BANCA D'ITALIA

Temi di discussione

del Servizio Studi

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Number 394 - February 2001

FIRM SIZE DISTRIBUTION AND GROWTH

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Abstract

We empirically characterize the sectoral distribution of firm size for a set of European countries, finding substantial differences. We then study the relationship between productivity growth at the sectoral level and size structure. We find a positive and robust association between average firm size and growth. Asking why size should matter for growth, we consider the role of innovative activity, to construct a test based on the differential effect of size on growth according to various indicators of R&D intensity at the sectoral level. Our results indicate that larger size fosters productivity growth because it allows firms to take advantage of all the increasing returns associated with R&D. We finally argue that our test can be interpreted as a test of reverse causality, which lends support to the view of firm size having a causal impact on growth.

Keywords: firm size, growth, R&D.

JEL classification: L11, L16, O30, O40.

Contents

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1. Introduction[1]

The process of European integration has directed a great deal of attention to the question of differences betweeen the EU member economies. A substantial amount of work has beendone on national differences in sectoral specialization (Amiti, 1997; Bugamelli, 1999). Less is known, at least on a solid quantitative ground, about the differences in the industrial structure within sectors. This paper takes one aspect of the industrial structure — firm size distribution — and, merging statistical information from different sources, studies the differences in size across European countries at the sectoral level and their relation to growth.

The study of the determinants of the steady-state distribution of firms has a long tradition in economics. Classical theories of size structure concentrated on technical factors, stressing returns to scale and efficient scale of operation as the fundamental determinants of size (Viner, 1932). Overwhelming empirical evidence both of a persistent dispersion in the cross-sectional distribution of firm size in an industry and of a certain stability in the stochastic pattern of evolution of firm size (*Gibrat's law* of independent increments) has challenged this view and prompted the formulation of theories to account for such regularities. Modern theories of size distribution assume that firms are heterogeneous along some dimensio that has a direct impact on their equilibrium size (typically, efficiency). They posit that the shape of the production function at the firm level is only one of the factors determining the equilibrium structure of the industry, which will also depend on such other factors as regulation, level of economic development, size of the market and so on.[2] This implies that national differences in terms of

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[1] We thank Chiara Bentivogli, Andrea Brandolini, Paola Caselli, Antonio Ciccone, Juan Dolado, Andrea Gerali, Luigi Guiso, Marco Magnani, Xavier Sala-i-Martin, Sandro Trento, Luigi Zingales and participants at the CREI-EC workshop held at UPF on June 5-6, 2000, at seminars at Ente Einaudi, the Bank of Italy, the university of Modena and of Torino for comments and stimulating discussions. Marco Chiurato and Antonio Covelli provided valuable research assistance. We are solely responsible for any errors. The opinions expressed in this paper do not necessarily reflect those of the Bank of Italy. E-mail: pagano.patrizio@insedia.interbusiness.it; schivardi.fabiano@insedia.interbusiness.it.

[2] In Lucas (1978), the size of a firm is detemined by the ability of the entrepreneur, with more able entrepreneurs optimally choosing a larger scale of operation and with entrepreneurial ability distributed randomly in the population. He shows that if the elasticity of substitution between capital and labor is less than one, average size is positively correlated with the level of developement (i.e. capital per-capita) of the economy. Jovanovic (1982) builds a model in which the optimal size of the firm is determined by a productivity parameter drawn upon entering and unknown to the firm, which learns about it during its life cycle. The model delivers a series of predictions in line with empirical evidence both on the evolution of firm size at the individual level and on the size distribution. Hopenhayn (1992) considers a similar model in which the productivity parameter is known, but evolves as a random process over time. He relates the exogenous characteristics of the industry, such as the entry cost, total demand and the stochastic process for the productivity parameter to the steady-state distribution of

institutions, such as regulation in the product and the labor markets, taxation and development of the financial sector can lead to substantial differences in the size distribution of firms, even in the presence of similar production technologies.

We do not directly tackle the problem of the determinants of size structure at the national level, but take it as given. Rather, our purpose is to investigate the growth impact of this predetermined size structure. Using Eurostat data on firm size, we document substantial differences in size structure among European countries. A significant part of the differences might be due to national characteristics, especially regulation and tax treatment, that could induce a bias towards certain size structures.[3] We find that countries with a given overall size structure tend to be characterized both by a larger share of employment in sectors that are "naturally" close to that structure and by a distortion toward that structure within sectors. This makes us confident that the comparison of size measures across countries is not invalidated by potential differences in measurement methods. Furthermore, we decompose the overall differences in mean size into the share attributable to sectoral specialization and that due to size differences within sectors, finding a significant role for the latter.

Having shown that there is a large degree of variability across countries in the intra-sectoral size distribution, we consider whether the differences influence growth at the sectoral level. Both exogenous and endogenous growth theories, assuming constant returns to scale, have neglected the role of size structure. However, size might be relevant to *dynamic* efficiency and therefore to growth. For example, as was recognized by Schumpeter (1934), innovative activity could grow more than proportionally with size.[4] Moreover, large firms might be better

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firms and to the process of entry and exit. Ericson and Pakes (1995), Pakes and McGuire (1994) endogenize the productivity parameter, assuming that its evolution is (stochastically) determined by the investment choices of the firms, and study the interaction of firms in determining the stochastic distribution of firms' size, the evolution of the industry and of the firm at the individual level.

[3] For example, Davis and Henrekson (1999) show that the Swedish tax system and regulatory framework have induced a firm population biased toward large firms. It is often argued that in Italy the regulatory framework has the opposite bias, both because some regulations apply only to firms above a certain employment threshold and because it is easier for small firms to elude regulation and to avoid taxation. Kumar, Rajan and Zingales (1999), using a previous release of the dataset used in this paper, explain differences in firm size mainly with country-specific characteristics, stressing the role of the institutions that regulate the economic environment, such as the judicial system and the level of development of the financial system.

[4] The emerging literature on *knowledge spillovers* (see for example Audtresch, 1998) has challanged the assertion that the firm is the relevant entity to study R&D. This literature argues that the proximity of firms induces substantial technological spillovers, which are not taken into account when considering firms in isolation. For example, in Italy the industrial districts, characterized by a large number of small, geographically close,

able to exploit the possibilities of a given innovation. Recent theories of endogenous growth have tried to incorporate these considerations into models that simultaneously determine size distribution, R&D and growth (Peretto, 1999a).

There is very little empirical work on the impact of size structure on growth[5]. We try to fill this gap. We track productivity growth in the nineties at the sectoral level for a set of European countries against the relevant size distribution of firms, finding a positive correlation between average size and productivity growth. We also find some evidence of a negative impact of size dispersion on growth; if dispersion is taken as a proxy of market concentration, this finding can be interpreted as an indication of a positive effects of competition on investment and therefore growth.

Finally we address the question of why firm size should matter for growth, considering its effect on R&D, which, as much of the endogenous growth literature mantains, is the main engine of productivity growth. To this end, we construct a test in the spirit of Rajan and Zingales (1998) and conclude that size structure influences growth through R&D and that this result is robust with respect to the problem of reverse causality that plagues most of the empirical literature on growth.

The rest of the paper is organized as follows. In Section 2 we document differences in size structure among eight European countries. Section 3 contains the growth regressions analysis, and Section 4 illustrates the test on the direction of causality. Section 5 concludes.

2. Size differential decomposition

In this section we perform a descriptive analysis of size structure at the sectoral level for a set of European countries. Comparing firm size across countries is a tricky task, because it involves defining the boundaries of a firm in a consistent way. This problem underlies the

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similar firms among which relevant information flows occcur (Guiso and Schivardi, 1999), might constitute an alternative model of organization based on small interacting firms with external economies, rather than large firms that internalize the economies of scale in R&D. We neglect this aspect in this paper, leaving the consideration of its implications to future work.

