What affects lifelong learning of scientists and engineers?

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Abstract

Purpose – The purpose of this paper is to enrich the discussion on the determinants of training participation and informal learning of scientists and engineers (S&Es).

Design/methodology/approach – Tobit analyses on survey data.

Findings – The authors find that both formal training and informal learning are particularly related to job and firm characteristics instead of labour supply characteristics. S&Es employed in firms that apply innovative production processes more often participate in formal training, and also benefit from the informal learning potential of their jobs. However, lifelong learning is not triggered in firms with many product innovations. S&Es who are employed in firms that operate on highly competitive markets also participate in formal training less often. The same holds for S&Es employed in small firms, although the latter compensate this by more hours of self-teaching. S&Es employed in jobs that require a high level of technical knowledge more often participate in formal training, whereas those employed in jobs that require more general skills are more involved in informal learning. Furthermore, older S&Es with long firm tenures participate in formal training less often, and have fewer opportunities for learning in their jobs. Therefore, their competence level is at risk.

Practical implications – Public policies that stimulate process innovation also appear to prevent skills obsolescence among S&Es. Public policies that aim to diminish labour market shortages of S&Es by discouraging early retirement should particularly take account of the necessity to keep the human capital of older S&Es with long firm tenures up to date.

Originality/value – The paper contributes to the literature on the determinants of human capital development by including both formal training and different modes of informal learning; and employee characteristics as well as job and firm characteristics in its analyses.

Keywords The Netherlands, Lifelong learning, Skills, Training, Informal learning, Innovation, Skill demands, Scientists, Engineers

Paper type Research paper

1. Introduction

The durability of knowledge in the fields of science and engineering is much shorter than in other academic fields (McDowell, 1982). Therefore, scientists and engineers (S&Es) need to update their human capital at a regular basis in order to prevent skills obsolescence. Obviously, these human capital investments do not merely refer to formal training courses but also include informal learning at the workplace. Lavoie and Finnie (1998) argued that this holds in particular for engineers because technology is based on knowledge and skills that are largely tacit. Moreover, as Burke and Baldwin (1999) show, formal and informal training may also interact. Skills taught in

The authors thank Annemarie Nelen and Jasper Van Loo and two anonymous referees for their helpful comments on earlier versions of this paper.

International Journal of Manpower
Vol. 33 No. 5, 2012
pp. 583-597

0143-7720
DOI 10.1108/01437721211253209

formal training courses can be transferred to the workplace through learning-by-doing (Shankar Subedi, 2004).

In this paper, we will analyze the determinants of S&Es' investments in human capital during their working lives. In our analyses, which are based on a survey of high-skilled S&Es in the Netherlands, we take account of both investments in formal training and different modes of informal learning, such as learning from colleagues in the workplace, self-teaching and having tasks from which one can learn. Whereas most studies on lifelong learning only focus on the relationships between particular worker characteristics and training participation, we will also include job- and firm-related (i.e. labor demand) characteristics in our analyses (cf. Shields, 1998). Among others, we include the skill demands of the job in which one is employed, the innovativeness of the firm and the severity of competition in a firm's sales markets. Our estimation results show that both formal training and informal learning are particularly related to job and firm characteristics instead of labor supply characteristics.

The paper will proceed as follows. Section 2 describes the relevant literature to which this paper contributes, and discusses the various possible determinants of human capital investments that we will include in this paper. Section 3 describes the data, and defines the variables we use in our analyses. In Section 4, we will present the estimation results. Section 5 concludes.

2. Determinants of human capital investments

2.1 Literature

In economic literature, human capital theory offers the theoretical framework for human capital investments in the workplace: Both firms and workers weigh the costs and benefits of investing in training (Becker, 1964). Formal training as well as informal learning contribute to the employees' productivity. The benefits of investments in training are therefore related to the working time during which firms can benefit from workers' higher productivity, and workers can benefit from higher future earnings. With respect to the investment costs, human capital theory distinguishes between the direct costs (learning material, costs of trainers, etc.) and the indirect opportunity costs of (working) time in which a worker is not or less productive. Human capital theory predicts that training investments are positively related with personal, job and firm characteristics that favor high benefits for either the firm or the worker and/or low training costs.

