European Economic Review 38 (1994) 1493–1504. North-Holland

Returns to scale in the French manufacturing industry*

Daniel Szpiro

Commission des Opérations de Bourse, Paris, France

Gilbert Cette

INSEE, Paris, France

Received March 1990, final version received March 1993

The link between the size of a company and its economic performance is of considerable importance when seeking to understand changes in the productive process and company population movements. The size–efficiency relationship in companies is studied here by estimating explicit production functions from individual data on 3,200 industrial firms belonging to the Banque de France Balance Sheet Data Centre.

The proposed production function generalizes the Solow function by allowing variations in returns to scale depending on company size (e.g. first rising, then constant, then diminishing returns). This model is estimated for each sector of the 40-item nomenclature and in most cases rejects the hypothesis of constant returns, in favour of optimal sizes mid-way between the largest and the smallest, in seven out of twenty-one sectors. In six other sectors, the optimal size is the largest, and in two sectors, the most productive firms are the smallest. In one sector only, production of household durables, are returns constant.

1. Introduction

Returns to scale is a particularly topical subject with the impending single European market[1] in mind. Moreover, there are many areas of industrial economics in which analysis of returns to scale is essential, for example, in analyzing the diversity of company growth rates depending on size,[2] the relative value to companies of internal or external growth (by restructuring),[3]

Correspondence to: Daniel Szpiro, Commission des Opérations de Bourse, Service des Etudes, 39 quai André Citroën, 75739 Paris CEDEX 15, France; and Gilbert Cette, INSEE, DEEE, 15 Bd Gabriel Peri-BP 10, 92244 Malakoff Cedex, France.

*We gratefully acknowledge the important contribution of Claude Truy to the data processing aspect of the work. The empirical work was done while the authors were at the Banque de France.

[1]See Sleuwaegen and Yamawaki (1988), for example, on these aspects.

[2]See for example the empirical research by Evans (1987), Segal and Spivak (1989), and a survey on French and Belgian firms by Jacquemin and De Jong (1979).

[3]See for example Hall (1988), Tremblay and Tremblay (1988) on this subject.

SSDI 0014-2921(93)E0043-K

or the relationship between profit rates and size. Theoretical justifications of both rising and diminishing returns are presented in Gold (1981) or Pratten (1988).

In this analysis, returns to scale will be measured through the estimation of a production function on individual data; following Griliches and Ringstad (1971) on Norwegian data, Mairesse (1974) and Dutailly (1983) on French data and generalizing previous studies by not ruling out a priori that returns to scale can vary according to company size. This methodology does not need the assumption of cost minimization or the availability of input prices, as it is the case for the estimation of production costs function.[4]

Section 2 presents the estimated model and the method used for this purpose, while section 3 presents the data and the econometric results. In section 4, the latter are used to evaluate the optimal dimension (from a strictly productive point of view) of manufacturing firms on a sectorial basis). It must be kept in mind that the conclusions on optimal productive size do not preclude different ones on optimal financial size.

2. The production model

The Solow production function is generalized, in order to allow returns to scale to depend on company size, in the following way:

$$Q_{it} = A_c \cdot \exp\{\gamma_{ct} + \lambda_c(t - AGE_{it})\}\, S_{it} f_c^n(s_{it}), \qquad (1)$$

where

- indices i, c, t refer respectively to the individual firm, the sector, and time;
- $S_{it} = K_{it}^{\alpha_c} L_{it}^{1-\alpha_c}$ is an index of the size of the company;
- Q, K, L, S respectively represent the volume of output (here, value added), the volume of fixed capital, the number of employees and the size of the company;
- A_c is a constant for each sector and α_c a parameter whose value lies between 0 and 1;
- AGE_{it} is the average age of equipment;
- $f_c^n(s_{it})$ is a polynomial of order n of the variable s_{it};
- lower case s_{it} refers to the logarithm of variable S_{it}: $s_{it} = \alpha_c k_{it} + (1-\alpha_c) l_{it}$;

In logarithmic form (where lower case letters stand for the logarithm of capital letter variables) it reads:

$$q_{it} = a_c + \gamma_{ct} + \lambda_c(t - AGE_{it}) + g_c^{n+1}(s_{it}) \quad \text{with} \quad g_c^{n+1}(s_{it}) = s_{it} f_c^n(s_{it}). \qquad (1')$$

[4]Other methodologies involve macro sectoral data [Nadiri and Schankesman (1981)], opinions supplied by experts [cf. survey by Pratten (1988)] analysis of market shares [Stigler (1958)], the surviver technique [Rees (1973)] and the estimation of production costs functions [De Brabander and Vanlommel (1978), Betancourt and Edwards (1987), Avazian et al. (1987), Shoesmith (1988), Deller et al. (1988), Switzer et al. (1988), Dietsch (1988) etc. ...].