[5] To our knowledge, the only study is a paper by Carree and Thurik (1998). For a sample of European manufacturing sectors, they regress the growth in overall output on the employment share of large firms in 1990 and find a negative correlation only after giving greater weight to industries with a large number of employees. Our study considers a different time span and concentrates not on total output or overall employment, but on growth in labor productivity, which is the relevant variable for the evolution of per capita income. As a consequence, our results should not be interpreted in terms of job creation or overall growth, particularly in the short run.

paucity of rigorous work on the subject. In recent years, the lack of comparable data has been partially remedied for Europe by the regular Eurostat report, *Enterprises in Europe.* The most recent report, issued in 1998, contains data on the size structure in 1994 for eighteen European countries, with breakdown by sector of activity according to the two-digit NACE Rev.1 classification. There are five size classes by number of employees (0,1-9, 10-49, 50-249, 250+), and a series of variables, including total employment and the number of firms, is supplied.[6] The unit of analysis is the enterprise, defined as "the smallest group of legal units producing goods or services and constituting an autonomous economic entity" (European Commission, 1998). The first size class is those with no employees, whose inclusion might be questioned, but all our results are robust to the exclusion of this class, in part because our measure of size, as we explaine below, weights observations according to their contribution to total employment. Following the classification scheme of the dataset, our measure of size is employment, which seems preferable to an indicator such as sales, which critically depends on the intensity of intermediate inputs.

Our aim in this section is to investigate the extent of differences in the size structures among European countries. We have selected the eight countries that, because of data availability, will be used in the econometric analysis in Section 3: Germany, France, the UK, Italy, Spain, Finland, Denmark and Sweden. They account for approximately 85 per cent of EU15 GDP. We consider the size structure in 1994, using data from 1995 or 1993 when those for 1994 are not available.

As noted, one problem is that the definition of firm may differ from country to country, thus leading to a potential bias in the size comparison. This problem is alleviated by the fact that our data come from a single data set, so that the accounting procedures have been harmonized as much as possible. Going further, together with the size analysis we perform a sectoral specialization analysis. As Davis and Henrekson (1999) note, if a country has policies that tend to favor a particular size structure, one should find both a distortion toward that structure in each sector and a higher proportion of employment in sectors that are "naturally" characterized by the same structure. Measures of sectoral specialization, based on the share of workers, are less problematic in terms of definitional differences. As we expect that country

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[6] For a detailed description of the SME (Small and Medium Enterprises) database see *Enterprises in Europe (1998).*

distortions to go in the same direction for both indicators, if we find that the results of size analysis are in line with those of the sectoral specialization, we can be fairly confident that the size differences observed correspond to actual differences and not to variation in measurement methods.

We set out our statistical workhorses. As a summary statistic of size we use "coworker mean" (Davis and Henrekson, 1999), i.e. average size within a class weighted by the employment share of the class. The coworker mean is the number of workers at the average place of employment of a randomly chosen worker. With respect to a simple arithmetic mean, it weights each firm's contribution to the average according to its own size, thereby smoothing out the contribution of very small firms.[7] This statistic is particularly well suited to our purpose, because in our econometric specification the dependent variable will be the growth rate of labor productivity, which is calculated using the same weighting scheme as the coworker mean.

For sector *i* in country j, define emp_{ij}^{c} as employment in class size c, $units_{ij}^{c}$ as the number of units, emp_{ij} and $units_{ij}$ as total employment and total number of units. The within class average size is calculated as

(1)
$$s_{ij}^{c} = emp_{ij}^{c}/units_{ij}^{c}.$$

The employment share in size class c in sectoral employment is

(2)
$$\omega_{ij}^{c} = emp_{ij}^{c}/emp_{ij}$$

while the employment share of sector i in total employment in country j is

(3)
$$\omega_{ij} = \frac{\sum_c emp_{ij}^{c}}{\sum_i \sum_c emp_{ij}} = \frac{emp_{ij}}{emp_j}.$$

We define the average firm size in sector *i* in country *j* as

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[7] As an example, consider three sectors, one with 2 firms with 50 employees each, one with 2 firms with 1 and 99 employees respectively, the third with 1 firm with 100 employees. The arithmetic means are 50, 50 and 100, while the coworker means are 50, 98.02 and 100, making sectors 2 and 3 much closer than 1 and 2.

(4) $$s_{ij} = \sum_c \omega_{ij}^c s_{ij}^c$$

and the average firm size in country j as

(5) $$s_j = \sum_i \omega_{ij} s_{ij}.$$

Before applying these definitions to the data, we need to take into account differences both in sectoral specialization and in size distribution that arise directly from some exogenous specificity of each country and not from the interaction of country characteristics with market forces. For example, the employment share of mining obiously depends on the presence of natural resources. Moreover, extraction activity is often subject to *ad hoc* national regulations. Similarly, some countries have legal monopolies in some sectors, often publicly owned, which tends to distort both average size and employment share in such sectors, because public monopolies have often been used as sources of jobs, regardless of optimal manning levels. We would like our measures to be as independent as possible of such factors, and restrict our attention to sectors where both employment and size structure are determined by the response of the markets to the institutional environment. We therefore exclude the following sectors: mining, public utilities (electricity, water, land transport, water transport, air transport, post and telecommunications) and health. For the remaining sectors, we aggregate the two-digit industries at the classification level reported in Tables 2 and 3, using the procedure described in Appendix A.1.

Table 2 compares the size distribution for the eight European countries selected. The first column gives the average size for the EU15 aggregate, with sectors in increasing order of size. This average value partially nets out national peculiarities and is used as a benchmark. The other columns report the size for each nation as a ratio to the EU15 average, so that a value above indicates that the average firm in the given sector and country is larger than the EU15 average.

The ranking of sectors is as expected, with light manufacturing, services and construction at the small end, chemicals, petroleum, finance and transportation equipment at the other extreme, and food and trade around the average value. Between the smallest (real estate) and the largest (transportation equipment) there is a difference of a factor of almost 20. There are sizeable differences among countries as well. Germany and the UK have the largest overall mean size, of about 60 per cent above the EU15 value. Sweden is 13 per cent above, Finland 6 per cent, France and Denmark have approximately the same average size as the EU15, while Spain and Italy are well below, with the average firm size equal, respectively, to 58 per cent and 42 per cent of the benchmark.

The table also gives a preliminary indication of the relative importance of sectoral specialization against idiosyncratic country features in determining overall average firm size. If the average intra-sectoral size tends to be similar across countries, then the overall size differences should be explained by the fact that some countries are more specialized in sectors characterized by small or large size. If this were the case, we would expect the values in Table 2 to be concentrated around one. If, on the contrary, the size differences were explained mainly by national factors inducing a consistent bias within sectors, then we would expect the countries with an overall value above (below) the EU15 average to be characterized by values generally above (below) one. The table shows that intra-sectoral differences are important: indeed, the rows display large variations, indicating that the same sector can be characterized by very different size structures in different countries. By computing the standard deviation by row, we find that the sectors that have the most highly dispersed size structure are Hotels & Restaurants, Wood, Construction, and Trade. Quite interestingly, all are non-manufacturing, which suggests that in manufacturing technological factors have a stronger role in determining optimal scale, reducing the effects of national peculiarities.

In terms of differences within countries, the results are less clear-cut. The four large economies of the monetary union show quite a consistent pattern: for Italy and Spain almost all sectors are characterized by average size below the benchmark,[8] while the opposite is true for Germany. This would indicate that national characteristics are a fundamental determinant of the size structure *even controlling for sectoral specialization*. For Finland, Sweden and the UK, instead, larger overall size is accompanied by a more dispersed pattern at the sectoral level, which suggests that their national specificities do not affect all sectors evenly. These are also the countries with the highest standard deviation by column.

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[8] For Italy, this is true in *all* sectors, showing a remarkeably consistent tendency to smallness.

