

SUPPLEMENTAL APPENDIX

Knowledge Spillovers, Competition, and Individual Careers

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APPENDIX A: Model details

A.1 Optimization problem of untrained job starter

Untrained job starters choose effort ω_i to maximize:

$$\max_{\omega_i} f(s_i) + G(\mu_i - (1 - \lambda_j)\mu_j + \omega_i - \omega_j)a - C(\omega_i)$$

The first order condition (FOC) is given by equation (2) in the main text, where g is the pdf related to G . Also, the second order condition needs to hold:

$$g'(\mu_i - (1 - \lambda_j)\mu_j + \omega_i - \omega_j)a - C''(\omega_i) < 0$$

Since g is a density function, g' can be positive. For the objective function to be concave, we require $g' < C''$ in the relevant range. Lazear and Rosen (1981) discuss that this condition holds provided that σ^2 is sufficiently large and assume this to be the case (see their footnote 2). This will yield an optimal effort level ω_i^* .

How then does ω_i^* depend on the quality of the untrained incumbent worker, μ_j ?

$$\frac{d\omega_i^*}{d\mu_j} = -\frac{dFOC/d\mu_j}{dFOC/d\omega_i^*} = \frac{-(1-\lambda_j)g'(\mu_i - (1-\lambda_j)\mu_j + \omega_i^* - \omega_j^*)a}{g'(\mu_i - (1-\lambda_j)\mu_j + \omega_i^* - \omega_j^*)a - C''(\omega_i^*)}$$

Note that g' will tend to be small if the distribution has fat tails. For a symmetric distribution function, g' is positive on the left tail and negative on right tail. The denominator will be positive if the second order condition holds. Better peer quality may increase or decrease own effort, depending on which tail of the distribution we are.

Similarly, the untrained incumbent chooses effort to maximize:

$$\max_{\omega_j} f(s_j) + [1 - G(\mu_i - (1-\lambda_j)\mu_j + \omega_i - \omega_j)]a - C'(\omega_j)$$

The first and second order conditions, determining the untrained incumbent's effort choice, are:

F.O.C.:

$$g(\mu_i - (1-\lambda_j)\mu_j + \omega_i - \omega_j)a - C'(\omega_j) = 0$$

S.O.C.:

$$g'(\mu_i - (1-\lambda_j)\mu_j + \omega_i - \omega_j)a - C''(\omega_j) < 0$$

Their optimal effort then depends on their quality as follows:

$$\frac{d\omega_j^*}{d\mu_j} = -\frac{-(1-\lambda_j)g'(\mu_i - (1-\lambda_j)\mu_j + \omega_i^* - \omega_j^*)a}{g'(\mu_i - (1-\lambda_j)\mu_j + \omega_i^* - \omega_j^*)a - C''(\omega_i)}$$

Hence, $\frac{d\omega_i^*}{d\mu_j} = \frac{d\omega_j^*}{d\mu_j}$ and the untrained job starter and incumbent will both choose the same effort level, $\omega_i^* = \omega_j^*$, provided that their cost functions are the same. In consequence, the expected untrained job starter's expected wage at equilibrium effort level, reduces to equation (3) in the main text:

$$E[W_i] = f(\mu_i + \lambda_j\mu_j + \lambda_k\mu_k) + G(\mu_i - (1-\lambda_j)\mu_j + \omega_j^*)a.$$

A.2 Allowing for some competition between the untrained job starter and the trained incumbent

We have set up the model under the assumption that the untrained job starter competes only with the untrained incumbent but not with the trained incumbent. We can relax this assumption by allowing for competition with both types of workers, but to different degrees. For this we define:

P_j : probability that the untrained incumbent competes with the job starter

P_k : probability that the trained incumbent competes with the job starter

Equations (4) and (5) in the main text then modify to:

$$\frac{dE[W_i]}{d\mu_j} = \underbrace{\lambda_j f'(\mu_i + \lambda_j \mu_j + \lambda_k \mu_k)}_{\text{knowledge spillover effect}} - \underbrace{P_j(1 - \lambda_j)g(\cdot)a}_{\text{competition effect}} \quad (\text{A.1})$$

$$\frac{dE[W_i]}{d\mu_k} = \underbrace{\lambda_k f'(\mu_i + \lambda_j \mu_j + \lambda_k \mu_k)}_{\text{knowledge spillover effect}} - \underbrace{P_k(1 - \lambda_k)g(\cdot)a}_{\text{competition effect}} \quad (\text{A.2})$$

