Non technical summary:

This paper analyses the determinants of factor demand for 27 west German manufacturing industries. Six production factors are distinguished: capital, energy, three types of labour and non-energy materials. The different determinants are factor substitution and price sensitivity of the different labour inputs, the impact of output growth and the time effect. Among these factors, knowledge of price and cross elasticities are important for policy makers. When considering policies to fight against high unemployment of unskilled labour by wage subsidies, the elasticities of substitution between different types of labour as well as own-price elasticities for different skill group are of interest.

The results show that price elasticities do not appear sensitive to imposing theoretical restrictions implied by optimising behaviour. The main result is the strong substitutability relationship between unskilled workers and workers having a degree from the vocational system. Furthermore, unskilled labour tends to be considerably more responsive to wage-rate changes compared to the upper skill levels. Our results show that the substitutability relationship between different types of labour with energy or materials is insignificant, except for the complementarity relationship between energy and unskilled labour. This suggests, that the energy price shock and declining material prices in the 1980s are unable to explain the difference in the subsequent employment changes of the three types of labour. Concerning the substitution pattern among non-labour inputs, we found on the one hand substitutability between energy and capital, and on the other between energy and non-energy materials. Hence, raising energy prices will rather stimulate capital investment.

Using decomposition analyses, the relative importance of price-, output- and time effects were examined. Of the three factors, the output effect is the most important in explaining the growth of the three different types of labour.

Curvature Conditions and Substitution Pattern among Capital, Energy, Materials and Heterogeneous Labour[†]

Martin Falk[*] and Bertrand Koebel[**]

ABSTRACT. This study deals with the determinants of factor demand in 27 industries of the manufacturing sector during the period 1978 to 1990. Using a quadratic cost function, six production factors are distinguished: capital, energy, three types of labour and intermediate materials. A parametric test of the concavity of the cost function in prices is provided and price elasticities are compared when curvature conditions are imposed or not. The results show, firstly, that in general estimates do not appear very sensitive to imposing theoretical restrictions implied by optimising behaviour. Secondly, demand for unskilled labour is relatively elastic to wage increases compared to the higher skill levels. Third, the substitutability is stronger between unskilled and medium skilled labour than any other pairs of inputs.

Keywords: curvature conditions, elasticities of substitution, skill structure.

JEL-Classification: E23, J21, J31.

---

† An earlier version of the paper was presented at the CEPR/ZEW/DFG conference in Mannheim, at the EEA in Berlin 1998 and at the Verein für Socialpolitik in Rostock, 1998. We thank Richard Blundell, Bernd Fitzenberger, Joachim Möller, François Laisney, Georg Licht, Jacques Mairesse and Winfried Pohlmeier for helpful comments on an earlier draft. We also acknowledge the invaluable research assistance provided by Florian Heiss. We are also grateful to Henrike Koschel and Stefan Vögele for data-related help. The first author acknowledges financial support from the German Science Foundation in the programme 'Industrial Economics and Input Markets'.

* Centre for European Economic Research (ZEW), P.O Box 103443, D-68034 Mannheim, e-mail: falk@zew.de.

** Otto-von-Guericke University, P.O. Box 4120, D-39016 Magdeburg, e-mail: koebel@ww.uni-magdeburg.de.

1. Introduction

In this paper a quadratic cost function is used to estimate price, output and time elasticities for a system of six input demand functions. There are few studies which have considered different skill classes of labour as well as disaggregated materials as distinct input of the production process. However, only under restrictive conditions on the technology and on the evolution of prices, can the different labour and material inputs be combined into single aggregate measures. Besides, when considering policies to fight against high unemployment of unskilled labour (by for example wage subsidies), the elasticities of substitution between different types of labour, as well as own-price elasticities for different skill groups are of interest. This information is typically not available when only aggregate inputs are considered. Therefore, we consider the wages of different types of labour, the prices of energy, material, capital, the level of output and the impact of time for explaining the evolution of different input demands.

The observed shift in demand away from unskilled labour is widely documented in the economic literature. One explanation is that technological change is skill labour augmenting (Berman, Bound and Griliches, 1994) and that higher skill labour is more complementary to equipment investment than lower skilled labour. Another reason for the shift in the employment composition is that employment changes in response to exogenous shifts in wages and output depend on the degree of skill (e.g., Bergström and Panas 1992, Betts 1997, Nissim 1984). Both effects are simultaneously investigated here. Most empirical studies in production analysis are based on flexible functions that have to satisfy some curvature conditions, but only few studies test these restrictions. Kodde and Palm (1987), Härdle, Hildenbrand and Jerison (1991) are notable exceptions in the consumer context. An originality of this paper is that we present a parametric test of the concavity of the cost function in prices. Furthermore, price elasticities are compared when curvature conditions are imposed or not. The factor demand system is estimated for 27 German manufacturing industries from the period 1978 to 1990. The skill categories are based on the highest formal qualification received: workers without any formal vocational certificate are categorised as low-skilled or unskilled; workers with a certificate from the dual vocational training system, who have attained either university level entrance degree ("Abitur") or vocational school degree, are categorised as medium-skilled or skilled; and finally, workers with a university or technical university degree are categorised as high-skilled workers.

Our research expands the work that has been carried out so far. First, skill categories are defined on the basis of the highest formal qualification received, instead of the categories blue and white-collar (see Kugler et al. 1989, for Germany).[1] Second, our model also explicitly includes materials and energy as a factor of production (contrary to, for example Fitzenberger and Franz, 1998, and Kugler et al., 1989). The inclusion of materials and energy as production factors does not only permit to avoid specification bias (see e.g. Basu and Fernald, 1997), but is also interesting in itself. Knowledge of the substitution elasticity between energy and labour is essential in evaluating the impact of raising energy taxes on the demand for labour. For homogeneous labour, the literature largely agrees on the substitutability between labour and energy. However, most studies summarised by Hamermesh (1993) report only small energy-labour elasticities of substitution. For labour disaggregated by different types of skills, information about the substitution elasticities among heterogenous labour and energy seems not to be available. Furthermore, in contrast to many studies on this subject, we do not assume restrictive assumptions on the technology with respect to separability, return to scale and the impact of technological change.[2]

The next section delineates the econometric model of factor demand, the price concavity test and aggregation of elasticities. Section 3 describes the data. The empirical results are contained in Section 4. Section 5 concludes.

[1] The study of Fitzenberger and Franz (1998) is also based on three types of qualification.
[2] The studies of e.g. Fitzroy and Funke (1995) or Kugler et al. (1989) are based on such assumptions.

2. The modelling framework

2.1 Cost and demand functions

The most widely used method for estimating multifactor demands is to fit the factor demand equations derived from the cost function by Shephard's lemma. The translog and generalised Leontief functions have been applied extensively in estimating price elasticities, but do not often satisfy the concavity in prices. We start directly with a functional form which can be constrained easily in this respect, the normalised quadratic cost function (see Diewert and Wales, 1987):[3]

$$c\left(p_{nt}, z_{nt}; \alpha_n\right) = p'_{nt}A_{pn} + \frac{1}{2}\left(\theta'_n p_{nt}\right)^{-1} p'_{nt}A_{pp}p_{nt} + p'_{nt}A_{pz}z_{nt} + \frac{1}{2}\left(\theta'_n p_{nt}\right) z'_{nt}A_{zz}z_{nt}, \tag{2.1}$$

where the subscripts t and n denote time and industry, respectively. The technological parameters to be estimated are gathered in the vector α_n. Given the data available, we define the vector of inputs as $x_{nt} = (e_{nt}, h_{nt}, k_{nt}, m_{nt}, s_{nt}, u_{nt})'$ and the prices as $p_{nt} = \left(p_{ent}, p_{hnt}, p_{knt}, p_{mnt}, p_{snt}, p_{unt}\right)'$, where the labour input h_{nt} denotes high-skill labour, s_{nt} denotes medium-skill labour and u_{nt} low-skill or unskilled workers. Labour is measured in total workers (full-time equivalent). In addition, e_{nt} denotes energy, m_{nt} material and k_{nt} capital. The net capital stock is assumed to be variable. Other explanatory variables entering the cost function are the level of production y_{nt} and a time trend t denoting impact of technological change. These variables are regrouped in a vector $z_{nt} = (y_{nt}, t)'$. The matrices of parameters to be estimated, $A_{pn} = [\alpha_{pn}]$, $A_{pp} = A'_{pp} = [\alpha_{pp}]$, $A_{pz} = [\alpha_{pz}]$ and $A_{zz} = [\alpha_{zz}]$, are of size 6×1, 6×6, 6×2 and 2×2, respectively. The term $\theta'_n p_{nt}$ appearing in equation (2.1) is introduced to guarantee that the cost function is linearly homogeneous in prices. The vector θ_n, of size of 6×1, is chosen to be equal to x_{n1}/c_{n1} so that $\theta'_n p_{nt}$ corresponds to a Laspeyres price index for total costs, normalised to '1' in the basis period for which $t = 1$. As underlined by Diewert and Wales (1987), this arbitrary choice of θ_n does not

[3] Recent applications of the normalised quadratic cost function can be found in Draper and Manders (1996) and Gagne and Ouellete (1998).

affect the flexibility properties of the cost function. In addition to linear price homogeneity, the price symmetry property is directly imposed on equation (2.1).