The effects of unincorporated technical progress are measured by the annual coefficients γ_{ct} which are not assumed to evolve regularly over time. The effects of technical progress incorporated into equipment are measured by the coefficient λ_c, assumed to be stable over the period of estimation. They are reflected through an indicator synthesizing the structure of equipment by generation: the average age of capital. This theoretical production model assumes, for the sake of simplicity, that the effects of technical progress are not influenced by company size. Similarly, substitutability between factors does not depend on size, and the elasticity of substitution is assumed constant and equal to 1.

Production is analyzed here, as opposed to production capacity; the difference between the two notions being the rate of utilization of production capacity. This rate has a cyclical component, and possibly also a systematic component corresponding to a better control of activity in large firms which may forecast sales more accurately and where demand randomness may be smaller because of the variety of products. It seems to us that this systematic part of the rate of utilization might therefore be related to company size and ought therefore to be included in the diagnosis of the relative efficiency of small and large firms.[5] Various studies [Folly and Gresh (1981), Abou et al. (1989)] have moreover shown empirically the existence of a positive correlation between rates of capacity utilization and company size.

Based on the previously mentioned production function, returns to scale $r(s)$ are defined as the elasticity of output relative to company size: $r(s) = (\mathrm{d}Q/Q)\cdot(\mathrm{d}S/S)$ or by approximation:

$$r(s) \approx \mathrm{d}q/\mathrm{d}s = \mathrm{d}g^{n+1}(s)/\mathrm{d}s = f^n(s) + s\cdot \mathrm{d}f^n(s)/\mathrm{d}s. \tag{2}$$

The returns to scale are a polynomial of order n. Except where $n=0$, the production function is not homogeneous and returns to scale $r(s)$ differ from the polynomial $f_n(s)$.

In order to compare the productive efficiency of firms belonging to different classes of size, ceteris paribus, we have calculated an empirical index of total factor productivity, PE, that eliminates the influence of technical progress. This measure of productivity is defined as

$$PE = (Q/\exp\{\gamma_{ct} + \lambda_c(t - AGE_t)\}. \tag{3}$$

This global empirical index of productivity will be used to determine the optimal size of companies (table 2 in this article). Theoretically this index is equivalent to

$$PT = S^{fn(s)-1}. \tag{4}$$

[5]Betancourt and Edwards (1987) discuss this question in the case of electricity generation.

Empirically, the difference between the two indices corresponds to estimation residuals. We shall see later on that the optimal dimensions defined by these two indices are relatively close. The first index is preferred because it is less sensitive to the particular functional form chosen for the production function, insofar as the residual captures departures from a more general function.

3. Estimating the model

3.1. Data

The model was estimated on a sample of companies reporting to the Banque de France Balance Sheet Data Centre.[6] The resulting panel contains over 3,000 companies observed regularly between 1972 and 1984. To provide a general view of the relative advantages of small and large firms, the study was conducted for each of the 21 manufacturing sectors of the 40-item classification. This evaluation of optimal sizes assumes that products and optimal production techniques are relatively homogeneous in each sector. Clearly, real life is likely to be quite at variance with this hypothesis in certain sectors.

Overall, the sample represents approximately 25% of the manufacturing work force (including agricultural and food processing industries, but excluding energy). Some sectors are less representative, i.e. ferrous metals, printing, press, publishing and the construction industries. In fact, what is important in this study is less the overall coverage than a good fit between the range of company sizes in the sample and that of the population as a whole. From this point of view, leaving aside the rubber and plastics processing sector, the sample may be regarded as satisfactory [cf. Cette and Szpiro (1989)].

Self-selection problems may arise for two reasons: Companies report to the Data Center on a voluntary basis, and we use a balanced panel data (i.e. firms initially disappearing from, or appearing in, the panel are discarded from the final data). It is quite likely that the member companies are, on average, healthier than those that prefer not to communicate their accounts, Similarly, those companies that disappear, either wholly or as a result of restructuring, are generally likely to perform less well than others insofar as they are more prone to be a target of a takeover.[7] However, this sampling bias chiefly concerns the non-optimal companies, and the determination of optimal size attempted here is probably relatively unaffected.

[6]See Appendix 1 for a general presentation of the sample and variables (available from the authors upon request).

[7]The empirical evidence is that a change in ownership affects, on average, firms that have a lower level of productivity, compared to similar firms in the same industry [see Lichtenberg and Siegel (1987)].