In economic literature, there are many studies that analyze the relationships between personal, job or firm characteristics and the participation of employees in formal training courses. Most studies focus on the relationships with personal characteristics, and confirm the expectation from human capital theory that the larger the amount of working time during which the benefits from training can be reaped by either the firm or the worker, the higher the participation in formal training. For example, several studies show that training participation is negatively related to workers' age, tenure, and being employed in a temporary or part-time job (see e.g. Bassanini *et al.*, 2007).

The effect of initial education on training participation can be twofold. On the one hand, training costs may be lower for higher educated workers than for lower educated workers which may favor investment in higher educated workers. On the other hand, lower educated workers face more skill gaps and for that reason the productivity increase due to the training may be higher for this group of workers (e.g. Smoorenburg and Van der Velden, 2000). Most empirical studies, however, found evidence for the

complementarity between investments in initial education and post-initial formal training (see Bassanini *et al.*, 2007 for an overview). Several studies on the determinants of training participation include basic firm characteristics, such as firm size, and sector of industry. All of these studies found that training participation is much higher in large firms than in small and medium-sized firms (e.g. OECD, 1999; Bassanini *et al.*, 2007). One of the reasons is that large firms face economies of scales in providing training to their workers (Black *et al.*, 1999). Furthermore large firms have more possibilities to retain their workers once the training is completed by offering them internal job opportunities. Lynch and Black (1998) found a positive relation between training participation and the quality of the job, as indicated by being employed in a "high-performance workplace" (McCartney and Teague, 2004). Other studies emphasize that firms may indeed gain from incorporating investments in the training of their workforce in a consistent human resource system, because this may reduce quit rates and therefore increase the returns on training (e.g. Ichniowski and Shaw, 2003). Finally, several studies found evidence for a positive relationship between technological innovations and training participation. Acemoglu (1997) referred to a number of studies which showed that an efficient adoption of new technologies is attributed to effective training strategies, whereas Groot and De Grip (1991), Bresnahan *et al.* (2002) and Sieben *et al.* (2009) more specifically found that the introduction of new information technology increases training participation of a firm's workforce.

Due to a lack of adequate data on informal learning, there are hardly any studies in economic literature that focus on the determinants of informal learning. In general, both direct and indirect costs of investments in formal training are expected to be higher than investments in informal learning. Therefore it is not surprising that workers spent more time on informal training than on formal training (Nelen and De Grip, 2009). It is to be expected that there are also differences in the costs of the various modes of informal learning. Particularly, learning-by-doing induces opportunity costs in terms of forgone working time, whereas self-teaching usually merely affects leisure time instead of working time.

Arrow (1962) was one of the first authors who emphasized the importance of "learning-by-doing", as an automatic by-product of the regular production process of a firm. For that reason, in human capital literature, informal learning is traditionally proxied by including the experience of workers in the labor market and their job tenure in earnings functions (cf. Mincer, 1974). However, this learning by doing is anything but random. Jobs may be deliberately structured so as to provide learning opportunities (e.g. Eraut, 2000). The learning potential of the job (Rosen, 1972) is likely to be greatest in jobs where skill requirements are changing rapidly. Whereas jobs characterized by repetitiveness, hierarchical control mechanisms, and low levels of autonomy may stifle learning opportunities for workers, more complex jobs with shifting job contents offer ample opportunities for informal learning (Allen and De Grip, 2012). From the perspective of the worker, accepting a job with a high-learning potential[1] can be a good strategy to maximize lifetime income (Sicherman and Galor, 1990), examples of such jobs are trainee jobs in large firms.

Building on other studies on the transition of engineers to managerial positions, Yeh (2008) analyzed the relationship between self-teaching and the career stages of older engineers in China. He found that engineers in middle-management positions have lower rates of self-teaching than "on-track careerists" who have been promoted to higher related management positions.

