and thus its skill mix is important for the occurrence of spillovers. Our results suggest that, for each type of worker, a skill mix exists that helps them to reach their performance optimum. While there are different types of workers, there might not exist a single optimal skill mix but several; one for each type. Managers should keep the existence of spillovers and reverse spillovers in mind when hiring workers. Changes in the composition of the workforce also results in different spillovers and thus in different productivities of each worker.

Our results also have several policy implications. Unlike the recommendation by Aghion and Howitt (2006) to generally increase tertiary education in developed economies, we argue that it pays to keep a well-balanced mix with vocationally educated workers (as opposed to unqualified workers). Even with a strong emphasis on tertiary education, firms should not neglect the importance of investments in the training of workers with good vocational skills, particularly on the secondary level. Workers from dual 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. As a consequence policymakers should also aim at involving firms in the formation of skills and knowledge instead of merely relying on the schooling or university system.

Notes

1. VET in Austria, Germany, and Switzerland primarily consists of a combination of extensive workplace training and vocational schooling. The training programs typically last three to four years and convey general and occupation-specific skills.
2. This procedure is based on Martins and Jin (2010).
3. The data set consists of repeated cross sections at the individual level and thus does not allow the inclusion of individual fixed effects.
4. The aggregation of the data results from the estimation strategy we choose in the following section.
5. 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 earnings of workers aged 25-60. 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.

6. A university of applied sciences offers three-year bachelors and two-year masters programs containing more practical education in comparison to universities or federal institutes of technology, which offer more theoretical education.
7. The share of workers with high school degrees in our sample is very small (2.6 percent on average). The group "other education" therefore mainly consists of workers with a mandatory schooling degree or a foreign unclassifiable degree.
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. (e.g. Bodenmann and Axhausen, 2012 show that in the St Gallen region, 1.77 percent 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 (2,000 Swiss Federal Population Census), we calculate a dummy variable indicating German-speaking and non-German-speaking regions.
9. In Table II, we use the number instead the share of workers with a distinct degree. Thus, we do not control for the relative composition of the workforce. It might be that firms that employ more workers with VET degrees are larger and also have a different composition of workers with tertiary degrees. The number of workers with VET degrees would then be a proxy for the educational composition of the workforce. In Table AI in the appendix, we list the share of workers with tertiary academic education and tertiary vocational education dependent on the number of workers with VET degrees. In general the ratio between workers with tertiary academic degrees and workers with tertiary vocational degrees remains constant. However, we find a higher ratio for firms with very few workers with VET degrees and with many workers with VET degrees. In the first case we also find a large standard deviation compared to all other standard deviations in the table. This could reflect diversity among companies: those with a workforce consisting only of workers with tertiary academic degrees and those consisting only of workers with tertiary vocational degrees. Firms that belong to the first case could be law firms, engineering offices, or think tanks; while firms that belong to the latter case could be crafts producers. The high ratio for the few large firms in our sample could reflect the fact that those companies have their own in-house R&D departments that require more workers with tertiary academic qualifications to do basic research.
10. For our estimations we use cluster-robust standard errors. In case of aggregated data standard errors might be biased. As a robustness check we re-estimate all specifications that use aggregated data with bootstrapped standard errors. The results are available in Tables AVI-AX. After using bootstrapped standard errors, we still obtain very stable results for *H1*. However, the results for *H2* are less stable. While some specifications support *H2* (Table AVI, Table AIX, and Table AX), other specifications show only marginally significant results (Table AVII).
11. 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 by those points.
12. Pedagogical universities prepare their students for becoming a teacher in grammar schools, high schools, or vocational schools. The teaching skills teachers learn at pedagogical universities are surely more practical than theoretical skills. However, in their daily teaching, teachers use more academic skills than vocational skills, especially those teachers that work in grammar schools and high schools. We therefore decide to classify graduates from pedagogical universities as tertiary academic instead of tertiary vocational.
13. In our initial specification we put high school degrees into the category "other education" as they do not directly qualify for any occupation.