Hence, differently from equation (5) in the main text, the spillover from the trained incumbent (equation A.2) is now a composite of a knowledge spillover effect and a competition effect and needs to be interpreted as a lower bound of the knowledge spillover effect. Moreover, under the assumptions $\lambda_k > \lambda_j$ (there is more to learn from the trained than untrained incumbent) and $P_k < P_j$ (there is less likely to be competition with the trained than the untrained incumbent), spillover effects from trained and untrained co-workers can be clearly

ranked: $\frac{dE[W_i]}{d\mu_k} > \frac{dE[W_i]}{d\mu_j}$

APPENDIX B: **The German Apprenticeship System**

The German Apprenticeship System is a vocational training program which combines practical firm provided on-the-job training, with state-provided classroom instruction. It is an important pillar of the German education system, with about 500,000 young people starting an apprenticeship contract in Germany each year (BMBF 2022, section 2.3 and Figure 3). Training typically starts after secondary school from the age of around 16. There are no formal entry requirements into an apprenticeship, but an apprenticeship contract must be concluded between the apprentice and the training firm, meaning that firms effectively screen applicants.

There are over 300 recognized occupations that offer apprenticeships, covering a wide range of blue-collar (e.g., craft, industrial, and technical) and white-collar (e.g., administrative and service) professions. The program usually lasts between two to three years. The classroom-based component at a vocational school makes up one third of the training time (1-2 days per week), leaving most of the time (3-4 days per week) spent learning in a work environment at the training firm under the instruction of a skilled supervisor. Firms pay the cost for the on-the-job training and pay the apprentice a remuneration, typically lower than what is obtainable for unskilled work.

The apprenticeship training system is strongly regulated. The standards for the training content are set by occupational profiles defined in training ordinances for each occupation. Qualification certificates are awarded through final examinations by the relevant competent bodies for each occupation (chambers of commerce, chambers of craft trades, etc.).¹

While completing an apprenticeship within a recognized occupation greatly facilitates labor market entry and career development, many occupations can also be entered without a

¹ See Franz and Soskice (1995), Hoeckel and Schwartz (2010), and Solga et al. (2014) for additional details on the apprenticeship system.

formal vocational qualification. For example, a salesperson in a retail shop can be untrained, or can hold an apprenticeship degree as a retail salesperson. This is the feature we exploit in the present paper, where we observe in many occupations trained and untrained workers working alongside each other.

References:

BMBF - Bundesministerium für Bildung und Forschung (2022). Berufsbildungsbericht 2022, available at https://www.bmbf.de/SharedDocs/Publikationen/de/bmbf/3/31749_Berufsbildungsbericht_2022.pdf

Franz, W., & Soskice, D. (1995). The German apprenticeship system. Institutional frameworks and labor market performance: comparative views on the US and German economies, 208-234.

Solga, Heike, Paula Protsch, Christian Ebner, and Christian Brzinsky-Fay (2014). The German vocational education and training system: Its institutional configuration, strengths, and challenges. WZB Discussion Paper No. SP I 2014-502.

Hoeckel, K., & Schwartz, R. (2010). A learning for jobs review of Germany. OECD Reviews of vocational education and training.

APPENDIX C: Details on the mediation analysis

In this section we discuss the mediation analysis reported in Table D.5.

Framework:

To explain the mediation analysis, we first re-write our baseline equation (6) using simplified notation as

$$y_i = a + bPEER_i + cX_i + \epsilon_{1i}. \quad (B.1)$$

For simplicity we have suppressed all subscripts other than i , we have renamed the treatment variable of interest as $PEER_i$ (the quality of trained peers), and we subsume all other right-hand side variables and fixed effects into X_i . Using the wage five years after exposure as an outcome, this equation measures the total spillover effect from trained peers, i.e., $b=0.019$ (see Table 2, Panel B, column 4). Now consider a set of P mediators M_i^p , for $p = 1, \dots, P$. These are intermediate outcomes that can drive the wage effect, such as job tenure, or the quality of the firm a worker is employed at five years after exposure. Adding these mediators as control variables to equation (B.1) yields

$$y_i = d + ePEER_i + \sum_{p=1}^P f^p M_i^p + gX_i + \epsilon_{2i}. \quad (B.2)$$

The coefficient e captures the direct effect of treatment on the outcome, conditional on mediators. Thus, e is the part of the effect of treatment that cannot be explained by the mediators. To complete the mediation model, consider a set of P regressions to capture the treatment effect on each of the mediators:

$$M_i^p = h^p + k^p PEER_i + l^p X_i + \epsilon_{3i}^p, \quad p = 1, \dots, P. \quad (B.3)$$

Each mediator's contribution to the treatment effect can be computed as $k^p f^p$, which is the product of how much the treatment shifts the mediator (k^p), and how much the mediator affects the outcome (f^p). Consequently, the total indirect effect that can be explained by the mediators is $\sum_{p=1}^P k^p f^p$.