To check the robustness of our results with respect to differences in measurement methods, let us consider sectoral specialization. As argued above, if a country's environment tends to privilege (say) smallness, then this should induce a higher employment share in sectors where technological factors favor small size. So we should expect that the countries with the smaller intrasectoral size to also be characterized by a higher employment share in the sectors with a small firm size in the EU15 benchmark (i.e. sectors in the top rows of Table 1). Table 3 summarizes the sectoral specialization of each country in relation to the EU15 average; for easy comparison with the previous table, sectors are again ranked in ascending order of average size at the EU15 level. In accordance with the previous table, the first column reports the actual values for the EU15 aggregate, i.e. the percentage of employment in each sector. A value larger than one indicates that the country is more specialized in that sector than the EU15 average. The table indicates that there are important differences in national specialization. For example, the share of employment in Leather for Italy is more than three times as great as the EU15 average, that for Textiles more than two times; these two sectors are well below the benchmark in Germany, Denmark and Sweden.

To control for the existence of a consistent pattern of specialization within countries towards sectors with "naturally" larger size, we regress the values in Table 3 on the log of the average sectoral size in the EU15 for each country separately. A positive coefficient indicates that the country tends to be more specialized in sectors characterized by naturally larger firms. The results, reported in Table 4, show that, of the six countries with average size significantly different from the benchmark, the relationship is significant for the three large EMU economies, with Germany characterized by a specialization in sectors with larger size and Italy and Spain with smaller. For the other three countries, the coefficient is not statistically significant.

Up to now we have shown that both the sectoral specialization patterns and the national peculiarities within sectors play a role in explaining overall size differences. Now we want to obtain a quantitative measure of these roles. Using the values in Tables 2 and 3, we can decompose the size differential from the benchmark into the following components:

$$s_j - \bar{s} \;=\; \sum_i \omega_{ij} s_{ij} - \sum_i \bar{\omega}_i \bar{s}_i$$

$$
\begin{aligned}
&= \sum_i (\omega_{ij} - \bar{\omega}_i)\bar{s}_i + \sum_i (s_{ij} - \bar{s}_i)\bar{\omega}_i + \sum_i (s_{ij} - \bar{s}_i)(\omega_{ij} - \bar{\omega}_i) \\
&= \Delta_\omega + \Delta_s + \Delta_{\omega s} \qquad (6)
\end{aligned}
$$

where, as before, s_{ij} is the average size in sector i in country j, ω_{ij} is the share of employment in sector i in country j, and barred variables are the corresponding benchmark values. The first term, Δ_ω, represents the difference due to differences in the sectoral composition of employment and the second, Δ_s, the differences due to the size differences within sectors and $\Delta_{\omega s}$ an iteraction term. If the latter is positive, size and sectoral composition deviate from the benchmark in the same direction. The rersults are reported in Table 5.

For all countries, the interaction term is positive, indicating that size and sectoral deviations tend to go togheter, confirming our previous result. Denmark and France are very close to the benchmark, Germany and the UK well above, Spain and Italy below. In terms of relative weights, the differences in size within sectors tend to be higher than those coming from sectoral specialization.

Summing up, from this analysis we draw two conclusions that form the basis for our econometric work:

A. There are sizeable international differences in intrasectoral size distribution, which gives enough variability in the covariates for the econometric analysis of the next section;

B. At the country level, average size within sector and the sectoral specialization pattern tend to affect overall size in the same direction, an indication that international size comparisons can be safely made.

3. Size structure and growth

In this section we examine the relationship between growth and firm size structure. Growth theories have long attributed to technological advances the role of engine. In the literature spurred in the nineties by the contributions of Romer (1990) and Grossman and Helpman (1991), technological progress has been endogenized and the incentives to undertake research and development activity have become the crucial factors in determining growth. Yet the role of the structure of the market has been neglected. For example, in Romer's (1990) model firms producing the final goods rent technological advances (in the form of different intermediate capital inputs) from the intermediate goods sector. Given that returns to scale in the final goods sector are constant, there is no role for firm size. In reality, part of the R&D is done within the same firms that produce the final goods, which use the advances themselves rather than rent intermediate goods produced with such advances out to other firms. In this case, the size of a firm will generally have an influence on the incentives to undertake R&D. Consider, for example, a cost-cutting innovation. For given output and prices, the benefits of a given reduction in costs are larger, the larger the scale of production. If the R&D expenditure has a fixed-cost character, then a larger firm will benefit more from investing in it.

In a series of papers, Peretto (1998, 1999a, 1999b) recognizes the simultaneity between R&D decisions — and thus economic growth — and market structure, pointing out the twofold aspect of this relationship: on the one hand market structure determines the behavior of profit-seeking firms by affecting the returns to investment (and thus growth); on the other, market structure changes in response to growth, insofar as the number and the size of existing firms change in response to demand and technology. Peretto identifies two effects of market structure on growth. First, increasing returns in R&D, internal to the firms, imply that the more concentrated the resources, the higher the growth (*dispersion effect*). At the same time, however, the full effect of market structure on growth also depends on the competition-induced increase in aggregate R&D (*rivalry effect*). In sum, in these papers, an increase in the number of firms potentially has two different effects on growth: (i) if *aggregate* R&D is held constant, it reduces *average* R&D and, therefore, reduces growth (dispersion effect); (ii) it may raise aggregate R&D and thus growth (rivalry effect).[9]

To investigate the relationship between size structure and growth, we integrate the data of the previous section with data on sectoral value added. Because of problems of data availability, we restrict the analysis to manufacturing. Where possible, we use the most highly disaggregated sectoral classification, that is the two-digit NACE rev. 1. For most countries, we are also constrained to use data referring to enterprises employing 20 persons or more, but we think this is not a fundamental limitation, in that all our results hold when we use alternative measures of firm size that ignore the left tail of the distribution. Other details of the data construction are given in Appendix A.1.

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[9] Note that in these papers the number of firms summarizes two dimensions of the notion of market structure — concentration and firm size relative to the size of the market. In our empirical investigation we will study the relationship between size structure and growth, neglecting issues related to market power. Clearly, firm size and market power are correlated. Still, given that other issues that we cannot address with our data are important for market power, we confine ourselves to size structure.

The framework is standard in the literature on growth (Barro and Sala-i-Martin, 1995). It relates the real per capita growth rate to two kinds of variables, a set of control variables — initial level of real per capita GDP and proxies for the level of physical and human capital — and a set of variables of interest, in our case measures of firm size distribution.

As noted above, this type of regression might suffer from problems of endogeneity. In fact, it could be argued that the correlation between growth and firm size masks a causality running also (or exclusively) from the former to the latter.[10] To address this issue, first our regressions take the average growth rate for the period after the year to which the size distribution refers. As the size data are for 1994, we consider growth as the compounded percentage change in real value added per worker between 1994 and 1998. The fact that we consider a relatively short time span could induce some bias in terms of the relative cyclical position of the various countries. This problem is mitigated by the fact that we only consider countries of the European Union, whose business cycles have been fairly synchronized, with the notable exception of the UK. We will show that our results are not driven by any particular country and that they also hold true when we use a growth rate for 1989-1998. Still, this restriction on the data might be insufficient to avoid endogeneity problems, particularly when the variables are characterized by a high level of persistence.[11] Therefore in the next section we run a direct test of reverse causality.

The basic regression we run is the following:

$$g_{i,j} = \alpha_0 + \boldsymbol{\alpha}_1{}' X_{i,j} + \alpha_2 \ln(S_{i,j}) + \lambda_i + \varepsilon_{i,j} \tag{7}$$

where g is the average rate of growth of real value added per worker in country j in sector i; X is a vector of control variables; S is the log of 1 plus the average firm size (co-worker mean) in country j in sector i in 1994; $\lambda_i^{'}$s are sectoral dummies and ε is an error term.

The dependent variable is the average annual growth rate of value added per worker, whose descriptive statistics are given in Tables 13 and 14. All our regressions include sectoral

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[10] For instance, in Lucas (1978) as capital per capita increases, the "marginal" entrepeneur finds it profitable to become an employee, thereby causing an increase in the average firm size.

