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Cities and Innovation

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Postal Address:
Institut d’Economia de Barcelona
Facultat d’Economia i Empresa
Universitat de Barcelona
C/ Tinent Coronel Valenzuela, 1-11
(08034) Barcelona, Spain
Tel.: + 34 93 403 46 46
Fax: + 34 93 403 98 32
ieb@ub.edu
http://www.ieb.ub.edu

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ABSTRACT: The empirical investigation into the economic relevance of knowledge codification lacks behind the allied theoretical contributions. The article empirically examines the link between codifiable work content and code-based technologies. For this purpose, we use detailed information about the tasks that employees performed at their jobs, and the work devices assisting them, in West Germany, over a period of 27 years. The main results suggest that automation decreased both the explicit manual task content within occupations and the job security of occupations specialized in such tasks. Occupations which frequently performed explicit manual tasks were disproportionally concentrated in middle of the wage distribution, contributing to the widely-observed polarization of jobs.

JEL Codes: J21, J24, J63, O33

Keywords: Skills, tasks, explicit knowledge, occupations, automation, job security.

Ljubica Nedelkoska
Research Training Group "Economics
of Innovative Change"
Friedrich Schiller University-Jena &
Max Planck Institute of Economics
Carl-Zeiß-Str. 3
D-07743 Jena, Germany
E-mail: ljubica.nedelkoska@uni-jena.de

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1. Introduction

The heated discussion on the economic relevance of tacit knowledge and knowledge codification (Cowan and Foray 1997; Cowan, David, and Foray 2000; Malerba and Orsenigo 2000; Johnson, Lorenz, and Lundvall 2002; Nightingale 2003; Balconi, Pozzali, and Viale 2007) remains detached from empirical verification that crosses beyond sparse case studies and anecdotal evidence[1]. Yet, the questions on the economic consequences of knowledge codification are in essence empirical ones. Recent research focusing on the relations between technology and work content observed at the task level provides promising avenue in understanding knowledge codification and its impact on job destruction and wage dynamics. This study attempts to advance the empirical investigation into the automation of codifiable or explicit task content and its impact on job security.

One frequently asked question in the literature on tacit knowledge is whether code-based technologies induced a wave of codification such that human activities that were possible to explicate and translate into a machine code became obsolete (Cowan and Foray 1997, Balconi 2002, Malerba and Orsenigo 2000). The economic relevance of this question is manifold. First, it has been claimed that the downsizing of the medium-paid jobs in developed countries in the last decades, which largely contributed to an increased earnings' inequality, was caused by automation[2] of routine or programmable tasks (Goos and Manning 2007; Dustmann, Ludsteck, and Schönberg 2009; Autor, Katz, and Kearney 2006; Autor, Katz, and Kearney 2008). Second, early recognition of skill obsolescence may provide signals for timely requalification and retraining of concerned occupations. By the same token, new tasks induced by technology may create skill shortages that can be addressed in a timely manner by educational and training institutions if acknowledged sufficiently early.

The evidence on the type of knowledge rendered obsolete by code-based technologies is mixed. Based on case studies in diverse Italian manufacturing, Balconi (2002) concludes that both situations occur frequently in reality: automation of highly tacit, and that of highly codified

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[1] Balconi (2002) provides case-study based evidence on the relationship between tacit and codifiable knowledge on one hand and technological innovations on the other. Balconi, Pozzali and Viale 2007 provide a review of case studies that emphasize the relevance of tacit knowledge for innovation, and science in general. Hǻkanson (2007) offers descriptive analysis of the relevance of knowledge articulation for innovation, division of labor, replication and control.

[2] Automation is defined as „execution by a machine agent of a function that was previously carried out by a human“(Parasuraman and Riley 1997, p. 231).

work tasks. Case studies in the American Banking sector reveal that although many explicit tasks of bank tellers were automated with the introduction of the automated teller machine (ATM), part of the new tasks of tellers were similarly routine, or explicit, but not yet programmable by commercially available technologies (Hunter et al 2001). Autor, Levy, and Murnane (2003) make a strong case that routine cognitive and routine manual tasks were automated in the last few decades in the U.S. Spitz-Oener (2006) provides comparable evidence for Germany.

We argue that the applied operations management based on Taylor's scientific methods of motion and time encouraged extreme codification of work processes on the production floor, setting the ground for consequent task automation through code-based technologies. Using detailed information about the tasks that employees perform at their jobs, we follow the changes in the explicit manual task content in West Germany in the period 1979-2006. We find that occupations decreased their explicit manual task content over time. Also the employment share of occupations which frequently perform such tasks declined over time. We further find support for the hypothesis that automation played major role in the shift away from explicit manual tasks. Automation did not only change the task content within jobs, but also affected the job security of certain occupations. These occupations are found in the middle of the wage distribution. The last observation supports previous evidence that automation contributed to the decline of the middle-paid jobs and therefore to the rise of wage inequality.

The rest of this paper is structured as follows. Section 2 discusses the theory and derives the hypotheses. Section 3 introduces the data, section 4 provides descriptive analysis of the task structure, task changes and the trends in automation, section 5 addresses the relation between explicit task content and automation, and explicit task content and job security. Section 6 investigates the link between explicit tasks and job polarization. Section 7 concludes.

2. Codification of manual explicit tasks and its economic repercussions

2.1. Taylorism: organizational theory and practice that strategically codified manual work activities

The Fordist production paradigm pervasive in developed economies until the late 1970s in practice incorporated scientific methods of motion and time aimed at breaking down work processes to their most elementary tasks and limiting the cognitive scope of interpretation through time standards for task performance. These methods pushed knowledge codification of manual work processes to its extreme[3].

The Fordist production system embraced the principles of Taylor's organizational theory and combined them with mechanization (Tomaney 1994, Lipietz 1997). Taylorism found its highest use in mass production processes enabled through the proliferation of assembly line and characterized by rather generic products. Taylor's organizational methods offered superior cost-minimizing solutions on the production floor and in the clerical departments through ascertaining the most efficient division of tasks between humans and technology. These methods introduced "separation of conception and execution, and extreme task fragmentation" (Tomaney 1994, p. 158). In the core of Taylor's scientific management were the method and time studies. These did not concern problem-solving and creative tasks, but the main objective of analysis were tasks of repetitive nature on which standardization could be imposed (March and Simon 1993). When describing Taylor's method and time studies March and Simon (1993) write:

> "[…] the scientific management group was concerned with describing the characteristics of human organism as one might describe a relatively simple machine for performing a comparatively simple task. The goal was rather to use the relatively inefficient human organism in the productive process in the best way possible. This was to be accomplished by specifying a detailed *program of behavior* (a "method," or set of methods) that would transform a general-purpose mechanism, such as a person, into a more efficient special-purpose mechanism." (p. 31/32, italics added).

[3] This argumentation is also present in the work of Coriat and Dosi (1998, p. 115) and Balconi (2002, p. 358).

What is striking is how detailed such programs of behavior indeed are. As described in Lowery, Maynard, and Stegemerten (1940), the operation machining nonferrous metal on a lathe consisted of 183 tasks, the first 10 of which were: "pick up part and move to machine, place medium part in chuck, tighten independent chuck 18-inch lathe, tighten chuck with pipe on wrench, true up part on chuck, pick up aligning bar from floor, pick up surface gage, align part in halves (with surface gage), remove aligning bar to floor, lay aside surface gage." (p. 388).