The evaluation of the company size/returns to scale relationship would be more appropriate if it had been conducted on establishments producing only a single product (and not on companies). These statistics being unavailable, a large firm may here consist of several establishments. The estimated productivity will reflect both the purely technical efficiency of the firm and its ability to make the most of the way production is spread among its units, corresponding to economies of 'scope' rather than to economies of scale in the strict sense of the term.

3.2. The method of estimation

The logarithmic form (1′) is linear if we know the value of the weighting coefficient, α_c, of the two factors of production. The value of α_c is estimated by non-linear least squares, scanning values between 0 and 1 (in each sector) in order to minimize the square of residuals of eq. (1′).

Instead of assuming a maximum order $(n+1)$ of the polynomial $g_{n+1}(s)$, it was determined by a rule of thumb which consists in scanning each sector, incrementing the order n as long as the following order did not yield a graphically identical polynomial[8] to that of the preceding order. In the course of these iterations, we observed that this parameter was particularly important to accurate estimation in the case of very large firms. A more standard approach to the selection of the order of the polynomial, like a maximum likelihood test, was not used here because an improvement in the overall likelihood was sometimes obtained at the expense of a large deterioration of the precision of the model for a small number of firms concentrated on some specific range of size, usually for very big firms. This could seriously impair our conclusions on returns to scale and optimal size. In our procedure, the specificities of large firms were controlled by running regressions weighted by output volume, in order to check that the results would not differ much from the unweighted regressions. At the end, under this procedure, an order 6 was selected for the polynomial g_{n+1} in most of the sectors, and an order 5 for four sectors,[9] hence returns to scale are generally a polynomial of order 5 of company size $(r_5(s))$ and the corresponding curve may consequently bend at most four times.

These estimates were first made for each sector on a cross-section, year by year, in order to assess the stability of the polynomial $g_{n+1}(s)$. This stability is not always assured for the first four years (1973–1976), probably because the data are less reliable, particularly for the stock of equipment [cf. Cette and Szpiro (1988)]. The results published in this article are those obtained by estimating the relation (1′) sectorially over the whole eight-year period 1977–

[8]Even if the individual coefficients were modified.

[9]Ferrous metals (T07), non-ferrous metals (T08), glass (T10), and consumer durables (T15B).

1984 for which stability is satisfactory.[10] This suggests that during the course of this sub-period, technical progress did not substantially alter the optimal size of companies for the manufacturing sectors. However, the stability of the returns to scale function is not a sufficient criterion to assert that technical progress is completely neutral as regards company size: a more detailed production function, not assuming regular change over time in incorporated technical progress, and alowing explicit interactions with returns, would be needed to underpin this first impression.

3.3. *Results of estimations*

The production function (1′), estimated for each of the 21 sectors, displays R^2 in all cases above 89%, which is not surprising in a relation where the variance in observations is related above all to size.[11] The hypothesis of fixed returns[12] was tested. The only sector where technology may be regarded as yielding fixed returns (at the 5% probability level) is the consumer durables. This conclusion may perhaps be due to the small number of observations in this sector (104), and to the resulting imprecision of the estimates. Also in this case, constant returns to scale cannot be rejected[13] (cf. table 1).

Results thus obtained can be compared with more usual estimates of fixed returns functions: Cobb–Douglas (without embodied technical progress) or Solow function (where technical progress embodied into equipment is taken into account). In many cases, fixed returns to scale (as shown in column 2 or 3 of table 1) are rejected in favour of the more general production function (last column).

Ordinary statistical tests are not stringent enough to assess the quality of the results, because what is needed is not a global precision of the estimates, but a good quality for each sub-group of observations corresponding to different sizes of companies. Hence, the quality of the estimation of the polynomial will be appreciated by comparing the index of theoretical productivity PT [defined by relation (4)] with the same index measured 'empirically' PE [defined by relation (3)] by strata. The difference between these two measurements arises from the estimation residuals. Obviously, their

[10] In the paper and paperboard sector (T21), the years 1981 and 1982 had to be eliminated for the same reasons.

[11] Because the explanatory variables include size (and powers of size), the residuals will in all likelihood not be correlated with size.

[12] Tests of individual coefficients have no particular significance. Writing the term $g_{n+1}(s)$, which forms part of the relation (1′), as $g_{n+1}(s)=\sum_{i=1}^{n+1}\mu_i s^i$, the null hypothesis is written $\mu_2=\mu_3=\cdots\mu_{n+1}=0$, and is tested by the maximum likelihood ratio.