14. The human capital that students acquire in academic education structurally differs from the human capital students acquire in vocational education. Tertiary academic education mainly covers theoretical courses on different subjects and contains only very few practical parts. Tertiary vocational education is based on and covers more practical knowledge and experience. The latter is thus closely related to and an extension of the knowledge of VET workers with secondary degrees. The first is closely related to and an extension of the knowledge of workers with high school degrees.
15. We provide descriptive results on the relationship between the share of university graduates in a firm, professional status, and earnings in Table AIV in the appendix. This table shows that university graduates earn less in firms that employ a larger share of workers of the same type. The share of university graduates in a firm does not seem to influence their professional status. However, we find larger shares of university graduates in smaller firms. Firms that are almost homogenous have about 30 employees on average. Thus, the lower earnings of university graduates who work in homogenous firms might be a size effect.
16. Eugster *et al.* (2011) use linguistic information to measure culture in Switzerland. They use linguistic data within Swiss cantons to control for canton-specific effects. In our paper we use a similar approach. Due to the lack of within-canton data, we use data at the canton level and control for major regions. We argue that language influences firms training tradition. In German-speaking region more firms train apprentices than firms in non-German-speaking regions. In Table AIII we show that firms in German-speaking regions also employ a larger share of workers with VET degrees that firms in non-German-speaking regions.
17. The number of graduates with higher vocational diploma could be influenced by demand. The number of new graduates with higher vocational diploma steadily increases until 2006. Thus, there seems to be a stable demand for workers with higher vocational diploma during our observation period from 1998 through 2004.
18. The overidentification test cannot provide credible results if both instruments are endogenous.

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Appendix 1. Swiss educational system

In Switzerland, compulsory education ends after nine 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 two to four years of on-the-job training with theoretical education. Apprentices usually have three to four days per week of on-the-job training and one to two 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 and humanities), a pedagogical university, or higher vocational school, and entails three to five 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 AI. Distribution of shares of workers with tertiary academic and tertiary vocational degrees

Number of workers with VET degrees in a firm's workforce	Tertiary academic degrees Share	Mode	*p*-value pairwise column comparison	Tertiary vocational degrees Share	Mode	*p*-value pairwise column comparison	Ratio tert. ac./tert. voc.	Obs.
< 10	0.1293 (0.2025)	0.0000		0.2802 (0.2314)	0.2000		0.4615	11652
10- < 20	0.0486 (0.1005)	0.0000	0.00	0.1608 (0.1254)	0.1282	0.00	0.3022	5668
20- < 30	0.0400 (0.0884)	0.0000	0.00	0.1431 (0.1157)	0.1139	0.00	0.2795	1883
30- < 40	0.0353 (0.0754)	0.0000	0.15	0.1332 (0.1133)	0.1019	0.03	0.2650	900
40- < 50	0.0383 (0.0727)	0.0103	0.45	0.1315 (0.1101)	0.0992	0.78	0.2913	531
50- < 60	0.0357 (0.0827)	0.0087	0.63	0.1311 (0.1165)	0.0928	0.97	0.2723	360
60- < 70	0.0433 (0.1005)	0.0093	0.34	0.1214 (0.1088)	0.0945	0.31	0.3567	223
70- < 80	0.0458 (0.0844)	0.0103	0.78	0.1208 (0.1190)	0.0813	0.96	0.3791	183
80- < 90	0.0397 (0.0811)	0.0092	0.50	0.1233 (0.1020)	0.1000	0.83	0.3220	161
90- < 100	0.0474 (0.0862)	0.0128	0.43	0.1156 (0.1017)	0.0832	0.52	0.4100	132
100- < 150	0.0409 (0.0769)	0.0101	0.45	0.1301 (0.1129)	0.0972	0.18	0.3143	361
150- < 200	0.0517 (0.0849)	0.0165	0.13	0.1090 (0.1070)	0.0763	0.02	0.4743	218
200- < 250	0.0480 (0.0690)	0.0177	0.65	0.1223 (0.0998)	0.1039	0.23	0.3924	140
250- < 500	0.0380 (0.0515)	0.0143	0.13	0.1016 (0.1005)	0.0782	0.05	0.3740	259
500- < 1000	0.0469 (0.0768)	0.0134	0.29	0.1030 (0.1093)	0.0705	0.91	0.4553	100
⩾1000	0.0930 (0.0978)	0.0614	0.00	0.1123 (0.0946)	0.1020	0.56	0.8281	66