[11] A comparative study of the major industrialized economies from the mid-sixties to the mid-nineties shows that the size structures display a high level of persistence, and that the structures across countries show little evidence of convergence (Traù, 1999).

dummies, so that we net out the average growth rate at the sectoral level: our estimates will relate each sector's own growth in deviation from the average sectoral growth rate across countries to size, again in deviation from the cross-country mean. This ensures that our results are not driven by the particular growth performance of any sector over the sample period. Moreover since, as we have shown, the countries in our sample are characterized by systematic size differences, we run our basic specification without country dummies, which would pick up a large part of the size effect we are trying to capture. This of course leaves the door open to the criticism that our results might be due to some omitted country variable, an issue that we will come back to in the next section. We always report heteroskedasticity-corrected standard errors.

The results of this basic regressions are reported in Table 6. The first column anticipates a result that will hold throughout all our analyses: *the average firm size is positively correlated with growth in value added per worker.* The coefficient of the average size is .018, and significant, with a t-statistic of 2.9. To get a crude appreciation of this result, it implies that, *ceteris paribus*, if average firm size increases by 10 per cent, the annual rate of growth of per capita value added would increase roughly by .18 percentages.

The positive correlation between size and growth might seem in contrast with the conventional wisdom that small firms are the most dynamic component of industry and grow faster than large ones. But, this is not so for two reasons. First, small (young) firms do grow fast, but *conditional on surviving*, and their exit rates are much higher (Dunne et al., 1989). Once this is taken into account, the results change drastically. For example, Davis et al. (1996) find a marginal role of small firms in job creation and destruction for the US economy. Second, we are not interested in individual growth rates for different size classes, but in the effect of a given steady-state size distribution on productivity growth at the sectoral level. In this respect, we find that larger size is associated with faster productivity growth.

The other columns of Table 6 expand the basic specification and run checks of robustness. Labor productivity depends on the capital/labor ratio, so when explaining changes in productivity one must control for changes in investment rates. The positive correlation between average firm size and productivity growth might be because our definition of firm size spuriously captures the effect of capital intensity on growth. However the result of column 1 holds even when we further control (column [2]) for country/sector differences in investment rates — a proxy for capital intensity — and also (column [3]) for country differences in human capital, indicating that the effect of average firm size on growth goes "above and beyond its effects on the incentives to invest" (Sala-i-Martin, 1997)[12]. The coefficient of initial real value added per worker is always negative, providing evidence of convergence across countries (within sectors)[13].

Eeckhout and Jovanovic (1998) study the relationship between the characteristics of the technological process, the size distribution of firms and steady-state investment and growth. They consider firms' ranking by capital and show that the dispersion in size can have positive or negative effects on growth depending on whether technological progress is "free-riding" or "rent-grabbing". When returns from investment are appropriable, a firm has a strong incentive to invest in order to improve its size ranking; when the distribution is very disperse, however, the cost of improving rank is greater than when it is concentrated, so inequality reduces growth.[14] In the free-riding case, each firm can benefit from spillovers from higher-ranking firms. Given that a higher ranking decreases access to the usable knowledge of others, the prospect of improving one's ranking is a deterrent to investment. In this case, the more disperse the distribution, the lower the increase in ranking due to investment. Therefore, dispersion reduces the negative component of return to investment from external economies and thus increases investment incentives and growth.

To investigate this issue, we need a measure of size dispersion. Unfortunately, our dataset only allows us to compute dispersion across classes; we have no information on dispersion within classes, which is likely to be the most important component of overall dispersion. As a measure of dispersion, we use the negative of the standard deviation of sectoral employment across classes. When employment is concentrated in one class, size dispersion is minimum (and standard deviation maximum); when it is equally distributed across classes, the reverse is true. Column (4) reports the results for the basic regression with the addition of the dispersion

[12] We have also experimented with the measures of human capital recently constructed by De la Fuente and Domenech (2000), with similar results.

[13] Bernard and Jones (1996) find that value added per worker in manufacturing does not exhibit convergence in a sample of OECD countries after 1975. This finding is not directly comparable with our result since we do not weight sectors with their own share in manufacturing and therefore the coefficient of y_0 cannot be used to recover the speed of convergence of value added per worker in total manufacturing across countries.

[14] A similar result is obtained in a class of models that study the incentives to develop a multi-stage patent: when competitors are close to each other, the rate of investment in R&D is higher (Budd, Harris and Vickers, 1993).

measure. We find suggestive evidence of a negative effect of dispersion on growth: the coefficient of the variance is negative but imprecisely estimated (the p-value is .15). Similar indications emerge when we use alternative measures of dispersion. We conclude that this aspect deserves further investigation, based on a more precise measure of variability than that available in our dataset.

The last three columns of Table 6 control for the robustness of our measure of size. The first column uses a simple arithmetic mean, defined as total employment divided by the number of firms. This assign a larger weight to small firms than does the co-worker mean. The coefficient is still positive but statistically not significant. In column 6, to deal with potential measurement error because of definitional differences between countries, we proxy average firm size with the share of employment in large firms (the last size class). This produces a positive and highly significant coefficient. Finally, in column 7 we also include country dummies using the basic measure of size as in column 1. The coefficient of average size, although still positive, becomes smaller and statistically not different from zero. We interpret this result as offering further confirmation that a good part of the size variability depends on country-level differences. In the next section we will argue that our findings on the relationship between productivity growth and size cannot be attributed to omitted country variables.

As a further check of robustness, to show that the results are not driven by any particular country, we have reestimated the basic specification in Table 6, column 1, for all possible subsamples, deleting one country at time. Figure 1 displays the estimated coefficient of average firm size and the 95 per cent confidence interval around it. To facilitate comparison with the baseline, the dotted line represents the coefficient estimates with the full sample. It is evident that sample composition does not significantly affect the coefficients.

Finally, we investigate the possibility that the results may be distorted by our short time span. Table 7 exactly replicates the regressions of Table 6, using as dependent variable the growth rate of labor productivity over the entire decade. The estimates, particularly those of the size coefficient, prove very stable. The main difference is that in Table 7 the coefficients tend to be more precisely estimated. The dispersion measure is now significant at 10 per cent. Moreover, we obtain a significant correlation between size and productivity growth also when we use the arithmetic mean as an indicator of sectoral size, further evidence of the robustness of the positive correlation between average firm size and productivity growth.

4. A causality test through R&D intensity

The evidence presented in the previous section points to a positive relationship between average firm size and productivity growth. Before interpreting this result as an indication of a causal relationship between size and growth, however, we need to address two questions. First, our basic regressions do not control for country effects, because, as we have argued, by including country dummies we get rid of an important component of the variability of the size indicator. Indeed, when we include country dummies, our results disappear. Second, the regressions are not immune to the criticism that plagues most of the empirical growth literature, i.e. the difficulty of establishing the direction of causality (the so-called *post hoc, ergo propter hoc* problem). This problem originates from the fact that the explanatory variable may simply be a leading indicator — and not a causal factor — of economic growth.[15] We tackle the problems of reverse causality and omitted variables using an idea from Rajan and Zingales (1998); this involves defining some sectoral characteristic that allows us to rank sectors according to the relative importance of size for growth. This characteristic should have two properties: first, it should potentially constitute a channel through which size influences growth; and second, it should display a certain degree of sectoral variability. If we find that size has a differential effect on growth in accordance with some such characteristic, we can conclude that our results cannot be generated by some general form of spurious correlation,such as that induced by reverse causality, which should deliver a homogeneous relation between size and growth.