The system of input demands $x^*(p_{nt}, z_{nt}; \alpha_n)$ is obtained by the application of Shepard's lemma:

$$\begin{aligned} x^*(p_{nt}, z_{nt}; \alpha_n) &= A_{pn} + (\theta_n' p_{nt})^{-1} A_{pp} p_{nt} - \frac{1}{2} (\theta_n' p_{nt})^{-2} \theta_n p_{nt}' A_{pp} p_{nt} \\ & \quad + A_{pz} z_{nt} + \frac{1}{2} \theta_n (z_{nt}' A_{zz} z_{nt}). \end{aligned}$$

Furthermore, for identification purposes, we directly impose the following 6 additional equality constraints on the matrices A_{pp}:

$$\iota' A_{pp} = 0, \tag{2.2}$$

where $\iota = (1, \ldots, 1)'$. Diewert and Wales (1987) show that the price concavity property of the cost function is equivalent to the negative semi-definiteness of A_{pp}. One advantage of retaining a quadratic cost function is that despite these restrictions, the form of equation (2.1) remains flexible, i.e. it can still provide a local approximation for an arbitrary cost function as well as its first and second order derivatives. In the empirical part of the paper, two models are used, one based on the concavity unrestricted cost function and the other making use of the concavity restricted cost function. We incorporate the concavity conditions by imposing a parameter restriction through a Cholesky decomposition of the matrix A_{pp} (for details see Diewert and Wales 1987).

This system of six input demands divided by the output level, to which a residual vector ν_{nt} is added, is used for estimating the parameter vector α_n:

$$x_{nt}/y_{nt} = x^*(p_{nt}, y_{nt}, t; \alpha_n) / y_{nt} + \nu_{nt}. \tag{2.3}$$

2.2 Price Concavity Test

As discussed by Diewert and Wales (1987), the signature of the singular matrix A_{pp} is identical to the signature of the Hessian of the cost function with respect to prices. Since the matrix A_{pp} is symmetric and has at most rank 5 (since (2.2) holds), only 15 parameters of A_{pp} can vary freely. Let a_{pp} be the vector containing these free parameters and Ω_{pp} be the corresponding covariance matrix (constructed from the covariance matrix Ω of α_n). The corresponding unrestricted estimates are respectively $\widehat{a}_{pp}$ and $\widehat{\Omega}_{pp}$. For testing negative semi-definiteness of the estimated matrix $\widehat{A}_{pp}$ we adapt the test proposed by Härdle, Hildenbrand and Jerison (1991). The null-hypothesis of this test is that the highest non-zero eigenvalue $\widehat{\lambda}_{\max}$ of $\widehat{A}_{pp}$ is less than zero. If $\widehat{\lambda}_{\max}$ is found to be significantly positive, the negative semidefinitess of $\widehat{A}_{pp}$ is rejected. Let $\lambda^0_{\max}$ be the true value of the highest eigenvalue of the matrix A_{pp}. Then asymptotically

$$\widehat{\lambda}_{\max} \approx N\left(\lambda^0_{\max}, \sigma^2_\lambda\right),$$

where σ^2_λ is consistently estimated by $\widehat{\sigma}^2_\lambda = \left(\partial\lambda_{\max}/\partial a'_{pp}\right)\widehat{\Omega}_{pp}\left(\partial\lambda_{\max}/\partial a_{pp}\right)\Big|_{a_{pp}=\widehat{a}_{pp}}$.

This distribution will be used for testing the sign of the highest eigenvalue. This test has the advantage of not requiring to use quadratic programming techniques for deriving the restricted eigenvalues. The expression of $\partial\lambda_{\max}/\partial a'_{pp}$ may be obtained from the spectral decomposition of A_{pp} given by $A_{pp}q_j = \lambda_j q_j$ and thereby $q'_j A_{pp} q_j = \lambda_j$, where q_j is the eigenvector associated to the eigenvalue λ_j. Since A_{pp} is symmetric and verifies (2.2), the coefficients of the above quadratic form satisfy[4]

$$\lambda_j = \sum_{h=1}^{6}\left(\left(-\sum_{k=1}^{h-1} a_{kh} - \sum_{k=h+1}^{6} a_{hk}\right) q^2_{jh} + 2\sum_{k=h+1}^{6} a_{hk} q_{jh} q_{jk}\right).$$

From this expression we obtain

$$\begin{aligned}\frac{\partial\lambda_j}{\partial a_{hk}} &= -q^2_{jk} + 2q_{jh}q_{jk} - q^2_{jh} \\ &= -\left(q_{jh} - q_{jk}\right)^2, \qquad \forall k > h, \quad j = 1, \ldots, 6.\end{aligned}$$

The eigenvector associated to $\lambda_6 = 0$ is proportional to $\iota = (1, \ldots, 1)'$ and therefore $\partial\lambda_6/\partial a_{hk} = 0$.

2.3 Elasticities aggregated across industries

In the empirical part of the paper own-price and cross-price elasticities are calculated together with the output elasticity of input demand and impacts of non-neutral technological change. We estimate the system of factor demands using a

[4] The following convention is adopted: for $h = 1$, the term $\sum_{k=1}^{h-1} a_{kh}$ is zero. For $h = 6$, the terms $\sum_{k=h+1}^{6} a_{hk}$ and $\sum_{k=h+1}^{6} a_{hk} q_{jh} q_{jk}$ also vanishes.

small panel of manufacturing industries. Since we are interested in the aggregate impact of factor price changes on input demand, we only calculate aggregate elasticities. Besides, it would be impossible to present more than 50 elasticities for each of the 27 industries. Moreover, since we do not allow for heterogeneity in slopes, it is not meaningful to calculate elasticities at the disaggregate level. The aggregation of sectoral elasticities will be derived on the example of aggregate output elasticity:

$$\frac{\partial I^*}{\partial Y_t}\frac{Y_t}{I^*}, \tag{2.4}$$

where the aggregate factor demand is $I^* = \sum_{n=1}^{N} i_n^*$ with $I = E,\ H,\ K,\ M,\ S,\ U$ and $i = e,\ h,\ k,\ m,\ s,\ u$ respectively. Aggregate output is by definition $Y_t = \sum_{n=1}^{N} y_{nt}$. In order to calculate the expression (2.4), we assume that the level of production y_{nt} of each industry depends on the aggregate level of production Y_t. In fact, this dependance is not deterministic, but can be though to be stochastic; we note $y_{nt} = \widetilde{y}_{nt}\left(Y_t\right)$. Then, holding input prices constant, it follows that

$$\frac{\partial I^*}{\partial Y_t} = \frac{\sum_{n=1}^{N} \partial i_n^*}{\partial Y_t} = \sum_{n=1}^{N} \frac{\partial i_n^*}{\partial y_{nt}}\frac{\partial \widetilde{y}_{nt}}{\partial Y_t}.$$

Hence the aggregate output elasticity can be written as:

$$\epsilon_{IY} = \sum_{n=1}^{N} \frac{\partial i_n^*}{\partial y_{nt}}\frac{\partial \widetilde{y}_{nt}}{\partial Y_t}\frac{Y_t}{I^*} = \sum_{n=1}^{N} \epsilon_{iyn}\frac{i_n^*}{y_{nt}}\frac{\partial \widetilde{y}_{nt}}{\partial Y_t}\frac{Y_t}{I^*}.$$

We assume that output shares of each industry remain constant when aggregate output grows; that is

$$\frac{\partial \widetilde{y}_{nt}}{\partial Y_t} = \frac{y_{nt}}{Y_t}. \tag{2.5}$$

Finally the aggregate output elasticity can be written as a weighted average of sectoral elasticities:

$$\epsilon_{IY} = \sum_{n=1}^{N} \epsilon_{iyn}\frac{i_n^*}{I^*}. \tag{2.6}$$

For testing the hypothesis (2.5), the following equation is estimated for each industry:

$$y_{nt}/Y_t = \alpha_n/Y_t + \beta_n + \eta_{nt}.$$

The hypothesis $\alpha_n = 0$ is rejected in 10 out of 27 manufacturing industries. Even being weakly rejected, the assumption (2.5) is not a nonsense. Indeed, elasticities are usually computed under a *ceteris paribus* assumption. For example, we study the impact of wage change for given levels of the other variables, even if in fact all variables are shifted simultaneously. Adapting the *ceteris paribus* reasoning to our aggregation problem of elasticities, it comes to the same as to study the impact of output growth, for given output shares of each industry in the aggregate output; indeed

$$\frac{\partial\left(\widetilde{y}_{nt}/Y_t\right)}{\partial Y_t} = 0 \Leftrightarrow \frac{\partial \widetilde{y}_{nt}}{\partial Y_t} = \frac{y_{nt}}{Y_t}.$$

Of course, aggregate elasticities can also be calculated on the basis of any other assumption for $\partial\widetilde{y}_n/\partial Y_t$.