To yield a decomposition that captures the true causal relationships, the mediation model would need to fulfil the following assumptions:

- (i) $PEER_i$ is exogenous in equations (B.1) and (B.3),
- (ii) $\text{Cov}(\epsilon_{2i}, \epsilon_{3i}^p) = 0$ for $p = 1, \dots, P$ (the mediators are exogenous),
- (iii) Any unobserved mediators are orthogonal to the observed mediators.

While assumption (i) is the same assumption on which our baseline empirical approach of equation (6) is based, assumptions (ii) and (iii) are strong additional assumptions. Assumption (ii) in principle requires an identification strategy for each of the mediator, while assumption (iii) requires that we observe all relevant mediators that are correlated with the included mediators. We therefore prefer to interpret the mediation analysis as a descriptive decomposition rather than giving it a causal interpretation.

Results:

In Table D.5 we present the results from the mediation analysis. Column (1) reports effects of a one-standard deviation increase in the peer quality of trained peers in the initial job on the mediators five years after exposure (k^p in equation B.3). In column (2) we show partial regression coefficients from our baseline regression equation (5) on wages 5 years after exposure, adding all the mediators as right-hand side variable (f^p in equation B.2). In column (3) we calculate for each mediator the part of the total treatment effect that runs through this mediator ($k^p f^p$, obtained as the product of the coefficients in columns 1 and 2). In the last column, we then express these indirect effects due to each mediator in percent of the total wage effect. We find that the mediators taken together explain 65% of the total effect, with by far the largest contribution coming from a better firm fixed effect (36%), followed by better peer quality (19%), having more labor market experience (5%), and being in a larger firm (3%). The contributions of all other variables are negligible.

APPENDIX D: Additional Tables

Table D.1: Top 20 occupations of unskilled job starters

Panel A: Overall Sample	
<i>Occupation</i>	<i>Sample share</i>
Cooks	6.6%
Warehouse transport workers	5.1%
Metal workers	4.8%
Packagers, goods receivers, despatchers	4.5%
Salespersons	4.4%
Construction worker	4.0%
Cleaners	3.5%
Gardeners, garden workers	3.4%
Plastics processors	3.2%
Waiters, stewards	2.6%
Office assistant	2.4%
Warehouse logistics worker	2.2%
Electrical appliance, electrical parts assemblers	2.2%
Housekeeping attendants	1.9%
Guest attendant, concierge	1.8%
Assembly worker	1.7%
Motor vehicle drivers	1.4%
Chemical plant operatives	1.3%
Laundry workers	1.1%
Meat, sausage goods makers	1.1%
Panel B: Sample of complex occupations	
<i>Occupation</i>	<i>Sample share</i>
Metal workers	21.5%
Electrical appliance, electrical parts assemblers	9.8%
Assembly worker	7.8%
Chemical plant operatives	6.0%
Meat, sausage goods makers	4.8%
Clothing sewers	3.8%
Sugar, sweets, ice-cream makers	3.6%
Rubber makers, processors	3.1%
Machinery, container cleaners and related occupations	2.2%
Concrete workers	2.2%
Ceramics workers	2.1%
Sheet metal pressers, drawers, stampers	2.1%
Street cleaners, refuse disposers	1.9%
Sewer, seamstress	1.7%
Printer's assistants	1.7%
Food preparer	1.7%
Footwear makers	1.6%
Agricultural workers	1.5%
Vehicle cleaners, servicers	1.5%
Spinners, fibre preparers	1.3%

Notes: The table shows the twenty most frequent occupations for the sample of all occupations of untrained labor market entrants (Panel A), and for a subsample of occupations with more complex tasks (Panel B).

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).

Table D.2: The Effects of Rank (Inverse Competition Effect, Complex Occupations)

Panel A: Mobility				
	Employed, t+5	Move by t+5 to new Firm Occupation		
Rank	0.066 (0.003)	-0.035 (0.005)	-0.041 (0.005)	
No. of obs.	172,242	85,963	85,963	

Panel B: Men vs Women				
	Earnings, rel. to mean, t+5		Log Wages, t+5	
	Men	Women	Men	Women
Rank	0.18 (0.009)	0.122 (0.009)	0.019 (0.004)	0.008 (0.005)
No. of obs.	95,707	76,535	54,987	30,976

Notes: The table shows the effects of (standardized) rank of untrained labor market entrants among their initial peers (i.e., coworkers in the same firm and occupation at labor market entry) on career outcomes five years after labor market entry. Rank is based on residualized wages net of experience to capture current performance relative to expectations based on seniority. Rank is standardized; a one-unit increase in standardized rank corresponds to an increase in rank of about 30 percentiles. Earnings are set to zero for the non-employed and are divided by mean earnings. All specifications control for initial occupation $\times$ cohort effects, initial firm $\times$ occupation effects, average peer quality, average coworker age, the coworker shares of trained and college-educated workers, the coworker share of females, the wage in the initial job, age at labor market entry, and sex. Standard errors are clustered at the firm level.