Bartel and Sicherman (1993) related on-the-job learning to technological change. They found that workers, who are employed in sectors of industry with high rates of gradual technological change, retire later[2]. Although the workers in these sectors of industry face more skill obsolescence due to the diffusion of technological developments, the net effect of technological change on their human capital is positive, because they continuously acquire new skills related to new technologies (cf. Van Loo *et al.*, 2001).

Informal learning is also at the heart of the economic literature on the emergence of "high-performance workplaces." Lindbeck and Snower (2000) argued that high-performance workplaces increase the demand for multi-skilled workers (cf. Coates *et al.*, 2007). This induces a shift from "intratask learning" to "intertask learning" in the workplace. This intertask learning takes place mainly through tasks rotation within teams. Lindbeck and Snower stated that intertask learning not only refers to acquiring a broader range of technical skills, but also includes the improvement of a worker's "people skills," and problem-solving skills.

Lavoie and Finnie (1998, p. 54) emphasized the importance of informal learning for engineers because "technology is accumulated through different learning processes or conversely, can depreciate if those processes are not present." However, their analysis only focusses on the depreciation risks by documenting the proportion of Canadian engineering graduates in various potentially "at-risk" situations, such as being unemployed, employed in a part-time or temporary job, and being employed in a job in which one's technical skills are not used to a significant degree. Their analysis also suggests that engineering graduates who go directly into management jobs use their engineering skills less than others and "miss the opportunity of developing experience-based tacit knowledge" (Lavoie and Finnie, 1998, p. 67).

2.2 Possible determinants of human capital investments of S&Es

In this study, we analyze to what extent the different modes of human capital investments of S&Es are associated with employee (i.e. labor supply) characteristics or job- or firm-related (i.e. labor demand) characteristics. The personal and career-related factors that we include in our analysis are related to the cost-benefit framework delivered by human capital theory. This includes S&Es' level of education in order to test whether post-initial human capital investments are complementary to the level of initial education. We also include several career-related variables on general work experience, firm tenure, and job tenure. These variables indicate to what extent human capital investments are concentrated at the beginning of the career and/or at the beginning of an appointment in a firm or job. We analyze to what extent the skill-gaps that S&Es perceive to have in their jobs, stimulate them to invest further in their human capital (cf. Smoorenburg and Van der Velden, 2000). Economic literature hardly gives any answers to the question whether formal training and informal learning are differently affected by particular determinants of human capital investments. However, differences may arise from the fact that workers have more possibilities for investing in informal learning without creating any additional costs for their employer (Nelen and De Grip, 2009). This holds in particular for self-teaching outside working time.

In our analyses, we also include several job characteristics and various skills required in the job. These variables indicate to what extent human capital investment is driven by the job in which someone is employed. Managerial jobs may provide for the acquisition of many non-technical skills not learned in initial education. We therefore analyze whether S&Es with management tasks more often participate in

formal training and/or informal learning. Furthermore, we take account of the different types of knowledge and skills required in the job. We here distinguish between technical knowledge and skills and various non-technical skills (cf. Dickerson and Green, 2004). Literature does not give any explicit hypotheses on whether these skills are usually acquired through formal training or informal learning, although the literature on the high-performance workplace emphasizes the importance of informal learning from colleagues and by doing tasks from which one can learn (Wood, 1999). More in general, we may expect that the various modes of lifelong learning are substitutes when it comes to acquiring a particular skill level. Our analyses will therefore show which modes of learning are the most relevant ones for acquiring particular skills.

Finally, we analyze to what extent human capital investments of S&Es are associated with particular firm characteristics (cf. Jacobs *et al.*, 1996). We focus on product market characteristics and firm size as well as on the innovativeness of the firm (cf. Cohen and Levinthal, 1989). S&Es who are employed in firms that sell their products in highly competitive and instable product markets, may participate in formal training less often, since both firm and employees may be reluctant to invest in human capital because of the less stable employment relation. This may, however, be less relevant for informal learning because informal learning involves less investments costs than participation in formal training. As mentioned above, several studies found that training participation is negatively related to firm size. However, employees of small firms may compensate this lower participation in formal training by a larger participation in informal learning at the workplace or by self-teaching at home. From previous studies we may expect that S&Es who are employed in highly innovative firms, participate in formal training more often, and also learn more at work because they continuously acquire new skills related to the new technologies (Bartel and Sicherman, 1993; Montizaan *et al.*, 2008).