2.4 Elasticities aggregated across labour inputs

Instead of aggregating across industries, we will now consider aggregation across the different labour inputs in order to derive comparative static measures for total labour which is defined as $L^* \equiv \sum_{n=1}^{N}\left(h_n^* + s_n^* + u_n^*\right) = H^* + S^* + U^*$. The derivation of the aggregate elasticities is presented explicitly for the elasticity of labour with respect to output, but the results can directly be adapted for the variables p_{Et}, p_{Mt}, p_{Kt} and t. Since

$$\frac{\partial L^*}{\partial Y_t} = \sum_{n=1}^{N}\sum_{i=h,s,u}\frac{\partial i_n^*}{\partial y_{nt}}\frac{\partial \widetilde{y}_{nt}}{\partial Y_t},$$

making use of assumption (2.5), it follows that

$$\begin{aligned}\epsilon_{LY} &= \frac{\partial L^*}{\partial Y_t}\frac{Y_t}{L^*} = \sum_{n=1}^{N}\sum_{i=h,s,u}\frac{\partial i_n^*}{\partial y_{nt}}\frac{y_{nt}}{Y_t}\frac{Y_t}{L^*} \\ &= \sum_{i=h,s,u}\sum_{n=1}^{N}\epsilon_{iyn}\frac{i_n^*}{L^*} = \sum_{I=H,S,U}\epsilon_{IY}\frac{I^*}{L^*}.\end{aligned}$$

The derivation of the input elasticities with respect to the aggregate wage p_{Lt} is a little more involved. Let us consider the aggregated demand for energy for example (the calculus are similar for capital and material demand):

$$\frac{\partial E^*}{\partial p_{Lt}} = \frac{\sum_{n=1}^{N} \partial e_n^*}{\partial p_{Lt}} = \sum_{n=1}^{N} \sum_{i=h,s,u} \frac{\partial e_n^*}{\partial p_{int}} \frac{\partial \widetilde{p}_{int}}{\partial p_{Lt}}.$$

Since we are interested in the impact of a change in p_{Lt} for a given distribution of disaggregate wages, we compute elasticities on the path were

$$\frac{\partial \widetilde{p}_{int}}{\partial p_{Lt}} = \frac{p_{int}}{p_{Lt}} \tag{2.7}$$

holds for $i = h, s, u$. Therefore,

$$\epsilon_{EP_L} \equiv \frac{\partial E^*}{\partial p_{Lt}} \frac{p_{Lt}}{E^*} = \sum_{n=1}^{N} \sum_{i=h,s,u} \frac{\partial e_n^*}{\partial p_{int}} \frac{p_{int}}{e_n^*} \frac{e_n^*}{E^*} = \sum_{i=h,s,u} \sum_{n=1}^{N} \epsilon_{ep_in} \frac{e_n^*}{E^*} = \sum_{I=H,S,U} \epsilon_{EP_I}.$$

Similarly, for the aggregate own-price elasticity, we have

$$\begin{aligned} \epsilon_{LP_L} &\equiv \frac{\partial L^*}{\partial p_{Lt}} \frac{p_{Lt}}{L^*} = \sum_{i=h,s,u} \left(\sum_{n=1}^{N} \frac{\partial h_n^*}{\partial p_{int}} + \frac{\partial s_n^*}{\partial p_{int}} + \frac{\partial u_n^*}{\partial p_{int}} \right) \frac{\partial \widetilde{p}_{int}}{\partial p_{Lt}} \frac{p_{Lt}}{L^*} \\ &= \sum_{i=h,s,u} \left(\sum_{n=1}^{N} \frac{\partial h_n^*}{\partial p_{int}} \frac{p_{int}}{H^*} \frac{H^*}{L^*} + \sum_{n=1}^{N} \frac{\partial s_n^*}{\partial p_{int}} \frac{p_{int}}{S^*} \frac{S^*}{L^*} + \sum_{n=1}^{N} \frac{\partial u_n^*}{\partial p_{int}} \frac{p_{int}}{U^*} \frac{U^*}{L^*} \right) \\ &= \sum_{I=H,S,U} \left(\epsilon_{HP_I} \frac{H^*}{L^*} + \epsilon_{SP_I} \frac{S^*}{L^*} + \epsilon_{UP_I} \frac{U^*}{L^*} \right). \end{aligned}$$

Note that elasticities which do not involve labour inputs and wages (as ϵ_{EY} and ϵ_{MP_K} for example) remain unaffected by the aggregation across labour inputs. Furthermore, under the assumptions (2.5) and (2.7) taken for our aggregation experiment, symmetry and linear homogeneity will still hold at the aggregate level (over industries and labour inputs). Therefore, the restrictions $\sum_{J=E,K,L,M} \epsilon_{IP_J} = 0$ will still hold for $I = E, K, L, M$.

3. Data

The data sample used consists of cross-section time series on 27 German industries for the period 1978-90. Because energy expenditures and quantities are based on input-output tables available from 1978 onwards and wage data for different types of skills are only available for the period 1975 to 1990, we are unable to use more recent data. The derivation of factor prices and quantities is fully described in the Appendix. A brief summary will suffice here. Data in this study come from different sources.

Our method consists of matching earnings by sector and skill group with employment data. Labour costs per worker are calculated first. Then workers by different types of skills are transformed to full-time equivalents (see Appendix A). Finally, quantity indices are derived by dividing total expenditures by their respective labour cost indices. Information on earnings are taken from the IAB_S for medium and unskilled labour and from Federal Statistical Office (wage and salary statistics) for high-skilled labour. Information on employment by education is taken from the Employment Register of the Federal Labour Office (Bundesanstalt für Arbeit). It contains information on employment by skill category and by industry as at 30 June for all employees paying social security contributions for the 1975-1996 period. Labour is divided into three groups: group 1 is defined as workers with a university or polytechnical degree, group 2 (medium skilled or semi-skilled) is made up of those having completed vocational training as well as technicians and foremen, and the remaining group 3 comprises workers without formal qualifications. The latter group also includes apprentices.

Data are collected for 31 industries. In some industries the number of total workers (respectively total labour costs) reported in the National Accounts does not exactly match total workers paying social security contributions (see Table A1 in Appendix). Since in some industries output and input price are either not available or unreliable, we drop four industries from our sample, leaving us with 27 industries. In particular, tobacco (45), refining (15), aircraft (30) and office machinery (27) are separated out. The gross value of production, gross materials and the net capital stock are obtained from national accounts (see Koebel 1998). Input-output tables are used to split up gross materials into non-energy materials and energy (see Appendix A).

Table 1 presents aggregate cost shares for capital, energy, heterogeneous labour and intermediate materials. Material expenditures accounts for over 60% of the total costs, followed by medium-skilled labour, capital and unskilled labour. The cost-shares of high-skilled labour and energy are fairly small.

Table 1: Aggregate cost shares in manufacturing 1978-1990 (%).

	78	81	84	87	90
high-skilled	1.4	1.5	1.7	2.1	2.2
semi-skilled	16.0	15.4	15.2	16.7	16.4
unskilled	9.9	9.3	8.5	8.7	7.6
capital	7.1	8.8	7.8	7.1	8.1
non-energy materials	62.1	60.4	62.1	62.1	62.7
energy	3.6	4.7	4.7	3.3	3.0

[a] Source: Federal Labour Office, Federal Statistical Office, IAB_S, own calculations.

Table A2 (Appendix B) provides disaggregated cost shares for capital, energy, heterogeneous labour and intermediate materials highlighting the heterogeneity across industries. The cost share for non-energy materials varies between 38% in ceramics to 77% in food and beverages. Cost shares for medium skilled labour varies between 7% in food and beverages and 25% in optical and precision instruments, as well as publishing and printing. The graduates cost share is very small: it varies from 0.4% in food and beverages and 10.4% in air and space. Finally the energy cost share is ranked between 1% in machinery and electrical equipment and 8% in the chemical industry. The cost share suggests that industries which use energy intensively require intensive use of capital (energy intensive industries have a higher capital share).

Figure A1 (see Appendix B) depicts the evolution of quantities and prices for the period 1978-1990. Table 2 gives the corresponding average annual percentage changes in output, input demand and nominal prices. As can be seen from this figure, the quantities of graduates grew at a faster rate than all other inputs. Whereas high-skilled labour jumped by an average annual growth rate of 4.6 percent, medium-skilled labour grew at an annual rate of 1.1 percent. As expected, unskilled labour decreased steadily over time, with an annual rate of 1.6 percent. Capital accumulation is quite moderate, with an increase of 1.0 percent.

The decreasing demand for less qualified labour is matched by relatively stable wages across different types of labour (see Figure 1). During the 1978-1990 period labour costs per workers increased by an average 4.7 percent for graduates, 4.3 for medium-skilled labour and 4.6 for unskilled labour. In contrast, the material deflator increased by only 2.5 percent per year. The energy deflator increased by 3.8 percent. Since relative prices between different types of labour and other input prices are rather similar, it does not seem likely that the substitution pattern could explain a large part of the changes in the labour composition.

Table 2: Annual percentage changes in inputs, output, wage and prices:[a]

Quantities	H	S	U	K	M	E	Y
	4.6	1.1	−1.6	1.0	2.6	−0.3	2.2
Prices	p_H	p_S	p_U	p_K	p_M	p_E	p_Y
	4.7	4.3	4.6	5.3	2.5	3.8	2.7

[a] Average growth rate over the period 1978-1990. Source: Federal Labour Office, Federal Statistical Office, IAB_S, own calculations.

4. Empirical results

For the 1978-1990 period, the factor demand equations for capital, energy, material and the three types of labour are estimated with the iterative SUR method, assuming that vector ν_{nt} has zero mean and constant variance.