Notwithstanding the high level of task fragmentation, none of these tasks is detailed enough to uniquely specify the cognitive image that each subinstruction triggers in a person. As March and Simon argue, neither of the 183 steps uniquely determines a set of muscular movements, but the freedom of movement is severely restricted by the time allowed for performing each one of them. In the given example, the task "pick up part and move to machine" can be understood in various ways, but the fact that it must be performed within 0.0049 hours tremendously reduces the options at hand. Hence, the codification of production knowledge does not aim at complete elimination of the tacit component of tasks, but at its reduction to a point where aligning of mental models results in bodily movements sufficiently similar across workers to produce identical outcomes within comparable time[4].

2.2. Taylorist task fragmentation as a basis for mass automation and process outsourcing

The codification of work processes through method and time studies may have resulted in at least two nontrivial economic consequences which are of interest for this article. First, the machine view of human labor in the fragmentation of tasks may have stimulated the development of technologies capable of replicating a sequence of unambiguously prescribed steps. It is widely acknowledged that technologies speeded up processes and reduced production errors. The "program of behavior" might have been replaced by a machine code and human effort might have been substituted by technology[5].

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[4] In this respect we fully agree with Polanyi (1966, 2009) in his argument that "[…] the ideal of a comprehensive mathematical theory of experience which would eliminate all tacit knowing is proved to be self-contradictory and logically unsound." (p. 21). We therefore believe that the 'algorithmic model' of knowledge production, as described by Cowan, David, and Foray (2000, p. 216), cannot exist in humans in its ideal form. The 'algorithmic economic agent' can only strive towards this ideal.

[5] In an influential management article Hammer (1990) explains that within a decade of intense automation companies mainly used technologies to automate already established production processes without

Autor, Levy, and Murnane (2003) propose microfoundations of the relationship between the type of tasks performed at the job and the use of computers. Unlike previous economic studies which unavailingly attempted to explain the relationship between labor and technology through scrutinizing macro and meso-level behavior, Autor, Levy, and Murnane recognize that in order to explain these relationships one must comprehend them at the level of tasks. They analyze the types of tasks that computers can easily process and those which they cannot. They propose that: "...[computers] rapidly and accurately perform repetitive tasks that are deterministically specified by stored instructions (programs) that designate unambiguously what actions the machine will perform at each contingency to achieve the desired result." (p. 1282). Such tasks are referred as routine tasks. "…a task is "routine" if it can be accomplished by machines following explicit programmed rules...Because these tasks require methodical repetition of an unwavering procedure, they can be exhaustively specified with programmed instructions and performed by machines" (p. 1283)[6]. The notion of routine tasks borrowed from computer science comes very close to what we call explicit or codifiable tasks. In our use, a task is explicit if it is accomplished by following unambiguously prescribed step-by-step procedure. This does not mean that such tasks are free of tacit knowledge, but only that the tacit dimension is substantially reduced. These tasks are often repetitive in nature, but repetition is not in the core of their definition[7]. Our first expectation is that the automation of the workplace reduced the demand for labor that mainly performs explicit tasks.

Second important economic implication of codification is that highly explicit knowledge can be conveyed to foreign labor through teaching without large cognitive mismatch between the instructor and the trainee. The extreme detail in instruction guarantees a high degree of compliance with the "manual". This is because it reduces the scope of thought stemming from cultural, educational, and institutional backgrounds. Compare for instance the previous example of machining nonferrous metal on a lathe with a task where a decision to fire an employee has to be made. While in the first case there is hardly any space for culture-dependent deviation in carrying out the task, a decision to fire an employee will be highly culture-dependent. The decision will not only be based on employee's performance capabilities, but will often

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exploiting the possibilities for reengineering of production which new technologies enable. The author argues that technologies have been wrongfully used to simply speed up existing processes.

[7] For instance, reaching analytical solution of a complex mathematical model, or presenting relationships between data in form of a statistical model are not necessarily repetitive tasks, but they are explicit.

incorporate the decision-makers' idea of what is acceptable work behavior, obedience level, and not that uncommon, racial, ethnical, family, and economic background of the parties.

Moreover, codified work processes have predefined outcomes, which makes the verification of proper implementation relatively easy. This is not the case with non-standardized work processes whose performance requires creativity, experimentation, and exploration. The expected output of a lathe worker will, for instance, have the following description: 100 pieces of C10100[8] hollow round forms with outer diameter of 25 mm, inner diameter of 13 mm, and 7 mm thick. The decision to fire does not have a predefined outcome from which properties one can judge the proficiency in the task performance of the decision-maker.

It is unlikely to be a coincidence that the international outsourcing of processes in manufacturing during the 1980s and the 1990s started exactly with the assembly line, a production unit with highest concentration of explicit manual tasks. Although we are not equipped with data that would allow us to directly test the relationship between task explicitness and outsourcing, we would like to point out that a potential shift away from jobs that perform explicit tasks will likely be driven by more than one factor.

It is not obvious though whether the access to computing technology or outsourcing only resulted in restructuring of task content within jobs or occupations, or whether it also shifted the occupational structure of economies away from explicit manual jobs. While the first case has consequences for skill upgrading, only the latter case has consequences for job security. In the Autor, Levy, and Murnane (2003) model the declining price of computers drives the wage paid for performing routine tasks down[9] and the relative price for performing non-routine tasks up[10]. Therefore, the marginal worker decides to specialize in non-routine tasks. Such situation results in decline of jobs specialized in routine tasks and an increase in jobs specialized in non-routine ones. Nevertheless, in reality such restructuring of tasks does not necessarily have to lead to restructuring of jobs or occupations. Unless a job is fully specialized in a certain task and incapable of adapting to new ones, such job can experience shift from routine toward non-routine tasks or vice versa without consequences on its employment.

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[8] Oxygen-free high-conductivity copper.

[9] Because computer-performed tasks and human-performed routine tasks are perfect substitutes.

[10] Because routine tasks and non-routine tasks are q-complements, meaning that an increase in the routine task input augments the marginal productivity of those performing non-routine tasks. Due to the falling price of routine tasks and their more frequent use as inputs in performing non-routine ones, the productivity and therefore the price of non-routine tasks increases.

Therefore, a first step in our estimation strategy would be to analyze whether the changes in explicit manual and cognitive tasks are mainly within or between-occupational changes. Since both situations are plausible we do not have an expectation for the type of change. A second step would be to establish a relationship between the change in the frequency of task performance and the adoption of automation. We therefore derive our hypotheses:

H1: The change in the level of explicit manual tasks is negatively related to the adoption of automation.

The interest of this study is not only to test for possible relations between task content and automation, but also to explore the implications that such relations may have on job security. Ceteris paribus, we expect that:

H2: Employees performing explicit tasks have higher layoff risk

3. Data

3.1. Qualification and Career Survey

The Qualification and Career Survey is a repeated cross section conducted at 6 to 7-year intervals, which started for the first time in 1979[11] and was repeated in 1985/1986, 1991/1992, 1998/1999 and 2005/2006. Its purpose, among others, is to track skill and task requirements of occupations. The survey is a rich source of information about the types of tasks employees perform in their jobs. Unfortunately, it repeatedly changed its structure, and many relevant questions are not consistently asked in each wave. After careful inspection of the questions in each wave we concentrate on those that are relevant for our purpose and are identical or closely comparable between waves (see table A1 in appendix A for a list of these questions).

[11] The Qualification and Career Survey is administrated by the Federal Institute for Vocational Education and Training (BIBB) and the Institute for Employment Research (IAB).