3. Data and descriptive statistics

For our analysis, we use data of an internet survey among Dutch S&Es with a Bachelor's or Master's degree at the end of 2006. All members of the Royal Institute of Engineers in the Netherlands (KIVI NIRIA) plus the subscribers of the weekly professional journal for S&Es (*Technisch Weekblad*) were approached by e-mail and invited to participate in the survey. KIVI NIRIA members received an e-mail from (the director of) KIVI NIRIA with a link to the survey web site, whereas subscribers of *Technisch Weekblad* received a similar e-mail on behalf of the editor. The response rate of the survey was about 20 percent, rendering 4,396 individuals respondents. Since only members of the KIVI NIRIA and the subscribers of *Technisch Weekblad* were selected, our sample is selective in the sense that it particularly focusses on S&Es who opted for a technical career will be represented in the survey. This means that in our study S&Es are seen as a broadly defined occupational field instead of those who graduated from a science or engineering study.

The questionnaire enables us to distinguish between S&Es' participation in formal training, and three different modes of informal learning: self-teaching, learning from colleagues, and performing tasks from which one can learn. The following two questions were used to measure formal training and self-teaching, respectively:

- How many hours did you spend on training courses (excluding self-teaching) during the last 12 months?

- How many hours did you spend on self-teaching during the last 12 months (e.g. by studying manuals, textbooks or software)?

The two other types of informal learning were measured by means of the following questions:

- How many hours do you usually spend each week on tasks from which you can learn?
- How many hours do you usually spend with your colleagues each week in order to learn from them (e.g. by demonstrating you certain tools or techniques, explaining you things, giving advice, etc.)

To obtain comparable figures for training and self-teaching on the one hand, and learning-by-doing and learning from colleagues on the other hand, we converted respondents' answers to the latter two questions into yearly hours by assuming 40 working weeks pro-year. Table I shows that by far most of the time in which S&Es further invest in their human capital refers to learning-by-doing (on average 383 hours in a year[3]). S&Es also spend quite some time on learning from their colleagues (on average 172 hours in a year). Far less time is devoted to participation in formal training courses (on average 39 hours in a year) and self-teaching (24 hours in a year).

Table I reports the means and standard deviations of the main explanatory variables of our analysis. The table shows that half of the S&Es have a Master's degree and only 8 percent are female. On average, they have almost 14 years of work experience and eight years tenure in the firm in which they are employed. The survey also included a range of questions on S&Es' competencies. First, respondents had to rate their overall knowledge and skill level in the previous year, with the reference that the skills required for optimal performance in their job is 100. Table I shows that respondents give themselves an average rate of about 78, leaving a skill gap of 22 percent in the previous year. The table also shows that 44 percent of all S&Es do not have any management tasks, whereas 8 percent spend more than 75 percent of their working time on management tasks.

Respondents also had to rate the skills demanded in their current jobs on a ten-point scale for a large number of skills, including technical, commercial and financial, (advanced) IT, management and planning, and general skills, such as analytical thinking and problem solving[4]. Table I shows that particularly the skill demands for technical knowledge and skills, and management and planning skills are relatively high. The latter is remarkable, because 44 percent of the S&Es have no management tasks at all. Apparently, the latter does not mean that they need no organizational and planning skills in their jobs. The average skill demands for advanced IT and commercial and financial knowledge are relative low. As indicated by the high standard deviations, the latter is due to the fact that for a large number of S&Es these skills are hardly relevant in their jobs.

Respondents also indicated the product market characteristics and the innovativeness of the firm in which they were employed on five-point scales. On average, competition in product markets is high, with an emphasis on product quality. With respect to the innovativeness of the firm, particularly the degree of product innovation is high. Finally, the table shows that more than half of all S&Es are employed in very large firms, whereas 20 percent are employed in firms with <100 employees.