4.1 Heterogeneity of slopes

To account for sectoral differences we estimate in a first step model (2.3) for skill and non-skill intensive sectors separately. Following the Gehrke et al. (1995) classification scheme, which is based on the proportion of skilled workers, manufacturing industries are divided into a skill and a non-skill intensive group.[5] Also, all factor demand equations contain an industry dummy. The null hypothesis that the slopes in the factor demand system (2.3) are identical across the two subsamples has been tested. Since the computed value of the chow-test statistic of 1.107 (with 30 and 2019 as degrees of freedom) has a significance level of 0.316,

[5] According to this classification, industries No. 14, 26, 28, 31, 32, 33 should be considered as skill-intensive and the remaining ones as non-skill intensive.

the null cannot be rejected at a meaningful significance level. For this reason, the slopes of (2.3) are assumed to be identical across all industries. Thus, the concavity unrestricted model contains 30 free parameters plus 27×6 industry dummies. A LR test is applied to (2.3) to test for equal intercepts across industries. The computed chi-squared statistic is 6649 which leads to rejection of this hypothesis.

4.2 Concavity of the cost function and own price elasticities

Table 3 presents the results for the price concavity test. Only one eigenvalue out of five non-zero eigenvalues is positive. Moreover the test suggests that the positiveness of the highest eigenvalue is significant. Therefore we reject the assumption of price concavity of the cost function.

Table 3: Test for the price concavity of the cost function

	all industries
Number of positive Eigenvalues	1
Highest eigenvalue[a]	0.55 (3.95)

[a] t-value in parentheses.

Table 4 presents own-price elasticities derived from both concavity unrestricted and restricted models. The concavity restricted results are obtained from the unrestricted estimates through minimum distance, as presented in Koebel (1998). Since the variations over time are not substantial, all price elasticities are evaluated at 1990 values. The corresponding t-statistic are based on White's correction for heteroscedasticity and are given in parentheses.

The first main result is that despite curvature violations, only a few discrepancies can be found between the price elasticities of the two different models. In particular, the ranking in the order of the absolute values of the price elasticity of demand (in absolute value) is not sensitive with respect to imposing curvature conditions. For the own-price elasticities obtained from the unrestricted model, 4 out of the 6 elasticities are statistically significant negative at a five percent level.

Table 4: Own-price elasticities (at 1990 data)[a]

	concavity unrestricted			concavity restricted		
	value	sig. cases	t-stat	value	sig. cases	t-stat
ϵ_{EP_E}	−0.030	27	(−3.1; −2.8)	−0.039	27	(−3.9; −3.5)
ϵ_{HP_H}	−0.048	0	(−1.1; −1.0)	−0.004	0	(−0.1; −0.1)
ϵ_{KP_K}	−0.034	27	(−4.4; −3.9)	−0.042	27	(−5.5; −5.1)
ϵ_{MP_M}	0.004	0	(0.3; 1.6)	−0.007	1	(−2.0; −1.5)
ϵ_{SP_S}	−0.056	27	(−2.4; −2.0)	−0.102	27	(−3.9; −3.7)
ϵ_{UP_U}	−0.276	27	(−4, 0; −3, 7)	−0.270	27	(−3, 9; −3, 7)

[a] Minimum and maximum t-values in parentheses.

As can be seen in Table 4, unskilled labour reacts quite responsively to wage rate changes, with an estimate of −0.28. In contrast, medium-skilled labour is much less responsive to wages: its own-price elasticity is equal to −0.06. The remaining factors are all quite price inelastic and often insignificant at the 5 percent level.

This finding suggests that own wage demand elasticities decrease with skill; a fact that is also found by most previous studies (see Hamermesh 1993). More recently, using aggregate data for France, Sneessens and Shadman-Mehta (1995) also report that the negative effects of wage increases appears to be sharper for unskilled labour than for skilled labour. This result was also found by Fitzroy and Funke (1998) for German manufacturing industries. However, they estimate a rather high value for the own-wage elasticity for unskilled labour of −1.00.

4.3 Cross-price elasticities

To measure factor substitution possibilities, we compute cross-price elasticities for the unrestricted (Table 5) and the concavity restricted model. In addition, the Morishima elasticities of substitution (MES) are calculated for selected input pairs (see Table 6).[6] For the concavity unrestricted model, out of 30 cross-price elasticities only 12 are significant at the 5 percent level. For the concavity re-

[6] Morishima elasticities of substitution provide a measure of changes in the input quantity ratio with respect to input price ratios.

stricted model the number of significant cross-price elasticities is slightly smaller.

The cross price elasticities between the three types of labour and the remaining factors are generally quite small and often not significantly different from zero. This means that the production structure is rather rigid, since inputs cannot be easily substituted the one against the other.

The dominant substitutability relationship concerns medium and unskilled labour. The value of cross-price elasticity of unskilled with respect to medium-skilled labour price, ϵ_{UP_S}, is 0.27. MES estimates for these factors is 0.4 when the price for unskilled labour changes and 0.3 when the price of medium skilled labour changes (Table 6). The result here is consistent with Steiner and Mohr (1998), who find that the aggregate elasticity of substitution between unskilled and medium skilled labour is around 0.3. The cross-price elasticities also are not very sensitive with respect to curvature conditions. For instance, using the concavity restricted model the cross-price elasticity between skilled and unskilled labour, ϵ_{UP_S}, slightly decrease from 0.27 to 0.23. The substitution elasticity between high-skilled and unskilled labour is not significant. Significant pairwise substitutability relationships can also be found between energy and capital, energy and materials, and material and capital. The cross-price elasticity between energy and capital is significantly positive in all industries, indicating that they are substitutes. A similar result is also found in most other previous studies for the US and Canada (see Thompson and Taylor, 1995).

Some complementary relationships can be found between energy and unskilled labour. However, the cross-price elasticity is very small in absolute value, with an estimate of -0.018 for ϵ_{UP_E}. The MES between unskilled labour and energy is close to zero, when the price of energy changes and 0.23 when the price of unskilled labour adjusts.[7] Turning to capital-skill complementarity, we find only little evidence for this assumption. Estimates of the cross-price elasticities between different types of labour and capital do not indicate that unskilled labour is more substitutable to capital than the upper skill levels.

Given the small and often insignificant cross-price elasticities between labour

[7] A pair of inputs which are complements based on cross-price elasticities do not necessarily have to be Morishima complements.

Table 5: Cross price elasticities (at 1990 data)[a]

	concavity unrestricted			concavity restricted		
	value	sig. cas.	t-stat	value	sig. cas.	t-stat
ϵ_{EP_H}	-0.001	0	$(-0.6; -0.5)$	-0.000	0	$(-0.2; -0.1)$
ϵ_{EP_K}	0.030	27	$(3.1; 4.6)$	0.033	27	$(3.3; 4.8)$
ϵ_{EP_M}	0.056	27	$(2.3; 3.0)$	0.014	0	$(0.3; 0.9)$
ϵ_{EP_S}	-0.013	0	$(-0.7; -0.5)$	0.033	0	$(1.4; 1.6)$
ϵ_{EP_U}	-0.042	27	$(-3.1; -2.6)$	-0.040	27	$(-3.0; -2.5)$
ϵ_{HP_E}	-0.002	0	$(-0.6; -0.5)$	-0.001	0	$(-0.2; -0.1)$
ϵ_{HP_K}	-0.013	0	$(-1.1; -1.0)$	-0.009	0	$(-0.8; -0.7)$
ϵ_{HP_M}	0.014	0	$(0.6; 1.2)$	0.009	0	$(0.2; 0.7)$
ϵ_{HP_S}	0.018	0	$(0.3; 0.3)$	-0.048	0	$(-0.9; -0.8)$
ϵ_{HP_U}	0.031	0	$(0.7; 0.7)$	0.053	0	$(1.2; 1.3)$
ϵ_{KP_E}	0.012	27	$(3.8; 4.6)$	0.013	27	$(4.2; 4.9)$
ϵ_{KP_H}	-0.004	0	$(-1.1; -1.0)$	-0.002	0	$(-0.8; -0.7)$
ϵ_{KP_M}	0.052	27	$(3.8; 4.4)$	0.035	27	$(2.5; 3.0)$
ϵ_{KP_S}	-0.021	1	$(-2.1; -1.6)$	-0.013	0	$(-1.3; -1.0)$
ϵ_{KP_U}	-0.007	0	$(-0.6; -0.2)$	0.009	0	$(0.6; 0.9)$
ϵ_{MP_E}	0.003	27	$(2.2; 2.6)$	0.001	0	$(0.3; 0.9)$
ϵ_{MP_H}	0.001	0	$(0.6; 1.1)$	0.000	0	$(0.2; 0.7)$
ϵ_{MP_K}	0.007	27	$(3.8; 4.4)$	0.005	27	$(2.5; 3.1)$
ϵ_{MP_S}	-0.017	27	$(-4.2; -3.4)$	-0.002	0	$(-1.1; -0.1)$
ϵ_{MP_U}	0.002	0	$(0.1; 1.3)$	0.003	0	$(0.4; 1.4)$
ϵ_{SP_E}	-0.003	0	$(-0.7; -0.5)$	0.007	0	$(1.4; 1.6)$
ϵ_{SP_H}	0.002	0	$(0.3; 0.3)$	-0.007	0	$(-0.9; -0.8)$
ϵ_{SP_K}	-0.011	1	$(-2.1; -1.6)$	-0.007	0	$(-1.3; -1.0)$
ϵ_{SP_M}	-0.066	27	$(-4.2; -3.4)$	-0.008	0	$(-1.1; -0.1)$
ϵ_{SP_U}	0.133	27	$(4.8; 5.1)$	0.117	27	$(4.2; 4.4)$
ϵ_{UP_E}	-0.018	27	$(-3.0; -2.6)$	-0.017	27	$(-2.9; -2.5)$
ϵ_{UP_H}	0.009	0	$(0.7; 0.7)$	0.016	0	$(1.2; 1.3)$
ϵ_{UP_K}	-0.007	0	$(-0.6; -0.2)$	0.010	0	$(0.6; 0.9)$
ϵ_{UP_M}	0.019	0	$(0.1; 1.3)$	0.028	0	$(0.4; 1.4)$
ϵ_{UP_S}	0.274	27	$(4.7; 5.1)$	0.234	27	$(4.1; 4.4)$

[a] Minimum and maximum t-values in parentheses.

and non-labour inputs, none of these factor price changes make a large contribution towards explaining the shift in demand away from unskilled and towards skilled labour.