3.2. Measurement of task codification

Two measures are of central interest in this paper: explicitness and repetitiveness of work tasks. Two questions in the Qualification and Career Survey that, we believe properly capture the degree of manual task codification appear in all five waves in a consistent manner. The first question reads: *In your day-to-day work, how often does it happen that your work process is predefined in every detail?* This is our indicator of task explicitness. The second question reads: *In your day-to-day work, how often does it happen that one and the same work process occurs repeatedly in every detail?* This is our indicator of task repetitiveness. The answer to these questions is given on a Likert scale: practically always, often, from time to time, seldom, practically never[12]. As we discussed in section 3, codifiable tasks are often repetitive, but task repetitiveness does not necessarily coincide with task explicitness. We therefore rather rely on task explicitness as our indicator of task codifiability. Table 1 presents the tasks which significantly correlate either with task explicitness or with task repetitiveness in the 1979 survey wave[13].

[12] In the 2005/2006 survey, the option "practically always" is absent.
[13] This wave has the most comprehensive list of work task variables.

Table 1. Correlations between task codification measures and other tasks

	Task explicitness	Task repetitiveness
Work under output norm	0.76	0.69
Work under time norm	0.72	0.51
Stitch, sew, quilt	0.38	0.16
Spin, wave, knit	0.25	0.23
Surface construction, building	0.19	
Pack, unpack, shipping preparation	0.17	
Underground construction	0.16	
Field, garden work	0.16	
Melt, cast, mould	0.16	0.13
Mill, press, extract, mix	0.15	
Measure length, height, temperature	0.13	
Bookkeeping	-0.35	-0.26
Procure, purchase commodities	-0.36	-0.19
Educate, teach	-0.36	-0.36
Negotiate, lobby	-0.42	-0.39
Filling out forms, data registry	-0.42	-0.37
Negotiate with customers, consult customers	-0.42	-0.26
Arithmetic, math, statistics	-0.44	-0.47
Coordinate, organize	-0.45	-0.48
Process improvement	-0.50	-0.55
Writing letters, reports	-0.53	-0.49
All positive correlations significant at the 5% level or higher are shown. The strongest ten negative correlations significant at the 5% level or higher are shown. The correlations are sorted ascending by task explicitness. Source: Qualification and Career Survey 1979 wave. Number of observations (occupations): 273		

At the occupational level, the explicitness of tasks correlates highest with working under output and time norm, but also fairly high with work processes in textile production. Weaker positive correlations are those with work in construction, product packaging, metal production (melt, cast, mould, mill, press, extract, mix), and measuring of physical characteristics. Occupations which report high instance of explicit tasks tend to report significantly fewer interactive tasks (coordinate, organize, educate, teach, negotiate, consult), but also fewer cognitively demanding tasks such as process improvement, writing reports, arithmetic, math, and statistics. Therefore, our measures of task codification capture the explicit manual aspects of work. Given the high correlations with time and output norms, we believe that task explicitness captures particularly well the types of tasks that were subject to method and time studies.

3.3. Measurement of automation

Each wave of the Qualification and Career Survey, except for the latest one (2005/2006) asks respondents to list the work devices which they use at the main job. From the list of devices we select those which indicate use of code-based technologies: computers, computerized numerical control (CNC), and half-automated devices. We further use the variables: simple manual device, manually-operated device, and electric manual device as controls because these devices are not code-based. Table A1 in appendix A contains the definitions and the coding of these variables.

4. Descriptive analysis

4.1. Tasks: Composition and changes

The aggregate changes in task quantity in an economy come from three sources: total employment growth, task level shifts within occupations, and changes in the occupational mix. We are interested in the task changes that stem from the latter two sources, namely, the within and the between-occupational task shifts. To illustrate what these types of changes mean, let us take the occupation of 'turner' in the metal production as an example. The primary task here is the production and finishing of machine components through movements such as turning, drilling, grinding, and molding.[14] Therefore, this is one of the occupations with high explicit work content. The employment share of this occupation in the total employment declined from .58% in 1979 to .50% in 2006, a decline of almost 14%. This contributes to the *between-occupational shift* away from explicit tasks.[15] Moreover a lower percentage of employees in this occupation performed explicit tasks in 2006 (38%) than in 1979 (47%), which contributes to the *within-occupational shift* away from explicit tasks.

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[14] The occupation of 'turner' has existed in Germany since 1939. Before the introduction of computerized numerical control (CNC) in the 1970s and the 1980s, its work operations were semi-automated. In 2002 due to changes in the task content, the occupational training and the occupation itself were also officially restructured. This occupation now carries the name of 'precision machinist' and is also commonly known as CNC turner.

[15] The estimates are based on the Qualification and Career Survey, waves 1979 and 2005/2006.

To disentangle the within and the between-occupational task changes we employ shift-share analysis. We therefore decompose the aggregate change in task level *j* into a term which reflects the changes between occupations and a term which reflects the changes within occupations: $\Delta T_{jt} = \sum_o (\Delta E_{ot}\overline{\gamma}_{oj}) + \sum_o (\Delta \gamma_{ojt} \overline{E}_o)$. Here T is the total task quantity of type *j* ; E is employment of occupation *o*; and γ is the task quantity of occupation *o; o* = 1,…,273[16] , *t* =1985, 1992, 1999, and 2006, *j* =explicit tasks, repetitive tasks, and process improvement[17]. Table 2 presents the shift-share analysis results for the period 1979-2006.

Table 2: Between and within occupational changes in task content

	Repetitive tasks (annualized % change)			Explicit tasks (annualized % change)			Process improvement (annualized % change)		
Period	Between	Within	Net	Between	Within	Net	Between	Within	Net
1979-1985	-0.06	0.08	0.02	-0.08	0.16	0.08	0.06	-0.24	-0.17
1985-1992	-0.04	0.22	0.18	-0.01	0.29	0.28	-0.01	0.60	0.59
1992-1999	-0.09	-0.09	-0.18	-0.11	-0.13	-0.24	0.08	-0.31	-0.24
1999-2006	-0.16	0.45	0.28	-0.07	-0.46	-0.52	0.18	0.17	0.36
1979-2006	-0.35	0.66	0.30	-0.27	-0.14	-0.41	0.31	0.22	0.54

Annualized between and within occupational percent changes of tasks. Unit of analysis: occupation. Source: Qualification and Career Survey, all waves. Results from a shift-share analysis

Table 2 shows that there were remarkable changes in the task content of the West-German economy in the period 1979-2006. The performance of explicit manual tasks, both within and between occupations decreased on average. The net decrease is .41% percent per year. The performance of process improvement became more common over time within same occupations, and the share of occupations that often perform process improvement increased in the economy. The annual net increase in these tasks is .54%. Interestingly, in the case of repetitive tasks, the between changes are all negative, while the within changes are mainly positive, meaning that, although the economy moved away from occupations with high instance of repetitive tasks, on average occupations increased their repetitive task content. The net changes in the performance of these tasks are positive.

[16] The number of occupations is reduced down to 229 in 2006. This reduction does not necessarily result from structural changes-it is also affected by the reduction of the sample size over time.

[17] We closely inspected the tasks that we can compare over time. We would have liked to compare changes in more routine cognitive tasks and those of interactive tasks. Due to continuous changes in the questionnaire design only few of these were sufficiently consistent to be comparable. The results for the rest of the tasks can be made available from the author on request.

4.2. Adoption of automation

Now we turn our attention to the adoption of automation between 1979 and 1999[18]. In this period, the automation of processes was mainly prevalent in manufacturing. We therefore focus on its proliferation in this sector. Table 3 shows the share of employees reporting use of half-automated devices, computerized numerical control (CNC), and computers in West Germany. While the share of employees using half-automated devices stayed relatively stable, with a comparatively modest increase of 3.6 percentage points (or around 19%), the adoption of CNC, and in particular computers was rapid. Only 3.8% of all employees in manufacturing used CNC in 1979, while 16.4% used it in 1999, an increase of 335%. The most rapid adoption was the one of computers. While 5.2% reported use of computers in 1979, 44.6% did so in 1999 (an increase of 762% within a period of 20 years).