[13] The student test is carried out conditional to the knowledge that returns are fixed, in order to determine whether returns are constant. To clarify this terminology, it should be pointed out that *fixed* returns correspond to a polynomial $f_0(s)$ of order 0 in relation (1), i.e. a constant, whereas *constant* returns correspond to a polynomial of order 0 and with (constant) value 1.

Table 1

Results of estimation comparison of returns to scale.

Sectors	Returns to scale assuming fixed returns[b]: Function: Cobb–Douglas[d]	Solow[d]	Estimated returns to scale not assuming fixed returns[a]: Estimated coefficients: $\alpha \times 10^2$	$\lambda \times 10^2$	μ_1	μ_2	μ_3	$\mu_4 \times 10^2$	$\mu_5 \times 10^2$	$\mu_6 \times 10^4$	R^2	$\sigma_u \times 10^2$	Test of variable returns[c,d]	Optimal company size[e]
T02 Meat and dairy produce	−0.007**	−0.009**	23.3	4.63	−8.48	5.45	−1.55	23.05	1.73	5.13	0.97	22.9	205	Big
T03 Other agricultural and food-processing industries	−0.007**	−0.013*	38.0	3.78	−27.07	10.87	−2.20	24.48	−1.42	3.36	0.94	35.7	174	Big
T07 Ferrous ores and metals	−0.023**	−0.019**	18.3	5.03	−10.86	5.38	−1.11	10.81	0.40	–	0.98	21.1	46	Int.
T08 Non-ferrous ores, metals and semi-finished products	−0.138	−0.124	29.5	7.41	49.77	−15.27	2.28	−16.46	0.46	–	0.97	36.4	58	Int.
T09 Building materials and other minerals	0.021	0.026	29.2	3.34	−29.38	14.33	−3.42	44.00	2.90	7.70	0.96	25.3	249	Big
T10 Glass	$+\varepsilon$**	0.020**	33.9	2.00	16.17	−3.75	0.43	−2.31	0.04	–	0.97	27.5	34	Int.
T11 Bulk chemicals, artificial and synthetic threads and fibres	0.015**	0.015**	8.9	0.36	−12.94	6.34	−1.40	16.27	0.95	2.16	0.90	56.9	28	Int.
T12 Parachemicals and pharmaceutical	0.054	0.048*	9.2	4.01	5.55	−2.80	0.85	−13.51	1.10	−3.56	0.97	30.4	109	Big
T13 Metal smelting and metalworking	0.012	0.008*	16.1	2.71	−26.93	11.31	−2.36	26.76	1.56	3.69	0.96	24.5	277	Int.
T14 Mechanical engineering	0.029	0.026	12.0	2.52	−16.07	8.05	−1.99	27.01	−1.92	5.52	0.97	24.2	260	Int.
T15A Electrical and electronic equipment	0.022**	0.004**	27.0	4.33	−42.58	16.32	−3.17	33.71	−1.86	4.15	0.98	23.4	151	Big
T15B Household durables	0.009	0.017**	0.8	1.80	−29.31	9.54	−1.47	11.20	0.34	–	0.99	14.3	1.7**	Int.
T16 Automobiles and other land transport equipment	0.022	0.018	19.2	3.47	−14.88	6.00	−1.13	11.34	0.58	1.18	0.99	19.1	101	Int.
T17 Shipbuilding, aeronautics and armaments	0.102	0.102	12.7	0.03	16.18	−5.38	0.96	−9.09	0.44	−0.87	0.99	25.4	27	Int.
T18 Textiles and clothing	−0.079	−0.073	23.6	5.13	−3.00	1.44	−0.29	3.29	−0.19	0.41	0.92	34.8	455	Small
T19 Leather and footwear	−0.050	−0.050	14.2	1.55	7.66	−4.02	1.13	−16.41	1.18	−3.32	0.89	41.4	29	Small
T20 Timber and furniture–miscellaneous industries	0.016*	0.013*	18.9	3.29	19.98	−10.33	2.85	42.19	3.21	9.82	0.94	26.0	89	Big
T21 Paper and paperboard	0.068	0.068	15.5	2.03	−7.01	2.32	−0.19	−2.58	0.52	−2.36	0.98	21.1	39	Int.
T22 Printing, press and publishing	0.055	0.061	22.3	4.56	−62.60	28.73	−6.81	89.22	6.13	17.27	0.96	25.5	177	Int.
T23 Rubber and plastics processing	−0.026	−0.022	25.8	3.65	7.12	−5.46	1.89	−31.96	2.66	−8.66	0.98	21.0	286	Int.
T24 Construction and civil engineering	0.024	0.019	10.2	3.73	0.41	0.70	0.18	2.52	0.17	0.39	0.97	20.2	443	Int.