Table 6: Morishima elasticities of substitution (at 1990 data)[a]

	concavity unrestricted	concavity restricted
σ_{EK}	0.043	0.053
σ_{KE}	0.064	0.075
σ_{EU}	0.012	0.022
σ_{UE}	0.234	0.230
σ_{SU}	0.330	0.336
σ_{US}	0.409	0.387

[a] Significant at the 5 percent level in all cases.

4.4 Output elasticities and impact of time

Table 7 presents time and output elasticities.[8] All elasticities are evaluated using 1990 data. These elasticities are, in most cases significant at the five percent level. The output elasticity for different types of labour is increasingly positive with rising skill levels ($\epsilon_{HY} > \epsilon_{SY} > \epsilon_{UY}$). This result here is consistent with Fitzenberger and Franz (1998) who find that output changes monotonously favour demand for higher skill levels. Whereas, high-skilled labour is quite responsive to output variation, the output elasticity for workers without any degree is rather small ($\epsilon_{UY} = 0.48$).

Calculations for the impacts of time are also given in Table 7. For given output and prices, unskilled labour is decreasing over time, by an annual rate of 0.9%. The time elasticities do not vary much over time: the corresponding value of ϵ_{Ut} for 1978 is similar. However, the interpretation of the impacts of time is delicate. Indeed, they may pick up effects others than technical progress, such as changing skill composition due to skill-upgrading.

Finally, elasticities aggregated across labour inputs (Table 8) are computed

[8] Given our two-step estimation procedure, the output elasticities and the impact of time stay almost unaffected by the concavity restrictions.

Table 7: Output and time elasticities (at 1990 data)[a]

	value	sig. cases	t-stat
Time elasticities			
ϵ_{Ct}	0.000	1	$(-2.1; 1.4)$
ϵ_{Et}	-0.003	22	$(-5.3; 0.0)$
ϵ_{Ht}	0.002	27	$(6.1; 8.1)$
ϵ_{Kt}	0.000	4	$(-2.1; 1.3)$
ϵ_{Mt}	0.002	27	$(2.0; 3.2)$
ϵ_{St}	-0.002	22	$(-4.7; -0.2)$
ϵ_{Ut}	-0.009	27	$(-12.2; -4.2)$
Output elasticities[b]			
ϵ_{CY}	0.908	24	$(0.0; 14.3)$
ϵ_{EY}	0.575	27	$(4.9; 10.3)$
ϵ_{HY}	0.908	27	$(5.6; 18.2)$
ϵ_{KY}	0.736	27	$(13.0; 20.4)$
ϵ_{MY}	1.052	27	$(22.5; 82.4)$
ϵ_{SY}	0.658	27	$(14.9; 26.5)$
ϵ_{UY}	0.475	27	$(5.8; 7.6)$

[a]Maximum and minimum t-values in parentheses.

[b]t-statistics for the null hypothesis that $\epsilon_{CY} = 1$ (constant return to scale) and $\epsilon_{JY} = 0$ for $J = E, H, K, M, S, U$.

Table 8: Elasticities aggregated across labour

	concavity unrestricted		concavity restricted	
	value	sig. cases / total cases	value	sig. cases / total cases
ϵ_{LP_E}	-0.007	27/81	0.000	27/81
ϵ_{LP_K}	-0.010	1/81	-0.002	0/81
ϵ_{LP_L}	0.052	108/243	-0.001	108/243
ϵ_{LP_M}	-0.036	27/81	0.004	0/81
ϵ_{EP_L}	-0.056	27/81	-0.008	27/81
ϵ_{KP_L}	-0.031	1/81	-0.006	0/81
ϵ_{MP_L}	-0.014	27/81	0.002	0/81
ϵ_{Lt}	-0.004	49/81	-0.004	49/81
ϵ_{LY}	0.626	81/81	0.630	81/81

according to the formulas derived in section 2.4. Three important points should be remarked. First, since only one out of 15 price elasticities is higher than 0.1 (Table 5) the absolute value of the aggregate price elasticities are rather small. This underlines that substitution between inputs is limited. The imposition of concavity does not have a great impact on the aggregate price elasticities. Second, the aggregate own price elasticity is not significantly different from zero. This is related to the fact that the main substituability relationships occur within the different types of labour rather than between labour and the remaining inputs. Third, the negative cross-price elasticity between aggregate labour and energy suggests that labour is complementary to energy.

4.5 Decomposition of factor demand growth

The observed change in factor demand can be explained by factor substitution, changes in output and the residual time trend. These effects can be separated by total differentiation of the labour demand equations and the following transformation into growth rates

$$\begin{aligned} \Delta\tilde{I}_t &\simeq \sum_{J=M,K,H,S,U} \frac{\partial I^*}{\partial p_{Jt}}\Delta p_{Jt} + \frac{\partial I^*}{\partial Y_t}\Delta Y_t + \frac{\partial I^*}{\partial t} \\ \Leftrightarrow \frac{\Delta\tilde{I}_t}{\tilde{I}_t} &\simeq \sum_{J=M,K,H,S,U} \varepsilon_{Ip_J}\frac{\Delta p_{Jt}}{p_{Jt}} + \varepsilon_{IY}\frac{\Delta Y_t}{Y_t} + \varepsilon_{It}, \quad I = H, S, U. \end{aligned}$$

where $\Delta\tilde{I}_t/\tilde{I}_t$ denotes the predicted percentage change in the three types of labour ($\tilde{I}_t = \widetilde{H}_t, \widetilde{S}_t, \widetilde{U}_t$). First, aggregate changes in the exogenous variables for the period 1978-90 are computed. Second, we use the estimated aggregate elasticities and compute the change in factor demand that we would expect from changes in the right hand variables. The first term on the right side measures the price and substitution effect, the second term the output effect and the last term denotes the impact of time. Note that the above decomposition is based on *first order* approximation, and is only precise for small Δp_{Jt} and ΔY_t. Whereas a second order approximation would be more precise, the separate identification of the impact of price, output and time would then no be longer possible.

The results of the decomposition analysis appear in Table 9. Since the predictions based on concavity restricted elasticities are quite similar, we only report predictions based on unrestricted elasticities. Column two and three give the observed and predicted change for the three types of labour. The three final columns show the decomposition analysis. As can seen from Table 9, the predicted change is close to the observed one except for unskilled labour. For instance, the increase in the level of semi-skilled labour is 1.1 percent which is close to the prediction of 1.3 percent.

Table 9: Determinants of employment by skill classes (percentages)

	actual change	predicted change	% change attributable to:[a] Price	Output	Time
unskilled labour	−1.6	−0.1	−0.1	0.9	−0.9
semi-skilled labour	1.1	1.3	0.2	1.4	−0.2
high-skilled labour	4.6	2.6	0.0	2.3	0.4

[a] Average growth rates and elasticities over the period 1978-1990. Insignificant price elasticities are not included.

As can seen in Table 9, price effects play a minor role explaining the employment changes of the three types of labour. This suggests that wage compression is a very small factor explaining the shift away from unskilled labour. In contrast, for all types of labour except unskilled labour, it is evident from column four and five that output is the major contributor to the shift in labour composition. In particular, 89 % of the increasing demand for graduates can be explained by output growth. The main cause of the decline in low-skill labour demand is the time effect.

5. Conclusion

Determinants of factor demand were estimated using concavity unrestricted and restricted models. In particular, we investigated the role of the substitution effect on the shift in labour composition. We use cross-section time series for 27 manufacturing industries for the period 1978-1990. Even though price concavity is rejected, the different price elasticities obtained from the restricted estimates were quite similar from those of the unrestricted estimates. Pairwise substitution dominates between medium and unskilled labour, energy and capital, energy and materials as well as materials and capital. In particular, the substitutability is stronger between skilled and unskilled labour than any other pair of inputs. Some complementarity is found between energy and unskilled labour. Furthermore, the demand for unskilled labour is more price-elastic than any other factor included in the model. However, the substitution pattern as well as the price effect do not explain observed changes in the different types of labour. The dominant factor explaining the shift against unskilled labour and towards skilled labour is the output effect which is increasingly positive with rising skills.