Table 3: Adoption of automation in West Germany

	Half-automated	CNC	Computer
1979	18.54	3.77	5.17
1986	17.42	2.73	10.14
1992	18.40	6.93	15.14
1999	22.14	16.39	44.56
Share of employees using automated work equipment. Source: Qualification and Career Survey. Note: these questions are not asked in 2006			

Table 4 further compares the prevalence of automation between those who report frequent performance of explicit tasks and those who do not. Evidently, those who report frequent instance of explicit tasks also report significantly more frequent use of half-automated devices and CNC, but significantly lower use of computers at the job. These results run contrary to what previous case studies proposed (see Balconi 2002), which suggest that automation seldom took place at the assembly line. Our observations suggest that certain type of automation was more prevalent in assembly line processes where most of the explicit tasks are concentrated. Around 6.4% of those who occasionally or seldom performed explicit tasks used CNC, while 8% of those who often performed explicit tasks used CNC at the job (t=-6.1). Also, while around 16% of those who occasionally or seldom performed explicit tasks were assisted by half-automated

[18] Unfortunately these questions are not asked in the most recent (2005/2006) wave.

device at the work, this was the case with 24.2% of those who frequently perform explicit tasks (t=-20.16).

Table 4: Prevalence of automation between employees who perform explicit tasks and those who don't

	CNC	Half-automated	Computer	Observations
Explicit=0	0.0635	0.1574	0.2183	22,586
	(0.0016)	(0.0024)	(0.0027)	
Explicit=1	0.0802	0.2418	0.1061	14,057
	(0.0023)	(0.0036)	(0.0026)	
t statistic	-6.1012	-20.1576	27.7764	
Observations: 14,057 employees report frequent use of explicit tasks (explicit=1) and 22,586 report occasional or seldom use of explicit tasks (explicit=0). Years: 1979, 1986, 1992 and 1999. Manufacturing only.				

5. Automation and explicit manual tasks

In order to test our hypothesis that the adoption of automation contributed to the decline of explicit manual task content, similar to Autor, Levy, and Murnane (2003, p. 1303) we estimate the following model:

(1) $$\Delta E_{ot} = \alpha + \boldsymbol{A}_{ot}\beta + \varepsilon_{ot} ,$$

where $\Delta E_{ot} = \Delta(E_{ot} / E_t)$ is the annualized change in the share of employees within an occupation *o* reporting explicit tasks between *t* and *t-1.* The matrix $\boldsymbol{A}$ contains variables that indicate the annualized change in the share of employees reporting different work devices: simple manual, manually-operated, half-automated, computerized numerical control (CNC), and computer.

We expect negative relationship between the change in the share of employees using computers on the one hand, and the change in the share of employees performing explicit tasks on the other. The same should hold for the relationship between the change in the share using CNC and the change in the share reporting explicit tasks. We expect non-negative relationship between the change in the share using simple manual or manually driven device on the one hand, and the change in the share reporting explicit tasks on the other. This is because these devices assist employees in performing, but are not designed to substitute labor. In the case of half-automated devices the relationship is not clear. Since they are partially automated, they may either be complementary to labor or substitute for it. Therefore, we have no prior expectation for this variable.

Model (1) is a first-differencing model between the periods 1979-1986, 1985-1992, and 1992-1999. Table 5 contains the estimation results.

Table 5. Automation adoption and changes in the explicit manual task content

	Model I	Model II	Model III
CNC	0.0854	0.0791	0.0850
	(0.0716)	(0.0766)	(0.0734)
Half-automated	0.0816	0.0823	0.0744
	(0.0682)	(0.0693)	(0.0668)
Computer	-0.120***	-0.123***	-0.0886***
	(0.0200)	(0.0259)	(0.0314)
Simple manual device	0.0504	0.0530	0.0862*
	(0.0445)	(0.0438)	(0.0445)
Manually-operated device	-0.116**	-0.121**	-0.0930
	(0.0566)	(0.0597)	(0.0599)
Electric manual device	-0.0941	-0.0968	-0.110
	(0.0741)	(0.0737)	(0.0719)
Period dummy 1986-1992	-	-	0.00515
			(0.0212)
Period dummy 1992-1999	-	-	0.0375**
			(0.0188)
Time trend	-	0.00245	-
		(0.0106)	
Constant	0.0381***	0.0342*	0.0179
	(0.00783)	(0.0201)	(0.0188)
R2	0.071	0.071	0.088
Observations	447	447	447
Dependent variable: Annualized share change of explicit task content. First differencing results. Robust standard errors in parentheses. Significant at: ***1%, **5%, and *10%. Mean occupational employment is used as weight. The unit of analysis is occupation. Only employees in manufacturing are considered.			

Model I has the basic specification, model II includes a time trend, and model III includes period dummies. The results suggest that only the adoption of computers affected the explicit task content. On average, occupations which adopted computers reduced their explicit task content.

The magnitude of the coefficient descends once we account for period-specific effects, but remains significant at 1% level or better. The coefficient of .089 (most conservative estimate in model III) suggests that, on average, 1% increase in computer use corresponds with .089% decline in the explicit task content. Given the rapid adoption of computers in the observed period, the effect is economically large. In the full model (model III) also simple manual device becomes marginally significant, suggesting complementarity with explicit tasks. The inclusion of a trend (model II) which could capture alternative effects (e.g., increased outsourcing of jobs over time) is insignificant and does not affect the results notably.

We cannot see how inverse causality may affect the interpretation of our results. Inverse causality would mean that the downsizing of explicit tasks led to computer technology upgrades at the job. Nevertheless, confounding may be of concern if certain managerial practices reduced the demand for explicit task content and at the same time increased the use of computers. For instance, the introduction of lean manufacturing could have caused both. Nonetheless, existing evidence points that lean manufacturing did not proliferate in Germany in the observed period (see e.g., Lorenz and Valeyre 2004, p. 13). Final concern would be the omission of outsourcing indicator in our model. As already argued in section 2, the shift away from explicit manual tasks in the economy could have been caused by international job outsourcing (see e.g. Goos, Manning, and Salomons 2009). Nevertheless, once we account for technology adoption, the trend variable does not indicate any further over-time changes that may have affected the explicit task content. Moreover, international outsourcing is largely enabled through reduced costs of computer communication and monitoring, meaning that outsourcing itself is likely to be endogenous to technology.

To conclude, the results suggest that computers have automated explicit manual tasks. The same cannot be said for computerized numerical control.

5.1. Task content and job security

Automation may change the task composition of a job without implications on job security (see discussion in section 2). Nevertheless, the results of the shift-share analysis suggest that, in the case of explicit work tasks, it was also the number of jobs with high explicit task content that declined over time. We would further like to highlight this observation and analyze the relationship between task content and layoff risk at the level of individuals. At this level we can control for individuals' socio-demographic characteristics, relatively complete work task portfolio, industrial affiliation and level of specialization.

In four out of five waves of the Qualification and Career Survey respondents were asked to assess the risk of layoff. The layoff risk is given at an ordinal scale, and therefore we estimate ordinal logit models. Since the survey is designed as a repeated cross-section, we estimate separate models for each wave. Moreover, most of the independent variables, as well as the dependent variable in these models are comparable, but not identical across waves. Therefore, we decide not to pool the samples together. Appendix A contains the descriptive statistics of these models and the definitions of the variables.