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).

**Table D.3: The Effects of Average Peer Quality When Controlling for Rank
(Knowledge Spillover, Complex Occupations)**

	(1)	(2)	(3)	(4)	(5)
			Log Wages, t+5		
	Employment, t+5	Baseline	Controlling for quality of peers in t+5	Stayer	Mover
Average peer quality	0.018 (0.007)	0.026 (0.008)	0.016 (0.007)	0.016 (0.010)	0.035 (0.011)
No. of observations	172,242	85,963	85,963	47,003	38,960

Notes: The table shows the effects of standardized quality of initial peers (i.e., coworkers in the same firm and occupation at labor market entry) on various career outcomes of untrained workers five years after labor market entry, controlling for the untrained worker's rank in the initial peer group (to capture competition effects). Average peer quality is standardized and measured by the average AKM wage fixed effects of coworkers. Rank among initial peers is based on residualized wages net of experience to capture current performance relative to expectations based on seniority. Earnings are set to zero for the non-employed and are divided by mean earnings. All specifications control for initial occupation × cohort effects, initial firm × occupation effects, the average coworker age, the coworker shares of trained and college-educated workers, the coworker share of females, the wage in the initial job, age at labor market entry, and sex. Standard errors are clustered at the firm level.

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).

Table D.4: The Effects of Average Peer Quality When Controlling for Rank (Knowledge Spillover): Men vs Women (Complex Occupations)

	(1)	(2)
	Male	Female
Employment, t+5	0.036 (0.010)	0.025 (0.012)
Actual experience, t+5	0.166 (0.036)	0.083 (0.047)
Firm fixed effect, t+5	0.021 (0.006)	-0.004 (0.007)
Peer quality, t+5	0.111 (0.025)	0.059 (0.037)
Log firm size, t+5	0.133 (0.057)	0.023 (0.073)

Notes: The table shows the effect of the (standardized) quality of initial peers (i.e., coworkers in the same firm and occupation at labor market entry) on various career outcomes of untrained workers five years after labor market entry, controlling for the untrained worker's rank in the initial peer group (to capture competition effects). Results are reported separately for male and female untrained workers. Average peer quality is standardized and measured by the average AKM wage fixed effects of coworkers. Rank is based on residualized wages net of experience to capture current performance relative to expectations based on seniority. Earnings are set to zero for the non-employed and are divided by mean earnings. All specifications control for initial occupation $\times$ cohort effects, initial firm $\times$ occupation effects, the average coworker age, the coworker shares of trained and college-educated workers, the coworker share of females, the wage in the initial job, age at labor market entry, and sex. Standard errors are clustered at the firm level.

Source : German Social Security Records from the *Beschäftigtenhistorik*

**Table D.5: The Effects of the Quality of Trained Peers in First Job on Future Wages:
Mediation Analysis (Complex Occupations)**

	Effect of quality of trained peers on mediator	Dependent variable: Log wage in t+5		
		Coefficient of mediator on wages	Indirect effect due to mediator	Percent of total effect of 0.019
	(1)	(2)	(1)×(2)	
Mediators				
Peer quality, t+5	0.042 (0.013)	0.086 (0.002)	0.0036 (0.0002)	19%
Firm Fixed Effect, t+5	0.007 (0.003)	0.971 (0.012)	0.0068 (0.012)	36%
Log firm size, t+5	0.044 (0.027)	0.012 (0.001)	0.0005 (0.0016)	3%
Ever referred	0.002 (0.002)	-0.005 (0.002)	-0.00001 (0.00001)	0%
Mean occupational log wage, t+5	0.004 (0.002)	0.027 (0.008)	0.00011 (0.0002)	1%
Actual experience, t+5	0.029 (0.019)	0.033 (0.001)	0.0010 (0.00034)	5%
Switching firm, t+5	-0.01 (0.009)	-0.007 (0.003)	0.00007 (0.0001)	0%
Switching occupation, t+5	-0.013 (0.009)	-0.017 (0.002)	0.00022 (0.00004)	1%
Total explained via mediators			0.012	65%