Note: Standard deviations in parentheses

Table AII. Distribution of degrees by linguistic region

	German-speaking region (1)	Non-German-speaking region (2)	*p*-value (difference (2)-(1) equals zero)
Number of workers with			
Tertiary degrees	15.7914 (85.7357)	10.9560 (35.8751)	0.00
VET degrees	36.9279 (151.5278)	17.7394 (65.3330)	0.00
Other degrees	18.7061 (110.9336)	16.9926 (112.628)	0.27
Observations	14,763	8,074	

Note: Standard deviations in parentheses

Table AIII. Distribution of degrees by linguistic region

	German-speaking region (1)	Non-German-speaking region (2)	p-value (difference (2)-(1) equals zero)
Share of workers with			
Tertiary ac. degrees	0.0655 (0.1409)	0.1289 (0.1926)	0.00
Tertiary voc. degrees	0.2106 (0.1895)	0.2217 (0.2102)	0.00
High school degrees	0.0164 (0.0496)	0.0445 (0.0911)	0.00
VET degrees	0.3725 (0.2567)	0.5312 (0.2363)	0.00
Obligatory schooling	0.1438 (0.1873)	0.2001 (0.2294)	0.00
Other degrees	0.0325 (0.1003)	0.0322 (0.0997)	0.82
Observations	14,763	8,074	

Note: Standard deviations in parentheses

Table AIV. Earnings and position in hierarchy of workers with tertiary academic degrees

	Workers with tertiary academic degrees					
	Log wages		Position in hierarchy		Firm size	
	Mean	Mode	Mean	Mode	Mean	Mode
Share of workers with tertiary academic degrees						
0- < 10%	9.1800	9.1778	2.9864	3	1,359.47	406
10- < 20%	9.1695	9.1603	3.3251	3	2,705.04	1,593
20- < 30%	9.2403	9.2558	3.4477	3	2,136.10	552
30- < 40%	9.2177	9.2165	3.2328	3	1,322.54	261
40- < 50%	9.1704	9.1649	3.2643	3	591.36	83
50- < 60%	9.1368	9.1433	3.3668	3	206.48	66
60- < 70%	9.1005	9.1143	3.5136	4	73.71	34
70- < 80%	9.0389	9.0408	3.3294	3	60.20	34
80- < 90%	9.0580	9.0495	3.0898	3	144.88	47
⩾90%	8.9988	8.9781	3.4024	3	30.79	19

Table AV. Linear spillover effects of workers with VET on workers with tertiary education (instrumental variable estimation)

Instrumental variable estimation Dependent variable	Spec. (1) First stage Number of workers with VET degrees	Spec. (2) Second stage Log average monthly gross earnings of workers with tertiary degrees	Spec. (3) Second stage (bootstrapped SE) Log average monthly gross earnings of workers with tertiary degrees	Spec. (4) Reduced form Log average monthly gross earnings of workers with tertiary degrees
Number of workers with				
Tertiary degrees	1.0899 (0.1643)***	−0.2740 (0.1226)**	−0.2740 (0.1065)***	0.0026 (0.0029)
VET degrees		0.2538 (0.1107)**	0.2538 (0.0972)***	
Other	0.3836 (0.0636)***	−0.0964 (0.0432)**	−0.0964 (0.0370)***	0.0009 (0.0017)
Instruments				
German-speaking region	0.1402 (0.0448)***			0.0308 (0.0159)*
Number of PET diplomas	0.0002 (0.0001)*			0.0001 (0.0000)***
Controls				
Firm characteristics	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes
Sector controls	Yes	Yes	Yes	Yes
Year controls	Yes	Yes	Yes	Yes
Hansen-*J* statistic	0.387			
p-value	0.5341			
Kleibergen-Paap Wald rk *F*-statistic	11.21			
Observations	22,837	22,837	22,837	22,837