Formally, this model can be written as follows:

(2) $$P(Y_i > j) = g(\mathbf{X}\beta) = \frac{\exp(\alpha_j + \mathbf{X}_i\beta)}{1 + \{\exp(\alpha_i + \mathbf{X}_i\beta)\}}, \; j = 1, 2, ..., M - 1;$$

where M is the number of categories in the ordinal dependent variable and β are the coefficients to be estimated. $\mathbf{X}_i$ is the matrix of independent variables.

Table 6 presents the results of the estimations. Models Ia, Ib, Ic, and Id present a specification which does not account for occupation-specific effects, and models IIa, IIb, IIc, and IId include occupation dummies. Reoccurring pattern in all the models is the positive link between task explicitness and layoff risk. For example, employees who reported frequent use of explicit tasks in 1998 and in 1999 were 1.2 times more likely to also report very high layoff risk (in contrast to reporting no risk, low risk, or high risk) ceteris paribus. Opposite is the case with interactive tasks, such as educate, teach, organize, and manage where, when significant, the odds ratios point toward lower layoff risk. Interestingly, R&D tasks correlated with higher layoff risk in the last two periods. One reason for this may be that R&D employees often have limited contracts and the question on layoff risk in these two periods additionally asks about the risk of not having your work contract renewed. There is no strong link between problem-solving tasks, such as process improvement and mathematics, arithmetic, and statistics on the one hand, and layoff risk on the other-in most periods the relationship is insignificant, and occasionally negative.

Table 6: Task content and job security

	1979		1991/1992		1998/1999		2005/2006	
	Model Ia	**Model IIa**	**Model Ib**	**Model IIb**	**Model Ic**	**Model Iic**	**Model Id**	**Model IId**
Explicit tasks	1.171***	1.161***	1.150***	1.160***	1.220***	1.219***	1.172***	1.176***
	(0.0147)	(0.0152)	(0.0149)	(0.0153)	(0.0174)	(0.0178)	(0.0215)	(0.0221)
Repetitive tasks	1.039***	1.042***	0.990	0.987	0.946***	0.945***	0.985	0.984
	(0.0143)	(0.0148)	(0.0140)	(0.0141)	(0.0146)	(0.0150)	(0.0181)	(0.0185)
Practice of law	1.041	1.132	0.801***	0.799***	0.910	0.959	1.024	1.018
	(0.170)	(0.186)	(0.0659)	(0.0658)	(0.0574)	(0.0610)	(0.0593)	(0.0609)
Process improvement	0.963	0.974	0.981	0.979	0.952**	0.960*	0.985	0.984
	(0.0289)	(0.0296)	(0.0245)	(0.0245)	(0.0208)	(0.0212)	(0.0268)	(0.0273)
Educate	0.736**	0.720**	0.629***	0.711***	0.821***	0.830***	0.965	0.957
	(0.107)	(0.108)	(0.0497)	(0.0575)	(0.0234)	(0.0241)	(0.0281)	(0.0287)
Taking care of people	0.876	1.209	0.704***	0.861	1.037	1.049*	1.082***	1.052
	(0.135)	(0.223)	(0.0616)	(0.0836)	(0.0273)	(0.0286)	(0.0327)	(0.0392)
Organize/manage	0.658***	0.665***	0.746***	0.730***	0.927	0.967	0.974	0.981
	(0.0650)	(0.0670)	(0.0518)	(0.0510)	(0.0609)	(0.0647)	(0.0279)	(0.0285)
Mathematics, arithmetic, statistics	0.888	0.912	0.891*	0.860**	0.997	1.009	1.076	1.102*
	(0.0793)	(0.0830)	(0.0572)	(0.0555)	(0.0520)	(0.0539)	(0.0569)	(0.0600)
Research and development	0.902	0.865	1.107	1.078	1.163***	1.153***	1.100***	1.095***
	(0.139)	(0.137)	(0.0825)	(0.0805)	(0.0428)	(0.0446)	(0.0348)	(0.0365)
Age	0.981***	0.980***	0.982***	0.982***	0.979***	0.980***	0.992***	0.992***
	(0.00151)	(0.00155)	(0.00132)	(0.00134)	(0.00159)	(0.00161)	(0.00191)	(0.00195)
Female	0.920**	0.976	1.057	1.028	0.881***	0.926*	0.922**	0.912**
	(0.0371)	(0.0467)	(0.0362)	(0.0365)	(0.0317)	(0.0387)	(0.0362)	(0.0399)
Apprenticeship	0.762***	0.808***	0.809***	0.799***	0.884***	0.898**	0.989	0.994
	(0.0333)	(0.0376)	(0.0305)	(0.0307)	(0.0365)	(0.0386)	(0.0674)	(0.0696)
Generalist job	0.997	1.010	0.926	0.929	0.903**	0.898***	0.919***	0.915***
	(0.0800)	(0.0818)	(0.0519)	(0.0521)	(0.0362)	(0.0362)	(0.0301)	(0.0305)
Education dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes	yes	yes	yes	yes
Occupation dummies	no	yes	no	yes	no	yes	no	yes
Log pseudolikelihood	-12,737	-12,583	-17,202	-17,152	-16,496	-16,281	-12,376	-12,258
Observations	22,516	22,516	20,471	20,471	16,426	16,351	12,569	12,520
Dependent variable: layoff risk; Results from an ordered logit model; Odds ratios reported; Robust standard errors in parentheses; Significant at ***1%, **5%, and *10% level; Unit of analysis: individual.								

The controls show the expected signs. Layoff risk is lower for older workers, which should capture seniority effects. It is lower for female workers, workers with higher levels of education[19], and those with completed apprenticeship. It is also lower for people employed in more general jobs[20].

6. Explicit tasks and job polarization

Job polarization is a phenomenon where the employment in the tails of the wage and skill distributions grows faster than the employment in the middle. In fact, the medium-paid jobs experienced downsizing in many economies in the last three decades, including Western Germany. Polarization of jobs was evidenced in several developed countries (Autor, Katz, and Kearney 2006; Goos and Manning 2007; Goos, Manning, and Salomons 2009; Dustman, Ludsteck, and Schönberg 2009). Goos and Manning (2007) argue that this hollowing out of the wage distribution can be explained by the nuanced theory of SBTC proposed by Autor, Levy, and Murnane (2003). They claim that the jobs where routine tasks were performed were the medium and not the lowest paid ones. They furthermore observe that the left tail of the wage distribution is dominated by the low-paid service jobs, which mainly perform non-routine interactive tasks. These tasks, as of now are not automated. The non-routine cognitive jobs are concentrated in the right tail of the wage distribution.

We are interested in finding out whether the downsizing of jobs which performed explicit manual tasks indeed contributed to the polarization of labor. We therefore observe the explicit task intensity along the wage distribution. Figure 1a compares the intensity of explicit tasks with the intensity of management and problem-solving tasks. Figure 1b compares the intensity of explicit tasks with the intensity of care and sales-related tasks. The intensity is measured in standard deviations, with 0 pointing the mean task intensity. It is evident from these figures that the medium-paid occupations were indeed those with highest explicit task intensity. Moreover, on all other tasks: management, problem-solving, care, and sales they score low. The highest-paid occupations show great intensity of problem-solving tasks (process improvement, mathematics, and research and development), but also above-average intensity of managerial and sales-

[19] For the sake of brevity we omitted the education dummies in the table. The results are available from the author on request.
[20] We created a simple measure of specialization here. The measure counts the number of reported tasks at the job, where the considered tasks are: educate, organize/manage, process improvement, mathematics/arithmetic/statistics, and taking care of people. It is important to note that a task is only counted toward the task portfolio if a person reports more than basic knowledge.

related tasks (such as marketing and bargaining). The lowest-paid occupations demonstrate above-average intensity of care and sales related tasks.