Following the R&D-based endogenous growth literature, as our candidate channel we take R&D intensity. It satisfies the two conditions outlined above. First, it is possible that a higher average size is more conducive to R&D and, therefore, sectors with larger firms may have higher productivity growth. The possibility that large firms might undertake more R&D was recognized by Schumpeter (1934). The fixed cost of many R&D projects implies that they are profitable only if their results can be applied to a sufficiently large production run, generating stronger incentives to invest in R&D. Moreover, R&D itself might be characterized by economies of scale and scope: once an innovation has been developed,

[15] For example, if the direction of causality runs from fast growth to larger firm size, and if the growth rate is persistent, then the positive correlation between average size in 1994 and the subsequent growth rate after that year could be due to the fact that the high growth sectors in the period we consider were growing fast earlier as well, thus inducing the ex-post correlation.

large and diversified firms may have better opportunities to exploit it. Finally, large firms presumably have greater capacity to finance R&D, with larger internal cash flow and better access to external funding. Second, there is sectoral variability in patterns of technological change and innovation opportunities and, as a consequence, equilibrium R&D intensity, as was noted, among others, by Pavitt (1984).

If we think that, *ceteris paribus,* the propensity to undertake R&D investment increases more than proportionally with size[16] or that an innovation might be better exploited by large firms, then one should expect size differences to be more relevant for growth in R&D-intensive sectors. For example, if the textile industry invests relatively little in R&D, then we should expect that size differences are not a major source of differences in growth rates. By the same token, the predominance of small size in an industry such as chemicals, typically R&D-intensive, should have a much stronger negative influence on growth.

To test this intuition, we need a classification of R&D intensity external to our data set; because the actual R&D intensity of a sector in a country is endogenous with respect to the size structure; we use different indicators of R&D intensity at the sectoral level for the US economy. The US is a natural benchmark for determining the R&D propensity of sectors in an unconstrained environment, given the relatively low level of regulation and the advanced financial system, which should minimize funding problems. Given the well known problems associated with defining and measuring R&D activity, we use three different indicators to assess the robustness of our findings: the share of people employed in R&D, R&D expenditure over investment, and R&D expenditure over value added. The values are reported in Table 8, and details of the construction of our variables and of data sources are given in Appendix A.1.

For all indicators, the sectoral rankings in Table 8 are as expected: the least R&D intensive sectors are the traditional ones, such as textile, leather and wood, while at the top we find such high tech sectors as communication equipment and precision instruments. And while we cannot directly match the classification of Pavitt (1984) because of differences in the sectoral subdivision, a clear pattern emerges: the least R&D-intensive are the "supplier

[16] There is an extensive empirical literature on the relationship between size and propensity to invest in innovative activities at the firm level (see Symeonidis (1996) for a survey). Its findings are not conclusive, also due in part to problems related to the measurement of innovative activity, the endogeneity of firm size, and industry effects. A fairly robust finding is that small firms generally do not engage in R&D, indirectly supporting the view that smaller average size would lead to lower aggregate R&D.

dominated sectors", the medium range comprises the "production intensive sectors", and at the top we have the "science-based sectors". The range of variation is greater for the indicator based on the share of personnel in R&D activity, with a ratio of 132-to-1 between the most intensive (precision instruments) and the least intensive (wood), as against to 25-to-1 for R&D/Investment (other transportation equipment vs. wearing apparel) and 42-to-1 for the R&D/Value Added (communication equipment vs. textile). The rankings are very similar across the three indicators, the main exceptions being wearing apparel, which has a higher ranking according to the R&D/Value Added indicator, and chemicals, which ranks higher in the ranking by the personnel share. The coefficient of correlation is always high and, as should be expected, highest for the last two indicators (.95), and lowest for the first two (.83).

The first test we apply is based on a split of sectors according to the ranking of the US sectors by these three indicators. For each indicator we construct a dummy (1 for sectors above a certain value — usually the median[17]— in the distribution of US sectors by R&D intensity and 0 for those below). We then split the sectors of our sample according to this dummy, with the idea that the group of sectors characterized by higher R&D intensity should display a greater impact of size on growth. We do the same splitting sectors in three sub-samples.[18]

Table 9 presents the results for a regression similar to (7) in which the size coefficient is allowed to vary between groups. All the regressions give the same result: the higher a sector's rank by the R&D-intensity indicators, the greater the effect of average firm size on growth, while for the very low-intensity sectors (columns 2, 4 and 6) we can never reject the hypothesis that the correlation between firm size and growth is nil.

A more "formal" test of reverse causality is based on the estimation of equation (7) augmented as follows:

$$g_{i,j} = \theta_0 + \boldsymbol{\theta}'_1 X + \theta_2 \ln(S_{i,j}) + \theta_3 [\ln(S_{i,j}) \times D_i] + \lambda_i + \epsilon_{i,j}. \quad (8)$$

D is the variable that captures the differential sectoral effect of firm size on growth, i.e. R&D intensity. If our sectoral classification is correct, and if the causality runs from size

[17] We control for cases in which the median splits sectors with very similar values. For further details see Appendix A.1.

[18] For further details see Appendix A.1.

to growth, the coefficient θ_3 should be positive and significant. Notice that if the thesis that size affects growth via D is confirmed, we should observe a decline in the estimate of the overall correlation of the effect between firm size and growth, captured by θ_2. If D is the only channel, only the interaction term should matter, and the estimate of θ_2 should approach zero.

Table 10 reports the results of the regressions. For all indicators of R&D intensity, the point estimate of the coefficient of firm size (s) is lower than the corresponding estimate without the interaction term (column 1 of Table 6) and, more importantly, it is always statistically not significant at conventional levels. The coefficient of the interaction term $s \times R\&D_{US}$ is always positive, and significant at 10 per cent when the indicator is employment share. When we drop the measure of average firm size (not interacted), the interaction is always significant. Our interpretation of the positive relationship between growth and this interaction term is that the influence of average firm size on growth is grater for sectors with an "intrinsically" high expenditure in R&D. In other words, the fact that the relationship between firm size and growth varies with an external sectoral ranking — namely R&D intensity in the US — leads us to conclude that the positive correlation we find is not generated by reverse causality.

The regressions of Table 10 control for sectoral but not country effects. A possible objection is that the positive coefficient of the interaction term could be due to omitted variables, varying across countries. In fact this term introduces a new source of intra-country variability that should not by wiped out by country dummies. Therefore, to limit the bias caused by the omission of potential explanatory variables at country level, we inserted in equation (8) a full set of country dummies. This amounts to restricting the exercise to a *within-country* prediction: the coefficient of the interaction term will now tell us whether *within each country* industries that are R&D-intensive grow more when firm size is greater[19].

The results, presented in Table 11, are striking. The coefficient of firm size alone is always literally nil, as expected from the result in column 7 in Table 6. On the contrary, the interaction term is positive and significant. In our opinion, this delivers quite a strong result: namely, controlling for idiosyncratic sectoral *and* country effects, we find that the impact of firm size on growth is magnified in R&D-intensive sectors. We interpret this result as supporting the thesis that average firm size affects growth through R&D intensity. This same

[19] See Appendix A.2 for a more formal derivation of this proposition.

test leads us also to conclude that there is evidence that causality actually runs from firm size to growth.

5. Concluding remarks

European countries display large variations both in sectoral specialization in the size distribution of firms within sectors. Using Eurostat data, we construct a measure of average firm size and find that differences in the size distribution within sectors play an important role in explaining cross-country differences in average firm size. We study the relationship between firm size distribution and economic growth. We find a positive association between average firm size and productivity growth. We also find evidence that size matters for growth through its influence on innovation activity.

Our results have important policy implications. First, policies and institutional settings that, by reducing firms' incentive to grow, induce a steady-state distribution of firms tilted toward small size, may adversely affect growth. The most common such policies are tax breaks and subsidies for small firms in terms of and thresholds below which some regulations, such as labor laws, do not apply. Such policies are often seen as a device to support small (and young) firms and, therefore, to foster competition and job creation. While there may be reasons to sustain firms in their infancy, particular attention should be paid to the possibility that the policies distort incentives to grow.