This study is restricted to the manufacturing sector. As such the results and implications are not necessarily transferable to the overall economy. Further research needs to be done in this area. First, we could expand the coverage to more industries. Second, the distinction between domestic and imported materials could help to determine the exact impact of trade on the employment demand for different types of skills.

References

[1] Basu S. and J. G. Fernald, 1997, 'Returns to Scale in U.S. Production: Estimates and Implications', *Journal of Political Economy,* 105, pp.249-283.

[2] Bender, S., J. Hilzendegen, G. Rohwer and H. Rudolph, 1996, *Die IAB-Beschäftigtenstichprobe 1975 - 1990*, Beiträge zur Arbeitsmarkt- und Berufsforschung, 197, Institut für Arbeitsmarkt und Berufsforschung der Bundesanstalt für Arbeit.

[3] Beissinger T. and J. Möller, 1998, 'Wage Flexibility and Employment Performance: A Microdata Analysis of Different Age-Education Groups for Germany, Regensburger Diskussionsbeiträge 307.

[4] Bergström V. and E. E. Panas, 1992, 'How Robust is the Capital-Skill Complementarity Hypothesis?', *Review of Economics and Statistics,* 74, pp.540-552.

[5] Berman E., J. Bound and Z. Griliches, 1994, 'Changes in the Demand for Skilled Labor within US Manufacturing, Evidence from the Annual Survey of Manufactures', *Quarterly Journal of Economics,* 109, pp.367-397.

[6] Betts J. R., 1997, 'The Skill Bias of Technological Change in Canadian Manufacturing Industries', *Review of Economics and Statistics,* 79, pp.146-150.

[7] Draper N. and T. Manders, 1996, 'Structural Changes in the Demand for Labour', Netherlands Bureau for Economic Policy Analysis, The Hague, June 1996.

[8] Diewert W. E. and T. J. Wales, 1987, 'Flexible Functional Forms and Global Curvature Conditions', *Econometrica,* 55, pp.47-68.

[9] Fitzenberger B., 1996, 'Wages, Prices and International Trade, Trends across Industries for an Export Champion', Universität Konstanz *Diskussionspapier* Serie II - Nr. 323.

[10] Fitzenberger B. and W. Franz, 1998, 'Flexibilität der qualifikatorischen Lohnstruktur und Lastverteilung der Arbeitslosigkeit: Eine ökonometrische Analyse für Westdeutschland', In: Gahlen. B., H. Hesse. H. and H.J. Ramser, *Zunehmende Ungleichheit? — Erklärungen und Konsequenzen.* Tübingen: J.C.B. Mohr.

[11] Fitzroy F. and M. Funke, 1995, 'Capital-Skill Complementarity in West German Manufacturing', *Empirical Economics,* 20, pp.651-665.

[12] Fitzroy F. and M. Funke, 1998, 'Skills, Wages and Employment in East and West Germany', *Regional Studies,* 32, 5, pp.459-467.

[13] Gagne R. and P. Ouellette, 1998, 'On the Choice of Functional Forms: Summary of a Monte Carlo Experiment', *Journal of Business & Economic Statistics*, 16, pp.118-124.

[14] Gehrke B., H. Legler, U. Schasse and F. Wagner, 1995, 'Wissensintensive Wirtschaft und ressourcenschonende Technik. Abgrenzung der Ressourcen', NIW, Hannover.

[15] Härdle W., W. Hildenbrand and M. Jerison, 1991,'Empirical Evidence on the Law of Demand', *Econometrica*, 59, pp.1525-1549.

[16] Hamermesh D. S., 1993, *Labor Demand*, Princeton: Princeton University Press.

[17] Koebel B., 1998, 'Tests of Representative Firm Models: Results for German Manufacturing Industries', *Journal of Productivity Analysis*, 10, pp.251-270.

[18] Kodde D. A. and F. C. Palm, 1987, 'A Parametric Test of the Negativity of the Substitution Matrix', *Journal of Applied Econometrics,* 2, pp. 227-235.

[19] Kugler P., U. Müller and G. Sheldon, 1989, 'Non-Neutral Technical Change, Capital, White-Collar and Blue-Collar Labor', *Economics Letters,* 31, pp.91-94.

[20] Nissim J., 1984, 'The Price Responsiveness of the Demand for Labour by Skill: British Mechanical Engineering 1963-1978', *Economic Journal,* 94, pp.812-825.

[21] Sneessens H. and F. Shadman-Mehta, 1995, 'Skill Demand and Factor Substitution', *CEPR Discussion paper* 1279, London.

[22] Steiner V. and K. Wagner, 1997, 'Relative Earnings and the Demand for Unskilled Labour in West German Manufacturing', *ZEW Discussionpaper,* 97-17, Mannheim.

[23] Steiner V. and R. Mohr, 1998, 'Industrial Change, Stability of Relative Earnings and Substitution of Unskilled Labour in West Germany', *ZEW-Discussion Paper,* 98-22, Mannheim.

[24] Thompson P. and T.G. Taylor, 1995, 'The Capital-Energy Substitutability Debate: A new look', *Review of Economics and Statistics,* 77, pp.565-569.

Appendix A: Data description

Wages and employment for different skill groups. Information on earnings for unskilled and medium-skilled labour is taken from the IAB_S, a 1% random sample of all persons covered by the social security system. This amounts to 200,000 individual workers for each year between 1975-1990.[9] Wages are measured as daily gross wages excluding employers social security contribution. In the first step, median earnings are calculated by each manufacturing sector and skill groups. The sample is limited to full-time workers. For manufacturing industries between 66,995 and 74,708 annual observations were used to calculate wages. In the second step the industry classification based on the IAB_S is matched together with the two-digit national accounts classification. Following Bender et al. 1996, annual wages are calculated by multiplying daily wages with the average number of *calendar days* (= 30) and then by multiplying by 12. Finally, non-wage labour costs measured as a percentage of gross wage are added to annual gross wage. One problem of the IAB_S is a structural break in the data (see Steiner and Wagner 1997): from 1984 onwards, more and more income components are added to labour earnings. However, comparing wages

[9] For applications using IAB_S data, see Beissinger and Möller (1998), Fitzenberger (1996), Fitzenberger and Franz (1998) and Steiner and Mohr (1998).

drawn from the wage and salary statistics with IAB_S data we find no differences between these two data sources. Since in the IAB_S data, monthly gross earnings for graduates are censored to the right we take earnings for high-skilled workers from the wage and salary statistics. The highest skill group refers to "professional and managerial workers" (category II white-collar). Earnings for high-skilled labour are converted into labour costs by adding the employers social security contribution.

Labor input by education is constructed in multiple steps. For approximately 5% of the employees, the occupational degree is not available (see Table 8). In the first step, two thirds of these workers were added to the unskilled group and one third to the skilled group. In a second step, labour is transformed to full-time equivalent employees. Part-time workers and trainees are weighted by one half.[10] We then check the sum of the three different types of labour costs against total labour costs obtained from the national accounts. Labour costs calculated at the sector level cover between 90-100 percent of total labour costs reported in the national accounts. Finally, wages are transformed to wage indices normalised to unity in 1978. These transformations generate p_{hnt}, p_{snt} and p_{unt}. The final labour input is obtained by dividing total labour costs by the respective wage indices.

In both data sources, annual average working hours are not available for the three skill groups. For assessing the stability of our results with respect to the measure of the labour quantity and price indices (number of workers versus man-hours), we also use data from the German microcensus, which reports average hours worked per week for every two years. Alternative labour input and labour costs are calculated using interpolated data for working hours. However, since the elasticities are not sensitive to changes in the definition of employment we did not use man-hours.

Energy and non-energy materials. Data on energy are not available in the National accounts. However, energy expenditures and quantities (measured in

[10] Since wages of apprentices do not necessarily reflect their marginal productivity, they should actually be excluded. We still included apprentices in the the group (or category) of unskilled labour as estimation results proved to be not sensitive anyway.

terajoule) based on the input-output classification have been provided by the Federal Statistical Office.[11] We use this information for splitting up gross materials into non-energy materials and energy. The data from the two sources (input-output tables and national accounts) are, however, not directly comparable.[12] For this reason the following adjustments have been made to make energy data based on input-output tables consistent with national accounts:

$$
\begin{aligned}
(p_e e)^{NA}_{n,78} &= (p_e e)^{IO}_{n,78} \times \frac{(p_y y)^{NA}_{n,78}}{(p_y y)^{IO}_{n,78}}, \\
(p_e e)^{NA}_{nt} &= (p_e e)^{IO}_{nt} \times \frac{(p_e e)^{NA}_{n,78}}{(p_e e)^{IO}_{n,78}}, \quad t = 78, \ldots, 90.
\end{aligned}
$$

The assumption underlying this approximation is that the output discrepancies between the two sources do not change over the period.[13] Energy deflators $p^{IO}_{en,t}$ are derived by dividing energy expenditures $(p_e e)^{IO}_{nt}$ by an indice for energy quantities e^{IO}_{nt} (also based on the input-output classification). $p^{IO}_{en,t}$ is normalized to one in 1978, and is assumed to be identical with $p^{NA}_{en,t}$. Finally, the quantity index for energy e^{NA}_{nt} is derived by dividing total expenditures by the energy price index:

$$
e^{NA}_{nt} = \frac{(p_e e)^{NA}_{n,t}}{p^{IO}_{en,t}}.
$$

Non-energy material expenditures (respectively quantities) are calculated by subtracting energy expenditures from material expenditures (respectively quantities). The deflator for non-energy materials is calculated by dividing non-energy material expenditures by their respective quantities.