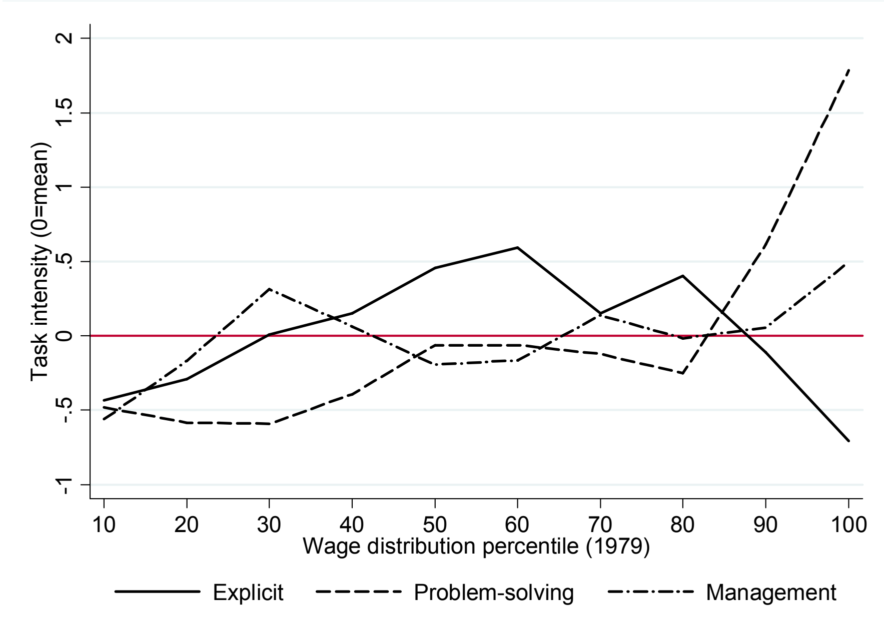

Figure 1a: Task intensity along the wage distribution[21]

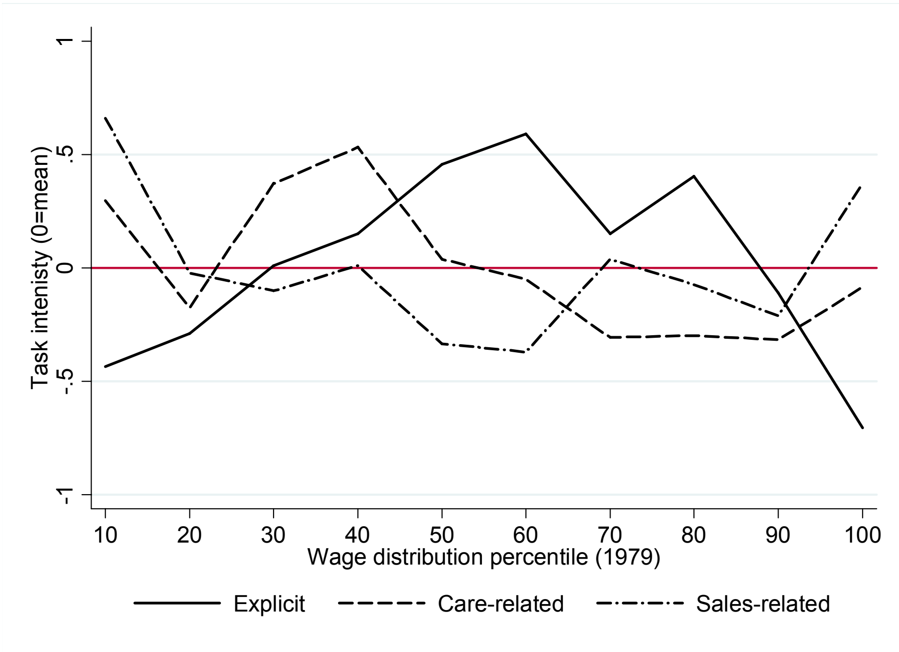

Figure 1b: Task intensity along the wage distribution

[21] Appendix B provides the technical details of the creation of Figures 1a and 1b.

7. Conclusions

The implementation of the Taylorist time and method studies on the production floor resulted in intense codification of manual work processes throughout much of the twentieth century. The tremendous standardization of the work procedures and outcomes set the ground for consequent task automation once code-based technologies became affordable. We find that occupations on average reduced their explicit or codifiable manual task content in West Germany during the 1990s and the 2000s. Moreover, the employment share of occupations which frequently performed explicit tasks decreased within the period 1979-2006. These declines in the explicit manual task content can be related to the adoption of computer-based technologies. Automation not only changed the task structure within occupations, but also affected the job security of occupations which specialized in explicit manual tasks. These occupations were the medium-paid ones at the end of the 1970s, suggesting that the automation of explicit tasks contributed to the polarization of jobs in the last few decades.

Based on these findings, we advocate that the codification of knowledge played a remarkable economic role in the last and the beginning of this century. The results support the nuanced skill-biased technological change theory proposed by Autor, Levy, and Murnane (2003). They also support previous findings that automation contributed to the hollowing out of the wage distribution (Goos, Manning, 2007; Autor, Katz, and Kearney 2006).

Some limitations of this study are worth mentioning. To this end we only examine the trends in the explicit manual work content, although one of the early purposes of computer design was the reduction of tedious, time-consuming, and often repetitive cognitive tasks. The reason for not pursuing with the question of routine cognitive tasks is that we do not believe that we can reliably capture these tasks with the data at hand[22]. Moreover, the findings about the relationship between explicit tasks and computer technology are only valid for manufacturing. In services we do not observe such relationship. Nevertheless, the world of expanding service sector deserves proper research attention. While the automation of manufacturing very likely reached its peak, the new wave of automation is expected in the healthcare sector, where the demand for elderly care due to the demographic aging of developed economies vastly exceeds the supply of care. Since care for others involves highly tacit knowledge and non-standardized

[22] For such attempt see Spitz-Oener 2006.

manual work, the challenges that automation faces here are far greater than those on the production floor. This promising market for automation is worthy of serious scientific attention and opens up an avenue for further understanding of the division of labor between humans and technology.

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Appendix A: Variables' definitions, descriptive statistics and correlations

Table A1: Definitions, availability and coding of variables

	1979	1985/1986	1991/1992	1998/1999	2005/2006
Process improvement, trying out new things	At your day-to-day work, how often does it happen that you improve a process, try out something new?				
Coding	Scale 1 to 5				Scale 1 to 4
Original variable name	v262	v64	v187	v268	F411_05
Task explicitness	In your day-to-day work, how often does it happen that your work process is predefined in every detail?				
Coding	Scale 1 to 5				Scale 1 to 4
Original variable name	v276	v61	v184	v265	F411_02
Task repetitiveness	In your day-to-day work, how often does it happen that one and the same work process occurs repeatedly in every detail?				
Coding	Scale 1 to 5				Scale 1 to 4
Original variable name	v277	v62	v185	v266	F411_03
Educate, teach	Task present at your job lately: nurture, lecture, educate, teach/ occupational, educational, personal, and spiritual counseling	Task that is part of your job: nurture, teach, educate, counseling		How often does the following task occur at your job: educate, teach, lecture?	How often does the following task occur at your job: educate, teach, lecture, nurture?
Coding	1=present; 0=not present	0=not present; 1=present; 2 predominant task	1=present; 0=not present	2=often; 1=seldom; 0=never	2=often; 1=sometimes; 0=never
Original variable name	v206	v29	v60	v189	F312
Math, specific knowledge (not only basic)	Do you need special knowledge (more than just basic calculus) at your professional activity?	NA	Do you need special knowledge in: arithmetic, mathematics, statistics		Do you need specialized knowledge in mathematics, specialist calculations, statistics?
Coding	1=present; 0=not present		1=present; 0=not present		1=no knowledge; 2=basic knowledge; 3=specialist knowledge
Original variable name	v309-v314		v77	v213	F403_08