[a]The estimated function is the following: $q=\gamma_t+\lambda(t-AGE)+\sum_{i=1}^{6}\mu_i s^i$ with $s=\alpha k+(1-\alpha)l$. These estimates are carried out by the least squared method. The value selected for the coefficient α is determined by scanning, minimizing the standard deviation of residuals. The estimation period is 1977–1984. The number of observations is thus, for each sector, eight times the number of firms. In the textiles and clothing (T18), the wool trade sector (code 4410) was excluded. In the paper–paperboard sector (T21), the years 1981 and 1982 have been excluded because they appeared atypical.

[b]The fixed returns correspond to the hypothesis: $\mu_2=\mu_3=\mu_4=\mu_5=\mu_6=0$ in the equation above. The model then becomes a Solow function. The Cobb–Douglas function corresponds to the supplementary hypothesis $\lambda=0$ (there is no embodied technical progress).

[c]The number indicated is the value of the likelihood ratio test $(2\log(\sigma_0/\sigma_1))$ which follows a χ^2 with four or five degrees of freedom depending on the sector.

[d]* or ** signify that returns are constant (for the Cobb–Douglas and Solow functions) or fixed (for the variable returns function) at the probability level 1% or 5%.

[e]The optimal sizes are those for which the index of empirical total productivity is the highest (see table 2). The optimal size described in this table is not a quantitative absolute value, but is relative to the actual range of size present in each sector. Int. stands for an intermediate optimal dimension (neither the biggest not the smallest) which is precisely defined in table 2.

Table 2

Returns to scale, productive efficiency and company size.[a]

Sector			Size class 3	4	5	6	7	8	9	10	11	12	13
T02	Meat and dairy produce	Largest work force	10	25	59	159	396	1,046	2,616	4,004	–	–	–
		Returns to scale	1.12	0.97	0.89	0.97	1.08	1.07	0.97	1.40	–	–	–
		Empirical productivity	92	94	84	83	80	90	92	100	–	–	–
		Theoretical productivity	91	96	90	82	84	90	91	100	–	–	–
T03	Other agricultural and food-processing industries	Largest work force	5	13	29	73	173	451	1,420	2,723	4,716	–	–
		Returns to scale	–	0.74	0.98	0.98	0.99	1.04	1.04	0.98	1.07	–	–
		Empirical productivity	–	91	91	89	83	84	85	90	100	–	–
		Theoretical productivity	–	100	92	90	89	90	94	94	94	–	–
T07	Ferrous ores and metals	Largest work force	–	33	68	195	491	1,369	3,089	–	–	–	–
		Returns to scale	–	1.34	1.11	0.94	1.00	1.04	0.41	–	–	–	–
		Empirical productivity	–	85	95	100	91	99	79	–	–	–	–
		Theoretical productivity	–	84	99	100	93	96	81	–	–	–	–
T08	Non-ferrous ores, metals and semi-finished products	Largest work force	–	25	49	189	–	660	1,755	4,496	10,315	–	–
		Returns to scale	–	1.81	0.68	0.66	–	1.14	0.93	0.78	1.28	–	–
		Empirical productivity	–	94	100	68	–	70	76	56	60	–	–
		Theoretical productivity	–	90	100	60	–	56	60	48	46	–	–
T09	Building materials and miscellaneous minerals	Largest work force	6	16	40	100	265	787	1,800	5,168	–	–	–
		Returns to scale	–	1.22	1.00	0.94	1.02	1.12	0.98	0.99	–	–	–
		Empirical productivity	–	82	87	88	86	93	95	100	–	–	–
		Theoretical productivity	–	80	90	87	85	92	100	98	–	–	–
T10	Glass	Largest work force	–	–	58	111	295	692	2,158	5,075	8,360	–	–
		Returns to scale	–	–	1.23	0.88	0.92	1.04	1.12	1.02	0.70	–	–
		Empirical productivity	–	–	83	100	82	82	83	97	87	–	–
		Theoretical productivity	–	–	91	92	83	82	89	100	90	–	–
T11	Bulk chemicals artificial and synthetic threads and fibres	Largest work force	16	37	98	266	603	1,738	3,965	10,541	14,760		
		Returns to scale	–	1.36	1.24	0.99	0.97	1.00	0.92	0.59	−0.04	–	–
		Empirical productivity	–	69	92	98	97	94	91	100	36	–	–
		Theoretical productivity	–	71	88	100	98	97	95	78	43	–	–
T12	Pharmachemicals and pharmaceuticals	Largest work force	15	39	109	304	752	1,737	3,756	–	–	–	–
		Returns to scale	–	1.01	1.05	1.05	1.07	1.11	0.97	–	–	–	–
		Empirical productivity	–	69	86	75	85	90	100	–	–	–	–
		Theoretical productivity	–	76	78	83	87	94	100	–	–	–	–
T13	Metals smelting and metal working	Largest work force	13	32	81	215	552	1,423	4,132	9,439	12,130	–	–
		Returns to scale	–	0.90	1.05	0.98	1.00	1.09	1.07	0.88	0.76	–	–
		Empirical productivity	–	86	88	91	87	100	98	98	94	–	–
		Theoretical productivity	–	85	86	88	87	90	100	99	88	–	–
T14	Mechanical engineering	Largest work force	16	38	99	244	630	1,610	5,232	–	–	–	–
		Returns to scale	0.69	1.01	1.03	1.05	1.07	0.99	0.90	–	–	–	–
		Empirical productivity	98	83	89	88	93	100	90	–	–	–	–
		Theoretical productivity	95	87	89	92	97	100	92	–	–	–	–
T15A	Electrical and electronic equipment	Largest work force	–	30	64	147	393	925	2,866	6,252	15,839	40,334	–
		Returns to scale	–	–	1.00	0.95	0.93	1.03	1.08	1.01	0.92	1.58	–
		Empirical productivity	–	–	86	86	81	78	84	85	86	100	–
		Theoretical productivity	–	–	93	91	85	83	89	93	89	100	–