Table II shows the correlation coefficients between the different modes of human capital development. The table shows that formal training and informal learning are

	Mean	SD	*N*
Formal and informal learning			
Training (incidence)	0.67	0.47	3,302
Training (hours)	44.56	58.63	2,206
Self-teaching (incidence)	0.43	0.49	3,058
Self-teaching (hours)	54.74	108.59	1,304
Learning from colleagues (incidence)	0.92	0.28	3,341
Learning from colleagues (hours)	187.24	245.86	3,049
Performing tasks from which one can learn (incidence)	0.95	0.21	3,448
Performing tasks from which one can learn (hours)	402.78	422.68	3,282
Personal and career characteristics			
Master's degree	0.49	0.50	4,012
Female	0.08	0.27	4,258
Work experience (years)	13.6	10.05	3,830
Work experience^2 (years^2)	285.93	347.06	3,830
Firm tenure (years)	8.35	8.14	3,503
Firm tenure^2 (years^2)	135.99	238.73	3,503
Knowledge and skill level in previous year ("skill gap")	77.82	18.00	3,325
Job characteristics			
No management tasks	0.44	0.50	3,753
Spending <75 percent of working time on management tasks	0.48	0.50	3,753
Spending >75 percent of working time on management tasks	0.08	0.28	3,753
Skill demands			
Required level of technicial knowledge and skills	7.59	2.05	2,435
Required level of general knowledge and skills	6.92	1.24	1,951
Required level of commercial and financial knowledge and skills	5.57	2.35	2,106
Required level of advanced IT knowledge and skills	5.70	2.69	2,129
Required level of management and planning skills	7.35	1.40	2,073
Product market characteristics			
Degree of competition in product markets	3.83	1.09	3,447
Degree of competition on quality instead of price	3.72	1.04	3,270
Degree of demand instability in product markets	2.99	1.01	3,376
Innovativeness of the firm			
Degree of product innovation	3.58	1.07	3,517
Degree of process innovation	3.09	1.03	3,236
Degree of organizational innovation	2.98	1.00	3,468
Firm is merely follower of innovation	2.66	1.19	3,533
Firm size			
<10 employees	0.03	0.18	3,602
10-24 employees	0.04	0.20	3,602
25-49 employees	0.06	0.23	3,602
50-99 employees	0.07	0.26	3,602
100-249 employees	0.10	0.30	3,602
250-999 employees	0.17	0.38	3,602
1,000 or more employees	0.53	0.50	3,602

Table I. Description of the variables

complements instead of substitutes, although most correlation coefficients are low. Hours of formal training are moderately correlated to the various modes of informal learning. The same holds for the correlation between self-teaching and the two other modes of informal learning. However, doing tasks from which one can learn is highly correlated to learning from colleagues. This suggests that informal learning of S&Es is fostered in particular by the combination of performing challenging tasks and peer feedback.

4. Estimation results

We estimate the determinants of formal training and informal learning by means of Tobit analyses. We apply Tobit analyses because substantial numbers of S&Es do not participate in formal training or some of the modes of informal learning. This particularly holds for self-teaching (56 percent of non-participants) and formal training (36 percent of non-participants).

Formal training

The first column of Table III reports the estimation results on formal training. Within this homogeneous group of higher skilled S&Es, there are hardly any relationships between personal and career characteristics and the participation in formal training. Only work experience is negatively related to the number of training hours. However, our estimation results show that training participation is related to the kind of skills demanded in the job: S&Es who are employed in jobs with high demands for technical knowledge and skills, advanced IT, or management and planning knowledge and skills, have a higher participation rate in training courses, whereas those employed in jobs which require a high level of commercial and financial knowledge and skills less often participate in training. The estimation results also show that training participation is highly related to various firm characteristics: S&Es who are employed in firms that face severe competition in their product markets have lower rates of formal training than those who are employed in firms that face less competition. And as has been shown in many other studies, firm size is positively related to the number of training hours. Moreover, we find that S&Es who are employed in firms with high degrees of (technical) process and organizational innovation, more often participate in formal training courses, whereas those employed in a firm with a high degree of product innovation participate in training less often.