Notes: Cluster-robust standard errors in parentheses (cluster level: firm). Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Appendix 3

Table AVI. Non-linear spillover effects of workers with VET on workers with tertiary education (pooled OLS Estimation)

Pooled OLS regression	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. var.: log average gross monthly earnings of tert. educ.					
Number of workers with					
Tertiary education	0.02588 (3.99)***	0.03204 (5.15)***	0.02854 (5.02)***	0.00485 (0.84)	0.00472 (0.82)
VET	0.02788 (6.10)***	0.02213 (5.26)***	0.01302 (3.58)***	0.01231 (3.41)***	0.01230 (3.43)***
Other	−0.02113 (−3.60)***	−0.02215 (−3.14)***	−0.01794 (−2.77)***	−0.00131 (−0.34)	−0.00133 (−0.34)
Sq. number of workers with					
Tertiary education	−0.00128 (−3.54)***	−0.00152 (−4.74)***	−0.00132 (−4.91)***	−0.00039 (−1.29)	−0.00038 (−1.28)
VET	−0.00052 (−2.12)**	−0.00039 (−1.99)**	−0.00024 (−1.70)*	−0.00030 (−1.93)*	−0.00030 (−1.94)*
Other	0.00035 (1.57)	0.00043 (1.48)	0.00037 (1.42)	−0.00004 (−0.38)	−0.00004 (−0.37)
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
Cluster	9,855	9,855	9,855	9,855	9,855
Observations	22,837	22,837	22,837	22,837	22,837
R^2	0.01	0.06	0.10	0.19	0.19

Notes: Bootstrapped standard errors, *z*-statistics in parentheses. Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Table AVII.
Non-linear spillover effects of workers with VET on workers with tertiary education (fixed-effects estimation)

Fixed-effects model	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)
Dep. var.: log average gross monthly earnings of tert. educ.				
Number of workers with				
Tertiary education	−0.05517 (−6.32)***	−0.05652 (−6.34)***	−0.05646 (−6.34)***	−0.05724 (−6.33)***
VET	0.02283 (3.91)***	0.02297 (3.92)***	0.02276 (3.96)***	0.02249 (3.92)***
Other	0.00073 (0.11)	0.00116 (0.18)	0.00122 (0.18)	0.00121 (0.18)
Sq. number of workers with				
Tertiary education	0.00175 (4.07)***	0.00181 (4.04)***	0.00181 (4.07)***	0.00184 (4.09)***
VET	−0.00029 (−1.48)	−0.00029 (−1.51)	−0.00029 (−1.49)	−0.00029 (−1.51)
Other	0.00008 (0.42)	0.00008 (0.42)	0.00008 (0.41)	0.00008 (0.42)
Controls				
Firm characteristics	No	Yes	Yes	Yes
Regional controls	No	No	Yes	Yes
Year controls	No	No	No	Yes
Cluster	9,855	9,855	9,855	9,855
Observations	22,837	22,837	22,837	22,837
R^2	0.00	0.02	0.02	0.02

Notes: Bootstrapped standard errors, *z*-statistics in parentheses. Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Table AVIII.
Fixed-effects model with VET/tertiary education ratio

Fixed-effects model	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)
Dep. var.: log average gross monthly earnings of tert. educ.				
Ratio (VET/tertiary)	0.00386 (4.36)***	0.00397 (4.34)***	0.00397 (4.34)***	0.00397 (4.32)***
Squared ratio (VET/tertiary)	−0.00001 (−0.98)	−0.00001 (−0.97)	−0.00001 (−0.96)	−0.00001 (−0.96)
Constant	9.03797 (2,103.74)***	8.34224 (55.11)***	8.35248 (54.25)***	8.35242 (53.91)***
Controls				
Firm characteristics	No	Yes	Yes	Yes
Regional controls	No	No	Yes	Yes
Year controls	No	No	No	Yes
Cluster	9,855	9,855	9,855	9,855
Observations	22,837	22,837	22,837	22,837
R^2	0.01	0.03	0.03	0.03