T15b	Household durables	Largest work force	–	–	147	417	1,075	2,790	7,124	10,674	–	–	–
		Returns to scale	–	–	1.02	1.05	0.99	1.01	1.04	0.73	–	–	–
		Empirical productivity	–	–	82	83	100	88	95	84	–	–	–
		Theoretical productivity	–	–	90	93	95	95	100	95	–	–	–
T16	Car making and other land transport equipment	Largest work force	–	30	74	217	492	1,137	4,181	7,931	26,975	68,982	110,336
		Returns to scale	–	–	1.19	1.03	0.94	0.93	1.05	1.07	1.07	0.95	1.05
		Empirical productivity	–	–	82	90	87	87	89	86	100	90	94
		Theoretical productivity	–	–	85	100	98	92	90	93	98	99	98
T17	Shipbuilding, aeronautics and armaments	Largest work force	14	35	123	325	664	2,115	4,911	12,001	25,070	35,961	–
		Returns to scale	–	1.11	0.91	1.07	1.19	1.21	1.15	1.07	0.91	0.71	–
		Empirical productivity	–	58	39	53	52	59	76	100	99	67	–
		Theoretical productivity	–	61	60	57	64	72	93	100	99	83	–
T18	Textiles and clothing	Largest work force	10	28	70	173	449	1,221	2,732	9,104	10,007	–	–
		Returns to scale	0.53	0.74	0.85	0.93	1.00	1.06	1.03	0.87	0.67	–	–
		Empirical productivity	100	65	57	50	51	52	59	56	42	–	–
		Theoretical productivity	100	74	60	54	53	55	57	56	48	–	–
T19	Leather and footwear	Largest work force	14	35	92	260	678	2,014	4,448	–	–	–	–
		Returns to scale	0.72	0.88	1.05	1.03	0.87	0.80	0.89	–	–	–	–
		Empirical productivity	100	90	92	90	84	79	68	–	–	–	–
		Theoretical productivity	100	85	83	87	83	70	57	–	–	–	–
T20	Timber and furniture – miscellaneous industries	Largest work force	12	29	74	195	531	1,409	–	–	–	–	–
		Returns to scale	–	0.94	1.05	1.01	0.98	1.13	–	–	–	–	–
		Empirical productivity	–	95	91	93	94	100	–	–	–	–	–
		Theoretical productivity	–	92	93	97	96	100	–	–	–	–	–
T21	Paper and paperboard	Largest work force	13	33	82	225	492	1,802	3,436	4,873	–	–	–
		Returns to scale	–	1.14	1.16	1.02	1.02	1.17	0.99	0.39	–	–	–
		Empirical productivity	–	58	63	71	73	78	100	86	–	–	–
		Theoretical productivity	–	58	67	73	73	78	100	88	–	–	–
T22	Printing, press and publishing	Largest work force	12	24	63	167	514	1,103	2,014	–	–	–	–
		Returns to scale	–	0.93	1.07	1.08	1.12	0.98	1.14	–	–	–	–
		Empirical productivity	–	76	74	80	83	100	98	–	–	–	–
		Theoretical productivity	–	75	77	84	93	100	100	–	–	–	–
T23	Rubber and plastics processing	Largest work force	–	–	–	–	–	–	–	–	–	–	–
		Returns to scale	–	–	0.96	0.95	0.97	1.16	1.01	−0.35	–	–	–
		Empirical productivity	–	–	91	92	86	91	100	92	–	–	–
		Theoretical productivity	–	–	90	87	82	86	100	69	–	–	–
T24	Building and civil engineering	Largest work force	18	41	104	272	742	1,972	5,474	10,195	–	–	–
		Returns to scale	–	0.98	1.00	1.05	1.10	1.09	0.88	0.53	–	–	–
		Empirical productivity	–	78	78	77	87	88	100	73	–	–	–
		Theoretical productivity	–	83	82	84	90	99	100	80	–	–	–