Self-teaching

The second column of Table III reports the results of a Tobit analysis on the determinants of the number of hours S&Es spend on self-teaching. Again, we find that

Table II. Correlation coefficients between formal training and modes of informal learning

	Formal	Informal		
	Training courses	Self-teaching	Learning from colleagues	Doing tasks from which one can learn
Training courses	–			
Self-teaching	0.0974*	–		
Learning from colleagues	0.0749*	0.0532*	–	
Doing tasks from which one can learn	0.0756*	0.1671*	0.4751*	–

	Training	Self-teaching	Learning from colleagues	Performing tasks from which one can learn
Personal and career characteristics				
Master's degree	4.050	−2.687	−25.411	33.999
	(1.28)	(0.45)	(2.24)**	(1.71)*
Female	−0.418	−28.886	46.793	3.024
	(0.06)	(2.16)**	(1.95)*	(0.07)
Work experience (years)	−1.472	−1.675	0.304	−4.332
	(2.27)**	(1.41)	(0.13)	(1.08)
Work experience^2 (years^2)	0.014	0.058	−0.015	0.104
	(0.80)	(1.76)*	(0.23)	(0.94)
Firm tenure (years)	0.698	0.066	−5.982	−6.935
	(1.05)	(0.05)	(2.55)**	(1.68)*
Firm tenure^2 (years^2)	−0.024	0.016	0.186	0.131
	(1.10)	(0.40)	(2.38)**	(0.96)
Knowledge and skill level in previous year (skill gap)	−0.147	−0.490	−1.358	−3.156
	(1.44)	(2.62)***	(3.71)***	(4.99)***
Job characteristics				
No management tasks (reference: >75 percent management tasks)	−8.569	−0.926	−55.684	−85.631
	(1.34)	(0.08)	(2.41)**	(2.13)**
Spending <75 percent of working time on management tasks	−6.930	−1.286	−21.745	−80.053
	(1.20)	(0.11)	(1.05)	(2.22)**
Skill demands				
Required level of technical knowledge and skills	1.970	0.588	2.550	14.554
	(1.99)**	(0.33)	(0.73)	(2.37)**
Required level of general knowledge and skills	−1.753	16.332	21.590	43.803
	(0.86)	(4.28)***	(2.93)***	(3.43)***
Required level of commercial and financial knowledge and skills	−1.780	−3.394	−1.138	−8.779
	(2.00)**	(2.03)**	(0.36)	(1.57)
Required level of advanced IT knowledge and skills	1.634	0.137	−1.667	−1.072
	(2.42)**	(0.11)	(0.70)	(0.25)
Required level of management and planning skills	4.006	−12.020	4.827	10.884
	(2.23)**	(3.61)***	(0.75)	(0.98)
Product market characteristics				
Degree of competition in product markets	−3.459	5.275	0.463	−19.889
	(2.00)**	(1.58)	(0.07)	(1.84)*
Degree of competition on quality instead of price	1.200	2.730	−8.560	−15.889
	(0.78)	(0.92)	(1.54)	(1.64)

(*continued*)

Table III. Determinants of formal training and informal learning (Tobit analyses)

	Training	Self-teaching	Learning from colleagues	Performing tasks from which one can learn
Degree of demand instability in product markets	−3.230	−3.477	−4.418	−6.240
	(2.07)**	(1.17)	(0.79)	(0.64)
Innovativeness of the firm				
Degree of product innovation	−5.498	5.215	11.776	26.534
	(3.22)***	(1.58)	(1.89)*	(2.46)**
Degree of process innovation	4.091	1.105	−3.782	−6.533
	(2.37)**	(0.34)	(0.61)	(0.61)
Degree of organizational innovation	5.713	1.819	13.476	7.179
	(3.42)***	(0.58)	(2.28)**	(0.70)
Firm is merely follower of innovation	1.288	−3.229	−6.330	−15.717
	(0.85)	(1.12)	(1.16)	(1.66)*
Firm size (reference firms < 10 employees)				
10-24 employees	20.667	−24.658	40.936	27.603
	(1.62)	(1.27)	(1.03)	(0.40)
25-49 employees	25.148	−44.481	−3.425	−13.923
	(1.98)**	(2.27)**	(0.09)	(0.20)
50-99 employees	31.553	−53.857	3.128	0.396
	(2.61)***	(2.80)***	(0.08)	(0.01)
100-249 employees	44.033	−39.536	7.309	4.075
	(3.74)***	(2.17)**	(0.20)	(0.06)
250-999 employees	47.588	−53.632	10.464	−4.610
	(4.20)***	(3.09)***	(0.31)	(0.08)
1,000 or more employees	59.810	−48.272	22.434	10.127
	(5.50)***	(2.97)***	(0.69)	(0.18)
Controls for sector of industry are included				
Constant	−115.132	85.289	136.603	−312.528
	(1.30)	(0.58)	(0.40)	(0.61)
Observations	1421	1352	1425	1467