Practice of law	Task present at your job lately: practice, interpret laws, regulations	Task that is part of your job: practice, interpret laws, regulations/notarize documents		Do you need special knowledge in: labor law, collective bargaining law, other law	Do you need specialized knowledge in law?
Coding	1=present; 0=not present	0=not present; 1=present; 2 predominant task	1=present; 0=not present		1=no knowledge; 2=basic knowledge; 3=specialist knowledge
Original variable name	v202	v28	v59	v223/v224	F403_04
Organize/plan/coordinate/manage	Task present at your job lately: coordinate, organize, lead/direct employees, hire/fire, decide working hours, manage	Task that is part of your job: delegate, coordinate, organize, lead, manage, controlling	Task that is part of your job: decide coordinate, organize, delegate	Do you need special knowledge in: management, planning, personnel, organization	How often does the following task occur at your job: organize, plan (other employees' work)
Coding	1=present; 0=not present	0=not present; 1=present; 2 predominant task	1=present; 0=not present		1=often; 2=sometimes; 3=never
Original variable name	v214	v33	v64	v225	F310
Research/develop/analyze information	Task present at your job lately: research, analyze, investigate	Task that is part of your job: analyze, research, test, evidence, measure	Task that is part of your job: analyze, research, test, evidence, measure, plan	How often does the following task occur at your job: develop, research?	How often does the following task occur at your job: develop, research, design?
Coding	1=present; 0=not present	0=not present; 1=present; 2 predominant task	1=present; 0=not present	2=often; 1=seldom; 0=never	2=often; 1=sometimes; 0=never
Original variable name	v171	v21	v52	v199	F311
Taking care of people	Task present at your job lately: take care of, nurse, attend on patients	Task that is part of your job: nurse/attend on, medical/cosmetic care	Task that is part of your job: nurse, attend on, medical/cosmetic care, hairdressing	How often does the following task occur at your job: attend on, serve, take care of people?	How often does the following task occur at your job: nurse, take care of, cure?

Coding	1=present; 0=not present	0=not present; 1=present; 2 predominant task	1=present; 0=not present	2=often; 1=seldom; 0=never	2=often; 1=sometimes; 0=never
	v207	v30	v61	v201	F316
Layoff risk	How high do you assess the risk that soon you may involuntary have to change your job within the same firm or be laid off?	NA	How high do you assess the risk that soon you may be laid off from the firm?	How high do you assess the risk that soon you may be laid off from the firm or that your work contract may not be extended?	
Code	0=low; 1=medium; 2=high		0=no risk; 1=low; 2=high; 3=very high		
Original variable	v129		v32	v132	F517
Simple manual device	Which work device do you mainly work with: simple manual tool (hammer, rasp, spade, brush, handpump…)	If you work with tools and machines in production and repair, which ones do you work with: simple manual tool (hammer, rasp, spade, brush, handpump…)		Indicate the tools and devices which you often use at your main job: simple manual tool (hammer, rasp, spade, brush, handpump…)	NA
Coding	1=present; 0=not present				
Original variable	v100	v78	v130	v31	
Electric manual device	Which work device do you mainly work with: electrical device: manual drill, milking machine, drier, kitchen appliances	If you work with tools and machines in production and repair, which ones do you work with: electrical device (manual drill, milking machine, drier, kitchen appliances)		Indicate the tools and devices which you often use at your main job: electrical device (manual drill, manual saw, mixer, drier)	NA
Coding	1=present; 0=not present				
Original variable	v104	v83	v135	v33	

Manually-driven device	Which work device do you mainly work with: hand-operated machine (lathe, sewing machine, roentgen, milling machine)	If you work with tools and machines in production and repair, which ones do you work with: hand-operated machines (lathe, sewing machine, roentgen, milling machine)		Indicate the tools and devices which you often use at your main job: hand-operated machines (lathe, milling machine, sewing machine)	NA
Coding	1=present; 0=not present				
Original variable	v105	v84	v136	v39	
CNC	Which work device do you mainly work with: code-based machine, automat	If you work with tools and machines in production and repair, which ones do you work with: NC/CNC, Industrial robot		Indicate the tools and devices which you often use at your main job: NC/CNC, Industrial robot	NA
Code	1=present; 0=not present				
Original variable	v109	v87	v139	v41	
Half-automated device	Which work device do you mainly work with: half-automated machine (automated die cutter, lathe, loom, dishwasher, grinding machine)	If you work with tools and machines in production and repair, which ones do you work with: automated die cutter, lathe, loom, dishwasher, grinding machine	If you work with tools and machines in production and repair, which ones do you work with: automated die cutter, lathe, loom, dishwasher, grinding machine, printing machine	Indicate the tools and devices which you often use at your main job: hand-operated automated machines (die cutter, lathe, loom, dishwasher)	NA
Code	1=present; 0=not present				
Original variable	v106	v85	v137	v40	
Computer	Which work device do you mainly work with: computer, terminal, monitor	If you work with tools and machines in production and repair, which ones do you work with: computer, terminal, monitor		Do you work often with computers?	NA
Code	1=present; 0=not present				
Original variable	v110	v88	v140	v53	

Table A2: Descriptive statistics of the variables in Table 5

	Mean	Median	Std. Dev.	Minimum	Maximum	Observations
Δ share of explicit tasks	0.023	0.030	0.113	-0.629	0.636	447
Δ share simple manual	0.039	0.032	0.115	-0.892	1.033	447
Δ share manually-operated	0.040	0.015	0.110	-0.410	0.766	447
Δ electric manual	0.024	0.004	0.099	-0.834	0.729	447
Δ share CNC	0.048	0.015	0.096	-0.289	0.797	447
Δ share half-automated	0.023	0.017	0.106	-0.598	0.909	447
Δ share computers	0.138	0.047	0.210	-0.585	0.991	447

Table A3: Correlations of variables in Table 5

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δ share of explicit tasks (1)	1						
Δ share simple manual (2)	0.030	1					
Δ share manually-operated (3)	-0.097*	0.100*	1				
Δ electric manual (4)	-0.087	0.274*	0.332*	1			
Δ share CNC (5)	0.003	0.103*	0.324*	0.202*	1		
Δ share half-automated (6)	0.055	0.016	0.226*	0.131*	0.309*	1	
Δ share computers (7)	-0.210*	-0.015	0.014	0.028	0.205*	0.037	1
*Significant at the 5% level.							