[a]Key: In sector T02 (meat and dairy produce), size class in no. 4 goes from 10 to 25 employees. The median empirical productivity (94) is 6% lower than that of class 10, which is optimal. The median theoretical productivity (96) is 4% lower than that of class 10, which is also optimal with this second indicator.

Thirteen class sizes have been defined from 1 to 13 by breaking down the logarithms (s) of size (S): the transition from one class to the next thus results in a multiplication of size by approximately 2.71. Close correspondence between the size and work force indicators was observed in each sector. This allowed us to refer to each class by an interval of workers employed, rather than by the indicator of size, which is a more precise measurement, but whose meaning is less direct.

The returns to scale indicated are the median levels for each size class.

In each sector, and for each of the two indicators of global productivity, the table supplies the median figure for the class, the index 100 referring to the class in which it is highest.

The empirical productivity PE is the level of global productivity observed, technical progress excluded. It is defined by the relation (3) given in the text. *The theoretical productivity PT* is the global productivity calculated – excluding technical progress – by applying the estimated coefficients of the production model. It is defined by the relation (4). The difference between these two indicators therefore reflects the size of the estimation residuals.

sum is nil for all firms in each sector, but local divergences do however exist, and it is necessary to appreciate them by breaking down each sector into size classes. The class limits here correspond to integer values of the size variable s.

In two sectors out of twenty-one – other agricultural and food-processing industries, and glass – the comparison between PE and PT would not lead to the same optimal size. In three other sectors, the correspondence is good, and in the sixteen remaining sectors the correspondence is exact (cf. table 2). So these results are satisfactory on the whole. The index closest to the actual economic situation (PE) will be used subsequently.

It should be noted that for most industries, there is only a weak relationship between productivity and capital intensity. The exception is the non-ferrous ores, metals and semi-finished products industry where a correlation of 0.5 can be noticed. For the other industries, the correlations lie between -0.1 and $+0.2$. Hence, the fact that returns to scale are estimated independently of capital intensity should not induce an important bias on the results.

4. Optimum company size

From the point of view of an individual firm, the optimal size is obtained where the empirical total factor productivity (PE) is, ceteris paribus, the highest. A *class* of size is said to be optimal when the median productivity (of firms making up that class) is the highest, or – allowing for the imprecision of estimation – when it is at least equal to 95% of that of the class in which it is the highest.

Three groups stand out among the 21 manufacturing sectors in the 40-item classification (table 2):

– the largest size is optimal in six sectors: meat and dairy produce, other agricultural and food-processing industries, building materials manufacturing, parachemicals and pharmaceuticals, electrical and electronic equipment manufacturing, and printing, press and publishing;
– in two sectors, textiles and clothing, and leather and footwear, the smallest size is optimal;
– in the remaining thirteen sectors, the optimal size is intermediate (our production model, where returns are not constrained to be continually rising or decreasing, but depend on company size, thus appears particularly relevant for these cases):

• in seven out of these thirteen sectors, the optimal size, while not the largest, is high (over 500 employees): in metal smelting and metal working, household durables, paper and paperboard, rubber and plastics and con-

struction and civil engineering, or very large in car manufacturing and shipbuilding, aeronautics and armaments (between 10,000 and 30,000 people).
• in non-ferrous metals, the optimal size appears to be rather small (between 25 and 100 people).
• lastly, in the five remaining activities, several relatively distant classes of size appear to be optimal. This could reflect a degree of heterogenousness between activities within the industry and hence between efficient production techniques. The sectors in question are ferrous ores and metals, glass, chemicals, mechanical engineering, and timber and furniture.

