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On the mean/variance relationship of the firm size distribution: evidence and some theory[*]

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Abstract

In this paper we make use of firm-level data for a sample of European countries to prove the existence of a positive linear relationship between the mean and the variance of firms' size, an empirical regularity known in mathematical biology as the Taylor power law. A computerized experiment is used to show that the estimated slope of the linear relationship can be fruitfully employed to discriminate among alternative theories of firms' growth.

JEL classification: L1
Keywords: Taylor power law; Firm size distribution; Stochastic growth

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1. Introduction

Ample literature on the evolution of market structures and the relationship between firm-level and industrial dynamics has provided extensive support for two key stylized facts. First, several studies based on absolute and comparative micro-evidence have documented a considerable amount of cross-country, inter-sectoral and intra-sectoral heterogeneity in firms' characteristics, performances and behaviours.[1] This fact is hardly surprising, as the determinants of firms' size and business conditions suggested by economic theory - e.g. technological opportunities, market sizes, the efficiency of financial markets, the legal environment, and the degree of market competition - vary substantially in time and across countries and sectors.

In spite of the large variability in the dynamics of the firms' population, however, international comparisons also show that the shape of the firm size distribution is invariantly highly skewed to the right, especially if all operating firms are evaluated simultaneously.[2] While the precise analytical character of the best-fitting distribution is still the argument of a heated debate – whether it is lognormal, Pareto or a mixture of the two - the uniformity of the qualitative pattern is seen as one of the most robust regularities in the field of industrial organization.[3]

A combination of these two apparently conflicting facts entails serious restrictions on the scope of the theoretical explanations economists are allowed to use when explaining why and how firms grow. A strategy which has proved successful if applied to cross-sectional micro data consists in exploiting the apparent stochasticity of the evolution of corporate sizes, in order to identify firm-level random growth processes whose invariant distributions share the same features of empirical distributions (Geroski, 2000). The most renowned constituent of the class of stochastic growth models is unquestionably the random walk model implied by the *Gibrat's law of proportional effects* (LPE), which approaches in the long-run a log-normal distribution for sizes. Building on this cornerstone, several alternative models can be easily conceived to accommodate

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[1] See Ahn (2001) for a survey of evidence based on micro-data from OECD countries.

[2] A small but significant literature has emphasized that results based on cross-sectional data tend to conceal sectoral specificities. On this point see e.g. Hymer and Pashigian (1962) and Bottazzi and Secchi (2003). Axtell *et al.* (2006) show analytically that the evidence on sectoral distributions is perfectly consistent with highly skewed – namely, Pareto – distribution for the whole universe of firms.

[3] Confining ourselves to recent references, lognormal densities have been estimated by Hart and Oulton (1996) and Cabral and Mata (2003), while evidence of power law scaling in the firms' size distribution has been reported by Axtell (2001), Gaffeo *et al.* (2003) and Ramsden and Kiss-Haypal (2000).

empirically-based violations of the LPE, like reversion-to-the mean of firm sizes, dependence of average growth rates and their volatility on age and size, or a minimum size below which firms cannot operate. As shown in de Wit (2005), a modeller could ideally tune the stochastic processes governing entry, exit, growth and decline of firms in order to minimize the distance between the steady-state distribution associated to the random growth model under scrutiny and any empirically observed distribution of firms' size.

The main contribution of this paper is to further evaluate the explanatory power of some variations on the random growth theme, by exploring their consistency with a brand new empirical regularity regarding industrial distribution dynamics. Our plan will be accomplished in two stages. First, we make use of firm-level data for a sample of European countries to show the appearance of a scaling relationship between the average size and the cross-sectional volatility of firms' dimension. The key idea consists in exploiting a concept – the Taylor power law (TPL) - originally developed in biology and ecology to describe dispersion patterns in natural populations (Taylor, 1961; Taylor *et al.*, 1978). To our knowledge, this is the first time such an exploratory technique is applied in economics. In spite of the intuitiveness of the notion involved and the easiness of the analytics one needs to detect it, the TPL proves to be an operational concept which can be successfully employed to identify dissimilarities in national productive systems by means of one single statistic, namely the estimated TPL's slope.

Subsequently, several candidate random growth models are simulated to generate synthetic firms' size histories, and artificial data for homogeneous industries are used to assess whether a positively sloped linear mean/variance relationship typically appears. The slope of computer-generated TPLs β are then compared with the ones obtained from empirical observations on different national productive systems. Two results are worth mentioning. First, simulations show that the emergence of a TPL pattern is not a general feature of stochastic growth models. In our case, for instance, a demographic model inspired to the organizational ecology literature is not able in principle to return TPLs consistent with real data. Second, computational exercises for the remaining models result in a partitioning of the space of outcomes for β into three almost disjoint subsets. In particular, we find that the candidate model retaining the higher probability to replicate real firms' growth rates changes as the value of the empirical slope of the TPL shifts across the ranges (1.55, 2.05), (2.05, 2.35) and (2.3, 3.4). Therefore, simulations are used here as a means to gain first-approximation theoretical explanations, an approach which is gaining momentum in the analysis of industrial dynamics.[4] While space constraints force

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[4] See, for instance, McCloughan (1995), Axtell (1999), Harrison (2004).

us to limit our analysis to a small set of different models, our belief is that the stylized fact introduced here can be fruitfully employed for discriminating among a sensibly higher number of alternatives.