Table A4: Frequencies of the variables in Table 6

	1979		1991/1992		1998/1999		2005/2006	
	Categories	**Percent**	**Categories**	**Percent**	**Categories**	**Percent**	**Categories**	**Percent**
Layoff risk	low	79.36	no risk	57.46	no risk	32.99	no risk	35.11
	medium	17.59	low	36.3	low	53.99	low	54.62
	high	3.05	high	4.23	high	8.81	high	6.89
			very high	2.02	very high	4.21	very high	3.38
Total		100.00		100.00		100.00		100.00
Explicit tasks	never	40.30	never	21.34	never	23.46	never	24.38
	seldom	17.44	seldom	24.43	seldom	24.33	seldom	29.47
	from time to time	13.43	from time to time	17.27	from time to time	18.36	sometimes	24.73
	often	13.66	often	21.59	often	19.6	often	21.42
	always	15.17	always	15.37	always	14.26		
Total		100.00		100.00		100.00		100.00
Repetitive tasks	never	22.81	never	13.39	never	13.27	never	11.74
	seldom	13.24	seldom	15.7	seldom	16.15	seldom	17.74
	from time to time	19.54	from time to time	22.29	from time to time	22.98	sometimes	20.84
	often	24.6	often	30.19	often	30.89	often	49.68
	always	19.81	always	18.44	always	16.72		
Total		100.00		100.00		100.00		100.00
Process improvement	never	44.81	never	17.49	never	24.32	never	6.49
	seldom	16.13	seldom	24.37	seldom	23.94	seldom	18.95
	from time to time	18.59	from time to time	31.17	from time to time	30.52	sometimes	45.27
	often	12.64	often	21.54	often	17.4	often	29.29
	always	7.83	always	5.44	always	3.82		
Total		100.00		100.00		100.00		100.00
Law	not present	97.18	not present	88.32	not present	85.52	not present	80.86
	present	2.82	present	11.68	present	14.48	present	19.14
Total		100.00		100.00				
Educate	not present	95.67	not present	85.3	never	65.17	never	48.2
	present	4.33	present	14.7	seldom	22.62	sometimes	34.68
					often	12.21	often	17.12
Total		100.00		100.00		100.00		100.00
Care	not present	96.86	not present	93.46	never	53.49	never	77.74

	present	3.14	present	6.54	seldom	10.28	sometimes	6.58
					often	36.24	often	15.68
Total		100.00		100.00		100.00		100.00
Math	not present	59.52	not present	56.93	not present	67.56	not present	72.32
	present	40.48	present	43.07	present	32.44	present	27.68
Total		100.00		100.00		100.00		100.00
Research	not present	97.60	not present	87.00	never	88.59	never	65.38
	present	2.40	present	13.00	seldom	6.92	sometimes	22.14
					often	4.49	often	12.49
Total		100.00		100.00		100.00		100.00
Organize/manage	not present	82.86	not present	75.02	not present	86.42	never	34.65
	present	17.14	present	24.98	present	13.58	sometimes	29.04
							often	36.3
Total		100.00		100.00		100.00		100.00
Female	no	67.07	no	61.78	no	57.57	no	53.62
	yes	32.93	yes	38.22	yes	42.43	yes	46.38
Total		100.00		100.00				
Apprenticeship	no	27.54	no	28.69	no	29.26	no	32.05
	yes	72.46	yes	71.31	yes	70.74	yes	67.95
Total		100.00		100.00		100.00		100.00

Table A4 continued.

	1979		1991/1992		1998/1999		2005/2006	
Education	Elementary school/general secondary education (Hauptschule)	12.59	Without educational degree	0.97	Without educational degree	0.86	Without educational degree	1.27
	General certificate of secondary school	2.76	Elementary school/general secondary education (Hauptschule)	48.72	Elementary school/general secondary education (Hauptschule)	41.51	Elementary school/general secondary education (Hauptschule)	26.64
	Advanced technical college entrance qualification	0.12	General certificate of secondary school	21.19	General certificate of secondary school	25.64	General certificate of secondary school	33.03
	University entrance qualification	0.73	Advanced technical college entrance qualification	1.94	Advanced technical college entrance qualification	3.29	Advanced technical college entrance qualification	4.16
	Vocational school	53.31	University entrance qualification	3.78	University entrance qualification	6.44	University entrance qualification	12.58
	Full-time vocational school	9.63	Full-time vocational school	7.49	Full-time vocational school	3.14	Full-time vocational school	7.3

	Health school	1.53	Master school/Technical school	2.69	Master school/Technical school	9.67	Master school/Technical school	0.31
	Civil servants' school	2.98	University of cooperative education (Berufsakademie)	0.87	Advanced technical college	4.00	Advanced technical college	5.43
	Other vocational school	2.72	Advanced technical college	4.07	University	5.44	University	9.28
	Master school/Technical school	6.32	University	8.29				
	University of cooperative education (Berufsakademie)	2.87						
	University	2.56						
	Other	1.89						
Total		100.00		100.00		100.00		100.00
Industry	Agriculture, mining	3.96	Agriculture, mining	1.73	Agriculture, mining	1.78	Agriculture, mining	2.08
	Manufacturing	40.67	Manufacturing	37.26	Manufacturing	35.66	Manufacturing	30.56
	Construction	8.82	Construction	6.65	Construction	7.75	Construction	5.54
	Railways, road transportation	2.13	Railways, road transportation	1.24	Railways, road transportation	0.43		
	Service	34.31	Service	39.2	Service	44.27	Service	53.82
	Public administration	7.72	Public administration	10.44	Public administration	7.26	Public administration	4.78
	Energy, garbage removal	1.21	Energy, garbage removal	0.95	Energy, garbage removal	1.46	Energy, garbage removal	1.62
	Postal service	1.18	Postal service	2.53	Postal service	1.39	Postal service	1.59
Total		100.00		100.00		100.00		100.00
Observations		22,516		20,471		16,426		12,569

Appendix B: Job polarization

Figures 1a and 1b contain information both from the Qualification and Career Survey and the IAB Employment Samples (IABS). The latter data, administrated by the Institute of Employment Research is the most reliable source of wage information in Germany. At the same time the Qualification and Career Survey only provides categorical wage information in the 1979 wave. Therefore, to create reliable ranking of occupations along the wage distribution we merge the task information from the Qualification and Career Survey with the wage information from the IABS at the occupational level. The wage censoring in the IABS in 1979 only concerns some 4.6% of the observations, and therefore, we can easily decide on the observations that are within the highest decile of the wage distribution. The measures of problem-solving, managerial, care-related, and sales-related tasks are factors that result from a factor analysis. We employ principal factor analysis of 10 tasks from the 1979 wave because there is overlap in some of the tasks listed in different questions. The factor analysis helps us reduce the dimensionality of the data. For the 10 tasks we considered it results in 4 factors with eigenvalues above one, which account for 94% of the total variance in the data after orthogonal varimax rotation. These 4 factors we associate with problem-solving, managerial, care-related, and sales-related tasks or skills. The factor loadings for this analysis are provided in Table B1.

Table B1: Factor loadings

	Factor 1 Problem-solving	Factor 2 Sales	Factor 3 Care	Factor 4 Management	Uniqueness
R&D	0.7609				0.3921
Customer bargaining/Customer support		0.9406			0.0904
Practice of law					0.5736
Taking care of people			0.7541		0.3761
Medical examination and diagnosis/Body care			0.7626		0.4003
Negotiate/represent interests		0.5095		0.6124	0.2202
Coordinate/organize/delegate	0.8361				0.1322
Process improvement	0.7592				0.32
Explicit tasks					0.4596
Repetitive tasks	-0.508	-0.5107			0.4274
Arithmetic/mathematics/statistics	0.5598				0.373
Sales/marketing		0.9254			0.0202
Management	0.5148			0.6454	0.1146
Only loadings higher than .4 are reported					

2009

2009/1. Rork, J.C.; Wagner, G.A.: "Reciprocity and competition: is there a connection?"
2009/2. Mork, E.; Sjögren, A.; Svaleryd, H.: "Cheaper child care, more children"
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