Second, our results shed light on some stylized patterns of R&D expenditure at country level. For example, Italy and Spain have the smallest overall firm size and their corporate R&D expenditure is approximately half that of the European Union as a whole in proportion to GDP. Our findings thus suggest that a system geared to small-scale production may be ill-prepared to appropriate the full benefits of the current phase of massive and rapid technological change.

Appendix

A.1 **Data**

The link between the classification used in section 2 and NACE Rev. 1 is reported in Table 11.

The data on value added and investment rates are from Eurostat's NewCronos, theme 4, sbs, Annual enterprise statistics available at http://europa.eu.int/new_cronos. The long time series are limited to enterprises with 20 or more persons employed and to the NACE Rev.1 C to F sectors. Growth was calculated as the compound percentage change of real value added per worker between 1994 (1989) and 1998. Descriptive statistics are given in Table 13 (by country) and 14 (by sector). Investment rates are simple time average in the period between 1994 and the latest observation in each sector, usually 1996.

With respect to Table 2, we use the most disaggregated sectoral classification, i.e. the two-digit level for NACE Rev. 1. The only exception is sector 30 (computers and office machinery), which is lumped together with sector 29 (machinery and equipment not otherwise classified), because it employs a very small fraction of the labor force (0.2 per cent for the Eu15 aggregate) and is characterized by a rather erratic productivity path.

The sectors used in the growth regressions are in Table 15.

The data on human capital, measured as average years of schooling in the population over age 25 in 1985, are from Barro and Lee (1993).

The data on R&D in US sectors — to construct the reverse causality test — are:

1) *Share of R&D personnel in total employment*, in 1994, constructed as the percentage ratio between "Total R&D personnel and research scientists and engineers in the business enterprise sector, in full time equivalent" (from OECD's Basic Science and Technology Statistics) and "number of employees" (from Eurostat's NewCronos);

2) *R&D investment ratio*, average 1990 to 1994, is " R&D expenditure as a percentage of total physical investment" (from OECD's Main Industrial Indicators);

3) *R&D intensity*, average 1990 to 1996, is " R&D expenditure as a percentage of value added" (from OECD's Main Industrial Indicators).

In Table 9 for the ratio between R&D and total employment in column 1 we label as $high$ sectors above the median (1 per cent); in column 2 we label as $high$ sectors above 3 per cent and as low sectors below 0.6 per cent. For the ratio between R&D expenditure and investment in column 3 we label as $high$ sectors above the median (20 per cent); in column 4 we label as $high$ sectors above 60 per cent and as low sectors below 10 per cent. For the ratio between R&D expenditure and value added in column 5 we label as $high$ sectors above 7 per cent; in column 6 we label as $high$ sectors above the 9 per cent (75th percentile) and as low sectors below 1.2 per cent.

A.2 **The reverse causality test**

In this appendix we show that the coefficient of the interaction term in equation (8), when country dummies are included, tells us whether in each country the industries that are more R&D-intensive grow more the larger the firm size.

We use the analogy with the within estimator with a two-way error component (Baltagi, 1995). Assume that in each country/sector the average firm size is the sum of the average firm size in the country (across sectors) and the average firm size in the sector (across countries)

$$s_{ij} = C_j + T_i.$$

Abstracting from the other regressors, the augmented version of equation (8) is

(9) $$g_{i,j} = \theta_0 + \theta_3 \left[s_{i,j} \times D_i\right] + \lambda_i + \mu_j + u_{i,j},$$

where μ's are country dummies. The average across sectors is given by

(10) $$\bar{g}_{\cdot j} = \theta_0 + \theta_3 \left[C_j \times \bar{D}_{\cdot} + \bar{T}_{\cdot} \times \bar{D}_{\cdot}\right] + \mu_j + \bar{u}_{\cdot j};$$

that across countries is

(11) $$\bar{g}_{i\cdot} = \theta_0 + \theta_3 \left[\bar{C}_{\cdot} \times D_i + T_i \times D_i\right] + \lambda_i + \bar{u}_{i\cdot},$$

while the overall mean is

(12) $$\bar{g}_{\cdot\cdot} = \theta_0 + \theta_3 \left[\bar{C}_{\cdot} \times \bar{D}_{\cdot} + \bar{T}_{\cdot} \times \bar{D}_{\cdot}\right] + \bar{u}_{\cdot\cdot}.$$

Subtracting (10) and (11) from (9), and adding (12), gives

(13) $$\tilde{g}_{i,j} = \theta_3 \left(D_i - \bar{D}_{\cdot}\right)\left(C_j - \bar{C}_{\cdot}\right) + \tilde{u}_{i,j},$$

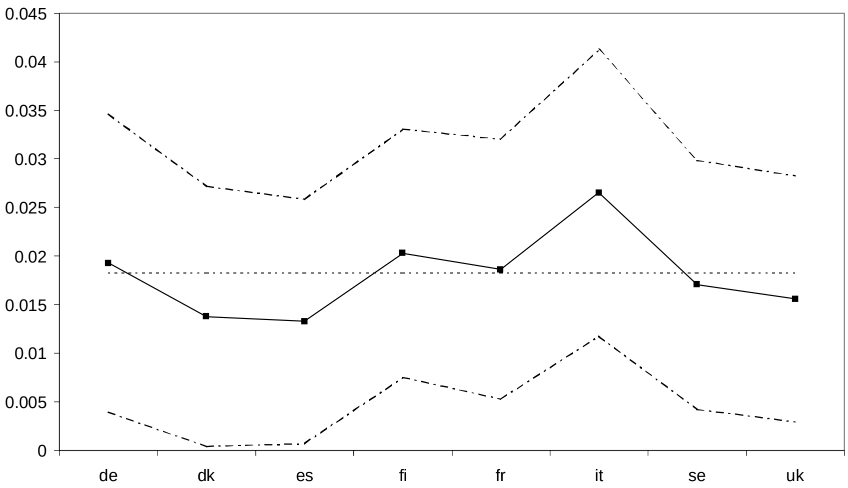
where $\tilde{g}_{i,j} = g_{i,j} - \bar{g}_{\cdot j} - \bar{g}_{i\cdot} + \bar{g}_{\cdot\cdot}$ and $\tilde{u}_{i,j} = u_{i,j} - \bar{u}_{\cdot j} - \bar{u}_{i\cdot} + \bar{u}_{\cdot\cdot}.$

According to equation (13), θ_3 tells whether R&D-intensive sectors have higher productivity growth in countries with larger firms, and whether, for given average firm size in a country, the impact of the firm size on industry growth is greater in the more R&D-intensive sectors.

Tables and figures

Figure 1

Robustness of α_2 to country deletion



Note: point estimate and 95 per cent confidence intervals of α_2 (specification [1] in table 6) after excluding the country shown on the horizontal axis. The dotted line is the coefficient estimate with the whole sample.