[11] Annual energy data based on Input-Output classification 1978-1990, unpublished data.

[12] There are three main differences between the national accounts and input-output concepts. In the national accounts, output does not include intra-firm trade. Furthermore, in the national accounts, output of trade is presented on a gross basis including the value of merchandise. The main difference between the two sources, is that the sectoral breakdown in the national accounts is mainly based on institutional units (establishment concept). Firms are classified into a given industry according to their main activity. In contrast, according to the input-output concept, outputs are broken down by commodity groups.

[13] These discrepencies between $(p_y y)^{NA}_{n,78}$ and $(p_y y)^{IO}_{n,78}$ are negligible for 26 out of 31 industries. Only for petroleum processing, iron and Steel, Foundry, Office and Data processing, printing and publishing some discrepencies were observed.

User costs of capital. The user costs of capital are computed using the investment price $p_{\triangle knt}$, the nominal interest rate r_t and the depreciation rate δ_{nt}:

$$p_{knt} = (1 + r_t)\, p_{\triangle knt} - (1 - \delta_{nt})\, p_{\triangle knt+1}.$$

The depreciation rate is calculated as $\delta_{nt} = 1 - (k_{nt} - \Delta k_{nt})/k_{nt-1}$, where Δk_{nt} denotes gross investment at constant prices. Annual interest rates are drawn from the Deutsche Bundesbank (long-term interest rate for public sector bonds).

Appendix B: Descriptive statistics

Table A1: Labour by different types of skills (1990):

No	sector	total workers, ths national accounts	social security st.
14	Chemical products	641	649
15	Petroleum processing	26	24
16	Synthetic material	312	305
17	Rubber	117	110
18	Stone and earth products	179	182
19	Fine ceramics	51	55
20	Glass	73	71
21	Iron and steel	201	204
22	Non-ferrous metals	76	78
23	Foundry	106	113
24	Fabricated Metals	276	262
25	Steel, light metal and tracked vehicles	185	197
26	Machinery	1196	1243
27	Office and data processing	101	84
28	Vehicles and repairs	1019	1056
29	Shipbuilding	36	37
30	Aircraft and spacecraft	66	66
31	Electrical machinery	1222	1121
32	Precision and optical instruments	215	220
33	Metal products	372	383
34	Musical instruments	68	52
35	Wood	46	43
36	Wood processing	318	305
37	Pulp, paper and board products	58	66
38	Paper and articles of paper	130	109
39	Printing and duplicating	246	235
40	Textile	55	67
41	Leather	230	235
42	Clothing	203	186
43/44	Food and beverages	742	686
45	Tobacco	16	15

Source: Federal Labour Statistics, IABS, own calculations.

composition in %				apprenti-	part-time in %		
H	S	U	degree n.a.	cies in %	H	S	U
social security statistics					IAB$_S$		
9.4	61.4	26.0	3.2	4.2	1.1	4.3	6.8
11.0	69.9	16.7	2.5	2.6	0.0	5.4	8.3
2.6	49.5	41.8	6.1	3.3	1.5	3.3	4.5
3.9	47.2	44.1	4.7	2.7	0.0	4.1	1.4
2.9	58.3	31.5	7.2	3.4	4.7	4.4	3.0
2.8	42.2	51.9	3.0	4.5	0.0	6.4	7.8
3.4	51.9	41.1	3.7	3.4	0.0	2.4	3.6
3.5	56.8	33.7	6.0	4.5	0.0	1.2	1.0
3.7	57.2	36.5	2.6	4.2	0.0	2.4	2.3
1.8	48.5	44.8	4.9	3.8	0.0	2.3	1.6
1.7	53.2	39.4	5.7	4.8	0.0	0.4	1.2
4.1	70.0	21.2	4.7	6.2	0.0	2.4	3.0
5.5	70.3	21.8	2.3	6.6	0.3	2.3	4.1
17.4	53.1	22.7	6.8	4.4	0.0	4.3	7.7
4.0	62.6	30.2	3.2	2.8	0.8	1.7	2.5
5.2	70.9	18.0	6.0	9.0	0.0	1.2	1.5
21.9	65.2	12.7	0.3	1.3	0.0	3.0	3.8
10.2	54.0	32.1	3.7	4.1	1.0	3.7	6.7
4.6	62.6	29.6	3.2	7.7	2.2	4.3	6.0
2.2	54.1	39.4	4.2	3.7	2.5	2.7	3.9
1.1	54.2	38.2	6.5	3.6	0.0	6.5	12.3
1.1	47.3	46.7	4.9	2.9	7.1	1.9	2.4
1.1	61.1	33.3	4.5	9.2	0.0	3.0	3.9
3.6	55.5	38.7	2.2	2.4	0.0	5.1	6.6
1.9	47.1	44.7	6.2	3.1	0.0	3.3	4.2
1.7	66.1	25.4	6.8	5.6	0.0	6.3	11.3
0.9	45.6	48.5	5.0	4.2	0.0	9.7	8.3
1.8	43.8	48.6	5.8	1.4	0.0	8.2	1.3
0.7	54.9	38.1	6.2	5.7	0.0	10.8	14.6
1.4	60.0	32.3	6.3	15.0	0.0	5.6	5.5
5.5	56.0	35.4	3.1	1.3	0.0	2.4	9.4

Table A2: Cost-shares (sector number in parentheses)

	year	E	H	K	M	U	S
Chemical Products (14)	78	9.4	2.2	9.2	59.6	7.1	12.5
	84	13.7	2.4	8.2	57.8	5.7	12.2
	90	8.0	3.6	9.8	58.6	5.2	14.8
Petroleum Processing (15)	78	77.2	0.3	6.3	13.4	0.8	1.9
	84	76.7	0.3	3.7	17.8	0.3	1.2
	90	49.6	0.4	3.9	43.9	0.3	1.8
Synthetic Material (16)	78	2.4	0.9	7.2	58.5	15.0	16.0
	84	2.7	1.0	7.4	63.8	11.2	13.9
	90	2.5	1.4	8.4	62.6	10.4	14.7
Rubber (17)	78	4.0	1.2	8.6	56.4	15.6	14.2
	84	4.4	1.4	8.5	58.9	13.4	13.4
	90	3.0	2.1	8.9	59.5	12.1	14.5
Stone and Earth Products (18)	78	9.8	0.8	12.0	51.9	10.8	14.7
	84	11.3	0.9	11.7	52.9	8.9	14.4
	90	7.9	1.2	11.6	55.8	8.2	15.2
Fine Ceramics (19)	78	8.4	1.7	9.6	32.0	28.5	19.9
	84	10.0	2.0	10.9	33.8	24.0	19.3
	90	6.0	2.6	11.3	38.3	21.5	20.3
Glass (20)	78	10.1	1.2	10.5	46.4	16.7	15.1
	84	15.6	1.2	12.0	44.5	12.6	14.1
	90	8.2	1.7	13.1	51.5	10.6	14.9
Iron and Steel (21)	78	6.8	1.0	11.7	58.2	9.7	12.6
	84	8.3	1.0	12.8	58.9	7.8	11.3
	90	7.0	1.3	11.2	58.5	8.0	14.0
Non-Ferrous Metals (22)	78	7.4	0.6	7.0	68.9	7.6	8.5
	84	7.6	0.6	6.2	72.8	5.3	7.5
	90	6.2	0.8	7.1	71.3	5.2	9.4
Foundry (23)	78	5.5	1.0	9.1	44.3	20.2	20.0
	84	7.7	1.0	9.5	47.0	16.6	18.2
	90	5.0	1.1	9.5	47.2	17.4	19.7