Table III.

Notes: Absolute value of *t*-statistics in parentheses; *,**,***significant at 10, 5, and 1%, respectively

only few personal and career characteristics are significant determinants. However, it is remarkable that female S&Es spend fewer hours on self-teaching than males. Conversely to our findings on formal training, we find that S&Es who perceive to have a skill gap appear to upgrade their skill level by self-teaching. The participation in self-teaching is also related to the kind of skills demanded in the job. Particularly high demands of general knowledge and skills appear to stimulate self-teaching. Remarkably, those employed in jobs with high demands for commercial and financial skills or management and planning skills have significantly lower rates of self-teaching. It is also interesting to see that S&Es who are employed in smaller firms seem to compensate their lower rate of participation in formal training by more hours of self-teaching. However, self-teaching is not related to any other firm characteristics or job characteristics.

Learning from colleagues

The third column of Table III shows the estimation results of a Tobit analysis on the number of hours S&Es spend with colleagues who give them advice or demonstrate work practices. Graduates with a Bachelor's degree appear to participate more often in this mode of informal learning than graduates with a Master's degree. The same holds for female S&Es, although here the coefficient is only weakly significant. As could be expected, S&Es with a higher firm tenure less often learn from their colleagues than those with less firm tenure. However, we do not find these relationships for work experience in general. The S&Es who perceive to have a skill gap also attempt to upgrade their skill level by deliberately learning from their colleagues. Remarkably, those who have no management tasks spend less time learning from their colleagues. Learning from colleagues appears to be less related to the kind of skills demanded in the job. Estimation results only show a positive relationship with the level of general skills demanded in the job. Product market conditions and firm size are not significantly related to learning from colleagues either. However, the estimation results show that learning from colleagues occurs more often when S&Es are employed in firms with high degrees of product innovation and organizational innovation, although the former is only weakly significant.

Tasks from which one can learn

The last column shows the results from a Tobit analysis in which the number of hours spent on tasks from which one can learn is the dependant variable. Estimation results show that this mode of informal learning is more important for graduates with a Master's degree than for graduates with a Bachelor's degree. Moreover, S&Es who perceive to have a skill gap also seem to upgrade their skill level by doing tasks from which they can learn. Remarkably, S&Es who mainly have management tasks more often perform tasks from which they can learn than those who have no or less management tasks. The kinds of skills demanded in the job are also related to learning-by-doing. S&Es who are employed in jobs which require a high degree of technical knowledge and skills or general knowledge and skills, spend more time on tasks from which they can learn. Moreover, learning by doing is significantly related to product market characteristics and the innovativeness of the firm. S&Es who are employed in firms that face severe competition in their product markets, more often have jobs with a lower learning potential, although this relationship is only weakly significant. Conversely, S&Es who are employed in firms with a high degree of product innovation spend significantly more time on tasks from which one can learn, whereas those employed in firms that are merely followers of existing innovations have fewer opportunities for learning-by-doing. Again, we do not find a relationship between this mode of informal learning and the size of the firm in which someone is employed.

5. Conclusion and policy implications

In this paper we found that human capital investments of S&Es are significantly related to personal, job as well as firm characteristics. However, there are remarkable differences between formal training and the three modes of informal learning we distinguished: self-teaching, learning from colleagues, and performing tasks from which one can learn.