Table 1

Firm size as percentage of EU15 average

	eu15	de	dk	es	fi	fr	it	se	uk
Real estate	81.66	0.76	0.22	0.37	0.94	0.91		1.32	
Wood	103.96	1.90	1.75	0.34	3.21	0.68	0.21	1.63	0.93
Leather	105.10	0.48			0.77	2.05	0.51	0.47	2.21
Construction	106.72	1.23	1.17	1.06	1.86	1.32	0.38	3.36	0.86
Textile	175.35	1.86	0.61	0.65	1.06	0.95	0.48	0.49	1.96
Hotel&rest.	182.68	0.83	0.71	0.33	1.31	0.84	0.43	0.78	3.56
Other serv.	204.85	1.40		1.22	2.44	0.72	0.68	1.08	1.38
Business services	254.28	1.14	1.12	0.63	0.77	1.40	0.30	0.70	1.23
Pap.&pub.	300.65	1.57	1.63	0.51	2.99	0.72	0.60	1.28	0.97
Metal prod.	305.03	1.55	0.45	0.59	1.71	1.05	0.48	1.22	0.90
Non-met. prod.	319.66	1.84	1.16	0.50	0.79	1.35	0.44	0.81	1.38
Food	338.66	0.91	1.95	0.58	1.68	0.84	0.75	1.69	2.46
Trade	343.04	1.35	1.11	0.44	0.63	0.76	0.16	0.62	2.91
Transport	347.03	1.57	0.51	0.60	1.02	1.32	0.70	0.89	1.35
Rubber	394.55	1.65	0.50	0.77	0.67	1.29	0.44	0.53	0.72
Machinery	406.08	1.33	1.09	0.56	0.89	1.44	0.94	1.09	0.92
Other manuf.	532.43	2.00	0.36	0.11	0.32	0.31	0.09	0.22	0.30
Chemical	728.99	1.72	0.94	0.43	1.06	0.87	0.70	0.84	1.07
Elett. mach.	780.51	1.49	0.30	0.46	0.78	0.79	0.52	1.48	0.62
Finance	1163.84	0.94	0.66	1.15	0.92	1.03		1.53	1.55
Petroleum	1196.54	1.40				1.15	0.87		
Transp. equip.	1742.63	1.93	0.31	0.67	0.42	1.14	0.88	0.84	0.72
Total	336.33	1.58	0.97	0.58	1.06	0.98	0.42	1.13	1.58

Table 2

Sectoral distribution of employment as ratio to EU15 average share

	eu15	de	dk	es	fi	fr	it	se	uk
Real estate	1.31	0.77	0.32	0.78	1.37	2.12	0.48	2.75	1.09
Wood	0.96	1.05	1.10	0.98	2.62	0.68	1.38	1.84	0.51
Leather	0.50	0.24	0.27	1.18	0.67	0.77	3.54	0.14	0.45
Construction	9.15	0.87	1.17	1.28	0.76	1.14	0.99	1.00	0.90
Textile	2.43	0.54	0.62	0.97	0.64	0.79	2.30	0.27	0.84
Hotel&rest.	5.61	0.74	0.89	1.46	0.64	0.84	1.07	0.60	1.22
Other serv.	3.71	1.04	0.53	1.06	0.69	0.89	0.93	0.61	1.23
Business services	11.13	1.10	0.95	0.95	0.75	1.07	0.71	0.96	1.23
Pap.&pub.	2.28	0.93	1.85	0.77	3.19	0.94	0.87	2.12	1.23
Metal prod.	3.70	1.11	0.99	0.86	1.17	0.98	1.47	1.23	0.80
Non-met. prod.	1.25	0.96	1.04	1.28	1.07	0.86	1.50	0.70	0.67
Food	3.51	0.94	1.79	1.17	1.32	1.17	0.98	0.90	0.70
Trade	21.20	0.77	1.26	1.21	0.88	0.94	1.15	0.97	1.00
Transport	1.35	1.06	0.85	0.84	1.30	0.98	1.01	1.25	1.10
Rubber	1.20	1.15	1.13	0.80	1.02	1.13	1.09	0.92	1.00
Machinery	2.88	1.26	1.72	0.56	1.61	0.85	1.39	1.779	0.83
Other manuf.	2.33	2.01	1.02	0.70	0.57	0.60	1.00	0.45	0.49
Chemical	1.74	1.19	0.97	0.83	1.02	1.11	0.95	0.87	0.84
Elett. mach.	3.60	1.84	0.77	0.43	1.01	0.83	0.90	0.98	0.68
Finance	4.30	1.01	1.23	0.95	1.24	0.97		0.94	1.16
Petroleum	0.17	0.77	0.07	0.55	2.74	1.36	1.14	0.69	1.32
Transp. equip.	2.32	1.27	0.67	0.83	0.79	1.23	0.97	1.67	0.90

Table 3

OLS regression of sectoral share on an index of EU15 size

	de	dk	es	fi	fr	it	se	uk
Size	.225	.031	-.152	.061	-.018	-.295	-.083	.050
	(.088)	(.123)	(.061)	(.193)	(.082)	(.166)	(.166)	.070
Constant	-.276	.782	1.807	.876	1.115	2.890	1.558	.629
	(.512)	(.718)	(.354)	(1.127)	(.482)	(.970)	(.971)	(.407)
R^2	.25	.003	.24	.01	0	.14	.01	.03

Table 4

Contribution to size difference: sectoral specialization and average size

Ctry	$\Delta_\omega/\bar{s}$	$\Delta_s/\bar{s}$	$\Delta_{\omega s}/\bar{s}$	$(s_{j-}\bar{s})/\bar{s}$
de	.10	.39	.09	.58
dk	.07	-.20	.10	-.03
es	-.06	-.39	.03	-.42
fi	.02	-.07	.11	.06
fr	-.01	-.03	.02	-.02
it	-.08	-.59	.09	-.58
se	.06	.04	.03	.13
uk	-.03	.57	.04	.58

Note: $(s_{j-}\bar{s})/\bar{s}$ is the deviation of overall mean size from the reference, $\Delta_\omega/\bar{s}$ the deviation due to sectoral specialization, $\Delta_s/\bar{s}$ the deviation due to smaller size within sector and $\Delta_{\omega s}/\bar{s}$ the deviation due to the interaction term.

Table 5

Growth and average firm size

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
y_0	-.038	-.042	-.036	-.0423	-.031	-.036	-.025
	(.018)	(.023)	(.023)	(.018)	(.018)	(.018)	(.026)
$\bar{\imath}$		.005	.008				
		(.016)	(.016)				
h_0			-.018				
			(.017)				
s	.018	.018	.019	.014	.0093	.096	.009
	(.006)	(.006)	(.006)	(.007)	(.0063)	(.033)	(.007)
v				-.0196			
				(.0137)			
Number of obs.	136	136	136	136	138	136	136
F [p-value]	.0040	.0060	.0022	.0016	.0398	.0120	.0000
R^2	.2698	.2705	.2770	.2820	.2215	.2626	.4654

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; the dependent variable is the compounded percentage change in real value added per worker between 1994 and 1998 ; y_0 is the logarithm of real value added per worker at the beginning of the period; $\bar{\imath}$ is the logarithm of the average investment rate in the period; h_0 is the logarithm of an index of human capital; s is the logarithm of average firm size, and v the logarithm of the variance, both in 1994. Firm size is defined as the co-worker mean (see text) in all columns but [5], where it is the arithmetic mean, and [6], where it is proxied by the share of employment in large firms. All regressions include a full set of sectoral dummies, column [7] includes also a full set of country dummies.

Table 6

Growth and average firm size: longer time span

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
y_0	-.059	-.067	-.069	-.061	-.060	-.059	-.028
	(.008)	(.008)	(.009)	(.008)	(.009)	(.008)	(.014)
$\bar{\imath}$		.025	.025				
		(.009)	(.009)				
h_0			.007				
			(.010)				
s	.014	.013	.012	.011	.013	.070	.004
	(.003)	(.003)	(.003)	(.004)	(.003)	(.017)	(.004)
v				-.0137			
				(.0078)			
Number of obs.	136	136	136	136	137	136	136
F [p-value]	.0000	.0000	.0000	.0000	.0000	.0000	.0000
R^2	.5516	.5830	.5852	.5634	.5241	.5330	.7181

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; the dependent variable is the compounded percentage change in real value added per worker between 1989 and 1998 ; y_0 is the logarithm of real value added per worker at the beginning of the period; $\bar{\imath}$ is the logarithm of the average investment rate in the period; h_0 is the logarithm of an index of human capital; s is the logarithm of average firm size, and v the logarithm of the variance, both in 1994. Firm size is defined as the co-worker mean (see text) in all columns but [5], where it is the arithmetic mean, and [6], where it is proxied by the share of employment in large firms. All regressions include a full set of sectoral dummies, column [7] includes also a full set of country dummies.