continued Table A2

	year	E	H	K	M	U	S
Fabricated Metal (24)	78	2.7	0.6	7.0	60.4	14.0	15.4
	84	3.3	0.7	7.7	59.1	12.8	16.4
	90	2.6	0.9	7.4	58.8	12.0	18.3
Steel, Light Metal and Tracked Vehicles (25)	78	1.5	1.4	4.0	64.8	7.7	20.7
	84	2.1	2.1	5.7	56.9	8.1	25.1
	90	1.2	2.3	5.1	59.9	6.9	24.5
Machinery (26)	78	1.4	2.2	5.7	57.5	8.8	24.4
	84	1.7	2.6	6.5	57.2	7.7	24.3
	90	1.2	3.1	6.5	57.9	6.5	24.8
Office and Data Processing (27)	78	1.7	6.6	16.3	53.2	6.8	15.4
	84	1.7	5.5	13.1	64.9	3.9	10.9
	90	1.7	5.8	11.5	66.1	3.6	11.4
Vehicles and Repairs (28)	78	1.7	0.9	5.9	64.4	8.6	18.5
	84	1.8	1.3	7.8	64.0	9.4	15.6
	90	1.3	1.6	7.7	66.7	7.2	15.6
Shipbuilding (29)	78	1.6	1.8	6.7	55.7	9.3	24.9
	84	1.6	1.8	7.8	60.4	7.6	20.7
	90	1.3	2.3	6.7	64.6	5.4	19.8
Aircraft and Spacecraft (30)	78	1.4	9.9	5.1	51.1	6.6	25.9
	84	1.4	9.3	7.2	54.8	4.7	22.6
	90	1.0	10.4	7.1	58.6	3.3	19.5
Electrical Machinery (31)	78	1.5	3.9	5.9	57.4	12.3	19.0
	84	1.8	4.9	6.9	59.0	9.5	17.8
	90	1.2	5.7	7.7	60.0	8.0	17.4
Precision and Optical Instruments (32)	78	1.6	1.9	5.3	52.1	14.5	24.7
	84	1.8	2.4	6.6	52.4	11.6	25.2
	90	1.3	3.4	7.2	53.0	9.6	25.5
Metal Products (33)	78	2.1	0.8	6.6	56.9	14.9	18.6
	84	2.5	1.0	7.5	58.6	12.5	17.9
	90	1.9	1.2	7.7	59.6	11.2	18.3
Musical Instruments (34)	78	1.9	0.4	6.5	64.6	11.6	15.1
	84	2.0	0.5	8.6	63.1	10.2	15.6
	90	1.8	0.6	9.6	65.1	8.3	14.6

continued Table A2

	year	E	H	K	M	U	S
Wood (35)	78	4.8	0.2	9.5	66.6	10.5	8.3
	84	5.2	0.3	10.2	65.1	9.4	9.8
	90	4.3	0.4	10.4	66.0	8.9	10.1
Wood Processing (36)	78	2.0	0.4	5.9	60.9	12.6	18.3
	84	2.4	0.5	7.1	59.6	11.3	19.0
	90	1.8	0.6	6.2	61.5	9.9	20.0
Pulp, Paper and Board (37)	78	11.5	1.0	12.2	56.6	8.7	9.9
	84	13.7	1.0	10.6	60.6	6.1	8.1
	90	11.2	1.3	13.5	59.5	5.2	9.3
Paper and Articles of Paper (38)	78	2.0	0.5	8.1	64.2	13.1	12.2
	84	2.6	0.5	8.7	67.0	10.5	10.7
	90	1.7	0.7	8.6	69.5	8.7	10.9
Printing and Duplicating (39)	78	1.5	0.8	8.9	50.1	10.0	28.8
	84	1.9	0.9	10.4	51.2	8.8	26.8
	90	1.6	1.0	10.1	52.4	8.7	26.2
Leather (40)	78	1.5	0.2	6.8	61.9	17.4	12.2
	84	1.7	0.3	6.9	64.5	15.0	11.5
	90	1.3	0.5	7.4	65.4	12.4	13.1
Textiles (41)	78	3.2	0.6	8.9	59.6	15.3	12.6
	84	4.1	0.7	9.1	61.0	13.3	11.8
	90	3.4	0.9	9.8	61.5	11.8	12.7
Clothing (42)	78	1.1	0.3	3.9	68.5	12.6	13.6
	84	1.4	0.3	4.4	70.3	10.2	13.3
	90	1.0	0.4	4.3	73.7	7.9	12.7
Food and Beverages (43/44)	78	2.6	0.2	5.9	78.7	4.7	7.8
	84	3.1	0.3	6.5	78.0	4.7	7.4
	90	2.4	0.4	7.5	76.5	4.6	8.6
Tobacco (45)	78	1.6	0.8	0.8	79.7	6.5	10.7
	84	1.6	1.0	1.5	82.0	5.4	8.5
	90	1.1	1.2	1.8	86.3	2.3	7.2

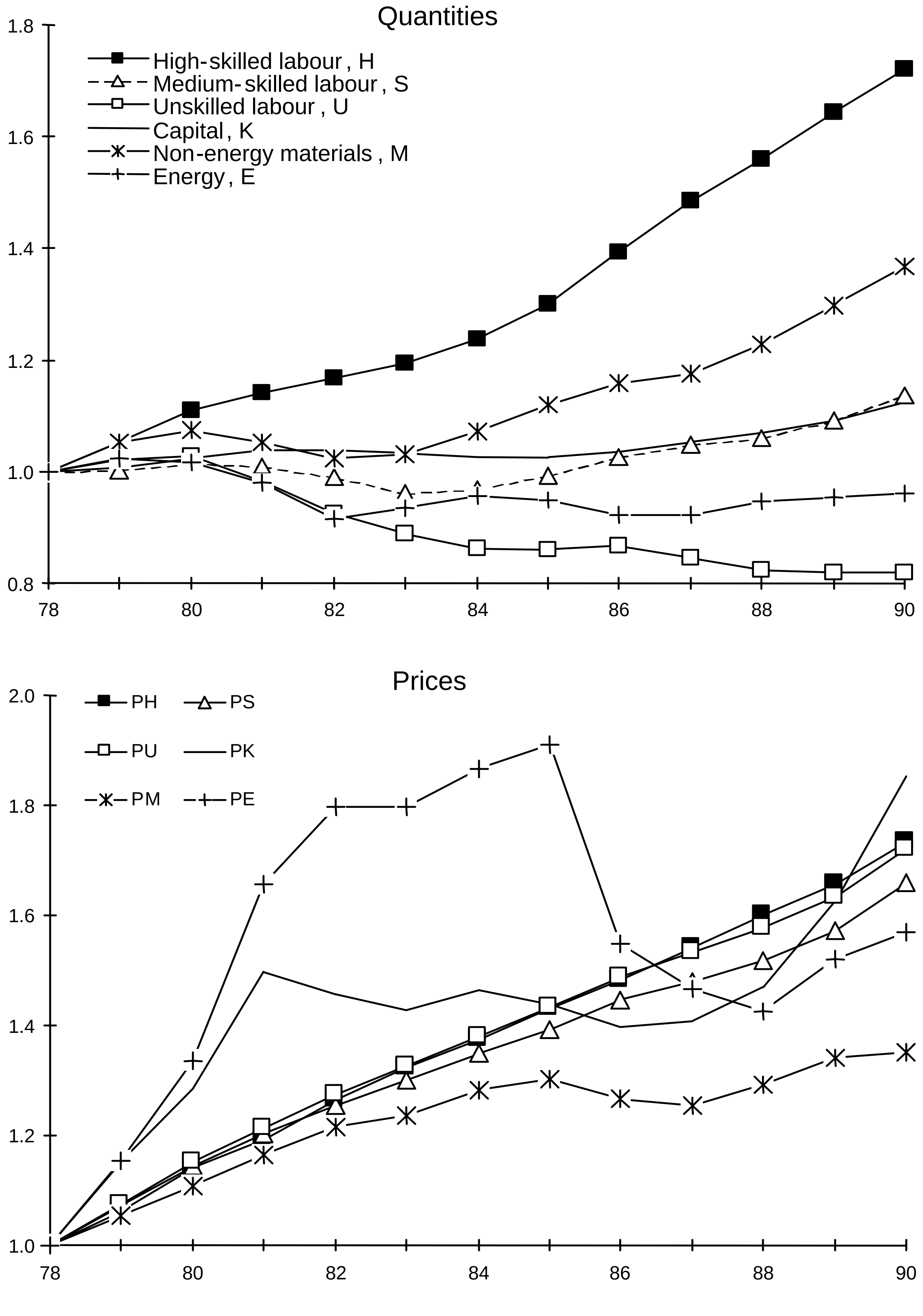

Figure 1: Changes in quantities and prices, total manufacturing, 1978-90

Appendix C: Further estimates

Table A3: Estimation results (concavity unrestricted)

Parameters	coeff	t-stat[a]	Parameters	coeff	t-stat[a]
α_{eh}	$-.002$	-0.57	α_{ku}	$-.021$	-0.59
α_{ek}	.029	3.86	α_{kt}	$-.003$	-2.16
α_{em}	.068	2.58	α_{ky}	.038	13.98
α_{es}	$-.013$	-0.51	α_{ms}	$-.381$	-3.51
α_{eu}	$-.048$	-2.95	α_{mu}	.024	0.26
α_{et}	$-.005$	-7.08	α_{mt}	.013	0.84
α_{ey}	.014	6.20	α_{my}	.568	40.00
α_{hk}	$-.009$	-1.07	α_{su}	.747	5.08
α_{hm}	.010	0.81	α_{st}	$-.017$	-4.65
α_{hs}	.014	0.30	α_{sy}	.080	18.29
α_{hu}	.023	0.70	α_{ut}	$-.031$	-12.84
α_{ht}	.002	6.61	α_{uy}	.027	6.28
α_{hy}	.015	10.27	α_{tt}	.001	0.61
α_{km}	.134	3.94	α_{ty}	.001	1.66
α_{ks}	$-.053$	-1.63	α_{yy}	.001	2.74
LR Test[b]	6649 (156)		Log. likelihood		8300.13
Adj.-R^2	$0.94 - 0.99$		Observations		$27 \times 13 \times 6$

[a] t-statistic based on heterocedasticity consistent standard errors. Coefficients on industry dummies are not reported.

[b] Log-likelihood ratio test statistic for the Null hypothesis that all dummy variables are identical. The number of degrees of freedom is in parentheses.