Our estimation results show there is no complementarity between S&Es' level of initial education and participation in formal training. However, those with a Bachelor's degree less often perform tasks from which they can learn, although they learn

significantly more from their colleagues than S&Es with a Master's degree. Female S&Es have a different pattern of informal learning than males. They spend less time on self-teaching, but more often learn from their colleagues. S&Es with more work experience participate in formal training less often but do not have significantly less informal learning. This shows that in particular formal training is concentrated at the beginning of a career, as expected by human capital theory. Moreover, S&Es with long firm tenures learn significantly less from their colleagues. This shows that skill spill-overs at work are particularly related to firm-specific skills. We also found that S&Es who perceive to have a skill gap more often participate in all three modes of informal learning. Remarkably, they do not bridge their skill gap by greater participation in formal training.

Our findings clearly show that different skill demands are acquired by different modes of training and learning. S&Es who are employed in jobs which require a high level of technical knowledge more often participate in formal training, and acquire more knowledge and skills by the tasks they perform. This does not hold for the acquisition of the non-technical skills required in the job. Those employed in jobs which require a high level of general skills, participate significantly more often in all three modes of informal learning we distinguished. Conversely, S&Es employed in jobs with high IT skill demands more often participate in formal training, but do not report a significantly higher participation in informal learning. Also those employed in jobs which require a high level of management skills more often participate in formal training. However, these S&Es spend less time on self-teaching. S&Es who are employed in jobs which demand high levels of commercial and financial skills significantly less often participate in formal training, and also spend less time on self-teaching.

Our analyses show that being employed in an innovative firm stimulates most modes of human capital investments. S&Es who are employed in firms which apply innovative production processes, more often participate in formal training and benefit from the learning potential of their jobs. Organizational innovativeness of the firm is also positively related to S&Es' participation in both formal training and informal learning. However, the relationship between human capital investments and firm innovations is not straightforward; S&Es who are employed in firms with many product innovations more often learn from their colleagues and from the tasks they have, but participate less often in formal training.

The competitiveness of the product markets of the firm also matters. As we expected, S&Es who are employed in firms which sell their products in highly competitive markets or instable product markets, less often participate in formal training. However, there is no significant relationship between the competitiveness of the product markets and investments in informal learning. Finally, as in many other studies, we find that those employed in large firms more often participate in formal training. Our results show, however, that this is partly compensated by a higher degree of self-teaching of the S&Es who are employed in smaller firms. Remarkably, we do not find any additional sector effects on either formal training or informal learning; this also holds for those employed in the R&D sector.

More in general, we may conclude that both formal training and informal learning are related in particular to job and firm characteristics. This suggests that labor demand characteristics are more important for the human capital investments of S&Es than labor supply characteristics, although previous skill gaps also seem to induce the various modes of informal learning. Moreover, only high demands for technological knowledge and organizational innovations boost both formal training and informal

learning. Conversely, high demands for commercial and financial skills are negatively related to both formal training and informal learning.

Having a workforce of S&Es with up-to-date knowledge and skills is a prerequisite for a competitive economy (cf. Galia and Legros, 2004). Our analyses show that lifelong learning of S&Es is fostered by innovative firms and suffers when firms face severe competition in their product markets. Therefore, public policies that stimulate innovation do not necessarily lead to skills obsolescence among S&Es as they also stimulate further human capital development. Moreover, we may conclude that the competence level of older S&Es with long-firm tenures is most at risk because these workers both participate less often in training, and have less learning opportunities in the workplace. Public policies that aim to diminish labor market shortages of S&Es by discouraging early retirement of experienced S&Es should therefore take account of the necessity to keep the human capital of older S&Es with long-firm tenures up-to-date.

Notes

1. It should be noted that a higher learning potential, in this respect, can also refer to a higher participation in formal training.
2. Bartel and Sicherman (1993) found a similar effect for older workers who have been employed in jobs in which it takes more time to become fully qualified.
3. The mean given in the table excludes those who report that they do not perform any tasks from which they can learn.
4. As these questions were optional only about one third of the respondents completed the questions on competences.

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