Notes: Bootstrapped standard errors, *z*-statistics in parentheses. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Table AIX. Pooled OLS estimation with shares of differently educated workers

Pooled OLS regression	Spec. (1)	Spec. (2)	Spec. (3)	Spec. (4)	Spec. (5)
Dep. var.: log average gross monthly earnings of workers with tert. ac. Education					
Share of workers with					
Tertiary vocational	0.18485 (3.13)***	0.01424 (0.27)	−0.01254 (−0.24)	−0.00208 (−0.04)	0.00248 (0.05)
High school	−0.07003 (−0.80)	−0.02006 (−0.24)	0.07157 (0.86)	0.00091 (0.01)	0.00090 (0.01)
VET	0.47465 (10.02)***	0.29170 (6.28)***	0.19807 (4.19)***	0.18022 (3.96)***	0.18069 (3.97)***
Obligatory schooling	−0.22151 (−5.14)***	−0.33971 (−7.53)***	−0.29472 (−6.58)***	−0.18092 (−3.89)***	−0.18311 (−3.93)***
Other	−0.22591 (−2.55)**	−0.37359 (−4.28)***	−0.35909 (−4.15)***	−0.23554 (−2.73)***	−0.23265 (−2.69)***
Squared share of workers with					
Tertiary vocational	−0.14028 (−1.65)*	0.03951 (0.51)	0.05858 (0.78)	0.06566 (0.89)	0.06104 (0.83)
High school	−0.01926 (−0.09)	−0.05696 (−0.28)	−0.15289 (−0.74)	−0.03487 (−0.17)	−0.03373 (−0.16)
VET	−0.28147 (−5.07)***	−0.18640 (−3.54)***	−0.11472 (−2.19)**	−0.10439 (−2.02)**	−0.10274 (−1.99)**
Obligatory schooling	0.38183 (4.96)***	0.39958 (5.15)***	0.37334 (4.89)***	0.31876 (4.12)***	0.32135 (4.14)***
Other	0.33008 (1.99)**	0.42868 (2.63)***	0.40958 (2.53)**	0.30214 (1.86)*	0.30071 (1.85)*
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
Cluster	5,196	5,196	5,196	5,196	5,196
Observations	10,050	10,050	10,050	10,050	10,050
R^2	0.03	0.11	0.13	0.16	0.16

Notes: Bootstrapped standard errors, z-statistics in parentheses. Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Table AX.
Non-linear spillover effects of workers with VET on workers with tertiary education (OLS estimation in selected sectors)

Pooled OLS regressions	Manufacturing	Hotels and restaurants	Education	Health and social work
Dep. var.: log average monthly earnings of tert. educ.				
Number of workers with				
Tertiary education	−0.02048 (−2.94)***	−0.69847 (−1.15)	0.01162 (0.21)	−0.16774 (−1.75)*
VET	0.02866 (4.69)***	0.19985 (1.70)*	0.94855 (4.90)***	0.08548 (2.22)**
Other	−0.00413 (−0.70)	0.03790 (0.32)	−0.50825 (−2.29)**	0.01719 (0.35)
Sq. number of workers with				
Tertiary education	0.00071 (2.03)**	0.69222 (0.25)	−0.00083 (−0.05)	0.00852 (0.23)
VET	−0.00063 (−3.05)***	−0.01338 (−0.29)	−0.99173 (−3.79)***	−0.00186 (−0.31)
Other	−0.00018 (−0.60)	−0.00144 (−0.04)	1.01163 (2.67)***	−0.00108 (−0.12)
Controls				
Firm characteristics	Yes	Yes	Yes	Yes
Regional controls	Yes	Yes	Yes	Yes
Year controls	Yes	Yes	Yes	Yes
R^2	0.10	0.16	0.19	0.10
n	6,659	717	1,321	1,792

Notes: Bootstrapped standard errors, z-statistics in parentheses. Number of workers was divided by 100. *,**,***Statistically significant at the 0.1, 0.05 and 0.01 levels, respectively

Corresponding author
Christian Rupietta can be contacted at: rupietta@wiwi.uni-wuppertal.de