Table 7

R&D intensity in the US (industry averages)

Sectors	$\frac{R\&D \text{ Pers.}}{\text{Empl't}}$	$\frac{R\&D \text{ Exp.}}{\text{Inv't}}$	$\frac{R\&D \text{ Exp.}}{\text{V.A.}}$
Food&bev. (15)	.59	12.29	1.17
Textile (17)	.29	8.26	.60
Wearing app. (18)	.11	8.26	.60
Leather (19)	.29	8.26	.60
Wood (20)	.09	8.29	2.66
Paper (21)	1.69	9.41	1.11
Publishing (22)	.24	9.41	1.11
Chemicals (24)	9.67	63.56	9.70
Rubber (25)	.91	23.46	3.17
Non metallic prod. (26)	.84	19.71	2.04
Basic metals (27)	1.11	11.03	1.51
Fabric. metal prod.(28)	.71	24.46	1.41
Machinery and comp. (29+30)	3.33	142.97	12.27
Electrical machinery (31)	3.21	105.93	7.10
Communic. equipment (32)	11.45	133.64	17.27
Precision instruments (33)	11.90	204.85	18.70
Motor vehicles (34)	5.38	120.37	20.10
Other transp.equip. (35)	8.68	211.89	25.42

R&D split

R&D as →	% personnel		% investment		% value added	
variables ↓	[1]	[2]	[3]	[4]	[5]	[6]
y_0	-.0410	-.0401	-.0381	-.0379	-.0380	-.0388
	(.0179)	(.0181)	(.0180)	(.0182)	(.0181)	(.0180)
s_{high}	.0288	.0263	.0222	.0261	.0262	.0264
	(.0090)	(.0098)	(.0092)	(.0099)	(.0098)	(.0129)
s_{med}		.0215		.0202		.0162
		(.0140)		(.0136)		(.0061)
s_{low}	.0092	.0087	.0145	.0098	.0133	.0143
	(.0074)	(.0082)	(.0080)	(.0088)	(.0076)	(.0103)
Number of obs.	136	136	136	136	136	136
F [p-value]	.0004	.0009	.0023	.0009	.0014	.0039
R^2	.2900	.2831	.2729	.2813	.2782	.2755

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; the dependent variable is the compounded percentage change in real value added per worker between 1994 and 1998; splits are according to the share of R&D personnel in total employment in columns [1]-[2], the ratio of total R&D expenditure to total fixed capital formation in columns [3]-[4], and the ratio of R&D expenditure to value added in columns [5]-[6], all in the US. For further details see Appendix A.1. All regressions include a full set of sectoral dummies.

R&D interaction

R&D as →	% personnel		% investment		% value added	
variables ↓	[1]	[2]	[3]	[4]	[5]	[6]
y_0	-.0378	-.0328	-.0382	-.0335	-.0387	-.0333
	(.0180)	(.0177)	(.0181)	(.0178)	(.0180)	(.0179)
s	.0098		.0104		.0127	
	(.0073)		(.0080)		(.0081)	
$s \times R\&D_{US}$	.00269	.00387	.00013	.00021	.00078	.00154
	(.00145)	(.00114)	(.00009)	(.00007)	(.00087)	(.00066)
Number of obs.	136	136	136	136	136	136
F [p-value]	.0004	.0002	.0007	.0003	.0023	.0017
R^2	.2933	.2813	.2857	.2736	.2780	.2594

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; dependent variable is the compounded percentage change in real value added per worker between 1994 and 1998; y_0 is the logarithm of real value added per worker in 1994; s is the logarithm of average firm size in 1994; $R\&D$ is the share of R&D personnel in total employment in columns [1]-[2], the ratio of total R&D expenditure to total fixed capital formation in columns [3]-[4], and the ratio of R&D expenditure to value added in columns [5]-[6], all in the US. All regressions include a full set of sectoral dummies.

Table 10

R&D interaction: controlling also for country effects

R&D as →	% personnel		% investment		% value added	
variables ↓	[1]	[2]	[3]	[4]	[5]	[6]
y_0	-.0206	-.0210	-.0247	-.0245	-.0268	-.0257
	(.0269)	(.0240)	(.0266)	(.0242)	(.0261)	(.0243)
s	-.0005		.0003		.0019	
	(.0082)		(.0087)		(.0090)	
$s \times R\&D_{US}$	.00300	.00296	.00015	.00015	.00095	.00105
	(.00128)	(.00103)	(.00008)	(.00006)	(.00075)	(.00059)
Number of obs.	136	136	136	136	136	136
F [p-value]	.0000	.0000	.0000	.0000	.0000	.0000
R^2	.4923	.4923	.4835	.4835	.4762	.4759

Notes: OLS estimates, heteroskedasticity-robust standard error in parentheses; dependent variable is the compounded percentage change in real value added per worker between 1994 and 1998; y_0 is the logarithm of real value added per worker in 1994; s is the logarithm of average firm size in 1994; $R\&D$ is the share of R&D personnel in total employment in columns [1]-[2], the ratio of total R&D expenditure to total fixed capital formation in columns [3]-[4], and the ratio of R&D expenditure to value added in columns [5]-[6], all in the US. All regressions include a full set of sectoral and country dummies.

Table 11

Sectoral classification in section 2

Our classification	Nace classification
Wood	dd20
Leather	dc19
Construction	f 45
Textile	db17 - db18
Hotel&rest.	h55
Other serv.	o90, o92,o93
Real estate	k70 - k74
Pap.&pub.	de21 - de22
Metal prod.	dj27 - dj28
Non-met. prod.	di26
Food	da15 - da16
Trade	g50 - g52
Transport	i63
Machinery	dk29-dl30
Rubber	dh 25
Other manuf.	dn 36 - dn 37
Chemical	dg 24
Elett. mach.	dl31 - dl33
Finance	j65 - j67
Petroleum	df23
Transp. equip.	dm34 - dm35

Table 12

Growth rate of average value added per worker (1994-98): by country

Ctry	mean	median	st. dev.	No. of sect.
de	.0281	.0312	.0279	18
dk	-.0137	-.0216	.0381	15
es	-.0028	-.0048	.0272	15
fi	.0320	.0207	.0418	18
fr	.0243	.0217	.0235	17
it	.0324	.0184	.0270	18
se	-.0058	-.0105	.0469	17
uk	.0487	.0419	.0371	18
Total	.0192	.0164	.0396	136

Table 13

Growth rate of average value added per worker (1994-98): by sector

Sector (Nace class. number)	mean	median	st. dev.	No. of ctry
Food&bev. (15)	.0224	.0165	.0279	5
Textile (17)	.0118	.0158	.0223	8
Wearing app. (18)	.0353	.0389	.0202	8
Leather (19)	.0290	.0219	.0563	6
Wood (20)	.0053	.0001	.0166	7
Paper (21)	.0088	.0168	.0363	8
Publishing (22)	-.0043	-.0102	.0311	8
Chemicals (24)	.0059	.0156	.0431	8
Rubber (25)	.0011	.0052	.0201	8
Non metallic prod. (26)	.0060	.0063	.0193	8
Basic metals (27)	.0218	.0275	.0357	8
Fabric. metal prod.(28)	.0178	.0151	.0334	8
Machinery and comp. (29+30)	.0193	.0108	.0407	8
Electrical machinery (31)	.0143	.0225	.0297	8
Communic. equipment (32)	.0755	.0645	.0641	7
Precision instruments (33)	.0255	.0339	.0374	8
Motor vehicles (34)	.0261	.0314	.0551	8
Other transp.equip. (35)	.0347	.0509	.0572	7
Total	.0192	.0164	.0395	136

Table 14

Data used by country and sectors

Ctry	Sectors (Nace Rev. 1)	No. of sect.
de	da15-dm35	18
dk	db17-db18, de21-dm35	15
es	da15-db18, dd20-dl31, dl33-dm34	15
fi	da15-dm35	18
fr	db17-dm35	17
it	da15-dm35	18
se	db17-dm35	17
uk	da15-dm35	18
Total		136

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