Notes: The table shows results for a mediation analysis of the effect of the quality of the initial trained peers (i.e., trained coworkers in the same firm and occupation at labor market entry) on the wages of untrained workers five years after labor market entry; see Appendix C for details. The total wage effect to be decomposed is 0.019 (see column 4, Panel B of Table 2). Column (1) reports the effects of the quality of the initial trained peers on a range of mediators, using our baseline specification from Table 2 (Panel B). In Column (2), the dependent variable is the wage, and the baseline specification is extended by jointly including the mediators, the effects of which are reported in the column. Column (3) reports the product of columns (1) and (2), representing each mediator's contribution to the total wage effect. Column (4) reports the contributions in relative terms. Standard errors are clustered at the firm level.

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).

Table D.6: The Position of Untrained and Trained Workers in the Firm Hierarchy at Labor Market Entry

	Firm wage decile	
	(1)	(2)
Trained	1.035 (0.006)	1.025 (0.011)
Cohort effects	Yes	
Firm effects	Yes	
Occupation effects	Yes	
Age effects	Yes	Yes
Cohort-firm-occupation effect		Yes
No. of observations	2,443,691	

Notes: The table reports the coefficient of a dummy variable for being a trained rather than an untrained labor market entrant on a worker's decile position in the firm-wage distribution (calculated excluding college graduates) in the first year of labor market entry.

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).

Table D.7: The Effects of the Quality of Trained and Untrained Peers in the First Job on Future Earnings: Varying the Threshold Defining Complex Occupations

	Share of workers in complex occupations							
	10%	20%	25%	30%	40%	50%	60%	70%
Quality of untrained peers	-0.055 (0.017)	-0.056 (0.011)	-0.053 (0.010)	-0.052 (0.010)	-0.045 (0.007)	-0.045 (0.007)	-0.038 (0.006)	-0.035 (0.005)
Quality of trained peers	0.042 (0.014)	0.035 (0.010)	0.037 (0.010)	0.03 (0.009)	0.021 (0.007)	0.018 (0.007)	0.012 (0.005)	0.008 (0.005)
No. of observations	68,964	146,426	172,242	215,928	290,794	358,784	434,868	497,200

Notes: The table reports results for the effects of the quality of initial peers (i.e., coworkers in the same firm and occupation at labor market entry) on the earnings of untrained workers five years after labor market entry when varying the threshold used to define complex occupations. The column labeled “25%” corresponds to our baseline definition of complex occupations (i.e., occupations that fall within the 25% of workers reporting the lowest incidence of predefined tasks). Column titles indicate the alternative cut-off used to define complex occupations, varying between 10% and 70%. Earnings are set to zero for the non-employed and are divided by mean earnings. All specifications control for initial occupation × cohort effects, initial firm × occupation effects, the average coworker age, the coworker shares of trained and college-educated workers, the average quality of college-educated peers, the coworker share of females, the wage in the initial job, age at labor market entry, and sex. Standard errors are clustered at the firm level.

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).

Table D.8: Heterogeneous Effects of Untrained and Trained Peers in the First Job by Learning Opportunities (Complex Occupations)

	Earnings, rel. to	Log wage,t+5	
	mean, t+5	All	Movers
Quality of untrained peers	-0.046	-0.024	-0.016
× high learning opportunities	(0.015)	(0.007)	(0.011)
Quality of untrained peers	-0.058	-0.004	-0.002
× low learning opportunities	(0.012)	(0.006)	(0.010)
Quality of trained peers	0.048	0.041	0.054
× high learning opportunities	(0.019)	(0.009)	(0.015)
Quality of trained peers	0.035	0.016	0.026
× low learning opportunities	(0.010)	(0.005)	(0.008)
No. of observations	172242	85963	38,960

Notes: The table replicates the main results of Table 2 (Panel B) for complex occupations in the paper but allows the effect of peer quality to differ according to whether the peer group has high or low learning opportunities. Peer groups with low learning opportunities are defined as peer groups with a ratio of the number of experienced trained workers to the number of untrained workers smaller than 1. All specifications control for initial occupation × cohort effects, initial firm × occupation effects, the average coworker age, the coworker shares of trained and college-educated workers, the average quality of college graduates, the coworker share of females, the wage in the initial job, age at labor market entry, sex, and a dummy variable indicating a peer group with “low learning opportunities”. Standard errors are clustered at the firm level. The coefficients on trained peers are included in the paper as Panel E of Table 7.

Source : German Social Security Records from the *Beschäftigtenhistorik* (BEH).