References

Abou, A., G. Cette and J. Mairesse, 1989, Degrés d'utilisation des facteurs de productivité: Une étude sur données d'entreprises pour les années 1981 et 1982, Mimeo. Paper presented to the 6èmes journées de Micro-économie Appliquée, Orléans, May 20–30, 1989.

Avazian, V.A., J.L. Callen, M.W.L. Chan and D.C. Mountain, 1987, Economies of scale versus technological change in the natural gas transmission industry, The Review of Economics and Statistics 69, no. 3, Aug.

Betancourt, R.R. and J.H.Y. Edwards, 1987, Economies of scale and the load factor in electricity generation, The Review of Economics and Statistics 69, no. 3, Aug.

Catinat, M., 1989, Les conditions de réussite du marché intérieur: Concrétiser les opportunités, Economie et Statistique no. 217–218, Jan.–Feb.

Cette, G. and D. Szpiro, 1988, L'appareil productif industriel: Durée de vie des équipements, productivité et rentabilité, Banque de France, Cahiers Economiques et Monétaires no. 28.

Cette, G. and D. Szpiro, 1989, Les entreprises françaises sont-elles bien dimensionnées?, Economie et Statistique no. 217–218, Jan.–Feb.

de Brabander, B. and E. Vanlommel, 1978, Economies of scale, minimum optimal plant size and effectiveness of market structure in Belgian industry anno 1970, European Economic Review 11.

Deller, S.C., D.L. Chicoine and N. Walzer, 1988, Economies of size and scope in rural low-volume roads, The Review of Economics and Statistics 70.

Dietsch, M., 1988, Economies d'echelle, économies d'envergure et structure des coûts dans les banques de dépôt françaises, Mimeo. Nov.

Dutailly, J.C., 1983, Investissement et créations d'emploi: Impact par secteur d'activité et taille d'entreprise, Economie et Statistique no. 156, June.

Evans, D.S., 1989, The relationship between firm growth, size and age: Estimates for 100 manufacturing industries, The Journal of Industrial Economics, 35, no. 4, June.

Folly, M. and H. Gresh, 1981, Les marges de capacité de production industrielle inutilisées, Economie et Statistique, no. 136, Sept., 17–28.

Fuss, M.A. and V.K. Gupta, 1981, A cost function approach to the estimation of minimum efficient scale, returns to scale, and suboptimal capacity, European Economic Review 15.

Gold, B., 1981, Changing perspectives on size, scale and returns: An interpretive survey, Journal of Economic Literature 19, Mar.

Griliches, Z. and V. Ringstad, 1971, Economies of scale and the form of the production function (North-Holland, Amsterdam).

Hall, B.H., 1988, The effect of takeover activity on corporate research and development, in: A.S. Auerbach, ed., Corporate takeovers: Causes and consequences (NBER, University of Chicago Press, Chicago, IL).

Jacquemin, A.P. and De Jong, H.W., 1979, European industrial organisation (Macmillan, New York).

Lichtenberg, F.R. and D. Siegel, 1987, Productivity and changes in ownership of manufacturing plants, Brookings Papers on Economic Activity 3, 643–683.

Maddison, A., 1987, Growth and slowdown in advanced capitalist economies: Techniques of quantitative assessment, Journal of Economic Literature 25, Jun.

Mairesse, J., 1974, Comparison of production function estimates on the French and Norwegian census of manufacturing industries, in: F.L. Altmann, O. Kyn and M.-J. Wagener, eds., On the measurement of factor productivities (Vandenhoek and Ruprecht, Göttingen).

Pratten, C., 1988, A survey of the economies of scale, EEC research on the cost of non-Europe, series documents, Vol. 2, Ch. 2.

Rees, R.D., 1973, Optimal plant size in the United Kingdom industries: Some survivor estimates, Economica 40, no. 160, Nov.

Segal, U. and A. Spivak, 1989, Firm size and optimal growth rates, European Economic Review 33.

Shoesmith, G.L., 1988, Economies of scale and scope in petroleum refining, Applied Economics 20.

Sleuwaegen, L. and H. Yamawaki, 1988, The formation of the European Common Market and changes in market structure and performance, European Economic Review 32.

Smith, A. and A.-J. Venables, 1988, Completing the internal market in the European community, European Economic Review 32.

Stigler, G.-J., 1958, The economies of scale, Journal of Law and Economics 1.

Switzer, L., J. Doukas and M. Lauzon, 1988, Economies of scale in branch banking: Evidence from Canada, Mimeo. (Concordia University, Montreal) Aug.

Tremblay, V.J. and C.H. Tremblay, 1988, The determinants of horizontal acquisitions: Evidence from the U.S. brewing industry, The Journal of Industrial Economics 37, no. 1, Sept.