The remainder of the paper is organized as follows. Section 2 lays out the intuition behind the simple statistics of the TPL, and it presents results at a 2-digit level for three European countries. Section 3 portrays the basics of four random growth models widely used in the literature. Results from simulations are illustrated and discussed in Section 4. Section 5 concludes.

2. A new empirical regularity: the TPL for firms' size

A relevant question for natural scientists deals with the identification of broad patterns in species' abundance and distribution either in space and time. Let S be a set of species belonging to the same taxonomic group, each species $s \in S$ being composed by a large number of homogeneous (at least along some relevant characteristic) individuals. For example, one may have data on the number of monthly cases of several contagious diseases in various cities, or data counts for different breeding bird species recorded at several routes over several years. In both cases, it is interesting to consider if there exists a species-specific relationship between the temporal or spatial variance of populations $\sigma^2(\mathrm{S}_s)$ and their mean abundance $\langle \mathrm{S}_s \rangle$. Empirical analysis in biology and ecology has shown that such a relationship typically turns out to be a power law with scaling exponent β

$$\sigma^2(S) \sim \langle S \rangle^{\beta}, \tag{1}$$

with (1) holding for more than 400 species in taxa ranging from protists to vertebrates over different ecological systems.

The intriguing trait of the TPL does not reside in the scaling relationship *per sé*, but in the values assumed by empirical estimates of the scaling exponent β. In fact, from a time series perspective $\sigma^2(S) \sim \langle S \rangle^2$ is precisely what one would expect as soon as populations' dynamics are modelled as homogeneous, independent random processes endowed with finite mean and variance.[5] Thus, an estimated slope lower (higher) than 2 signals that the per capita variability tends to decrease (increase) as the mean population abundance increases. From a spatial perspective, if there exists an equal probability of an organism to occupy a

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[5] Let X be a random variable with finite mean μ and variance σ^2, and k a constant. Then, the mean and the variance of kX are $k\mu$ and $k^2\sigma^2$, respectively. On a log-log plot, the relationship between $k\mu$ and $k^2\sigma^2$ is a line with a slope equal to 2.

given point in space, populations should be composed of many independent elements leading to a Poisson distribution, which is characterized by a variance-mean ratio equal to 1. It follows that estimates of β higher (lower) than 1 indicate spatial clustering (over-dispersion).

In their seminal contributions, Taylor and his co-authors reported estimates for β for various arthropods ranging from 0.7 to 3.08, but for the majority of species the scaling exponent lies between 1 and 2, a result largely confirmed both in ecological studies (e.g. Anderson *et al.*, 1982; Keitt and Stanley, 1998) and epidemiology (Keeling and Grenfell, 1999). Such evidence signals that the pattern of spatio-temporal distribution of natural populations is generally characterized by a significant degree of aggregation,[6] but at the same time abundant populations tend to be relatively less variable.[7] Keeling (2000) and Kilpatrick and Ives (2003) explain this empirical regularity by means of probabilistic models based on negative interactions among species and spatial heterogeneity.

As firms can be plausibly grouped into well defined sectors of activity – or, extending the biological metaphor, *species* - belonging to a national industrial system – that is, a single *taxonomic group* – which defines a common institutional and regulatory environment, it seems natural to start applying the TPL approach to economics from here. Hence, firms belonging to a certain sector *i* at year *t* may be considered as a single population. The relevant characteristic subject to measurement we choose is the members' size, so that we can calculate the mean $\mu_i(t)$ and variance $\sigma_i^2(t)$ of time *t* firms' size belonging to sector *i*.

The data we employ have been retrieved from the commercial dataset Bureau Van Dick's AMADEUS©, which contains annual balance sheet information at the firm's level for 38 European countries. For the sake of exposition, we select three countries of the Mediterranean area — namely France, Italy and Spain — which will prove to exemplify different identifiable behaviours in the relevant parameter's space. Our main point rests on the assumption that the dissimilarities rooted in the idiosyncratic institutional and regulatory national regimes surrounding firms are likely to create opportunities for growth, and to allow the deployment of management practices aimed at exploiting them, that vary from country to country. Differences in firms' structure and behaviour can then be substantiated through different reduced form laws of motion for firms' size. By limiting the number of empirical cases to one archetype for each relevant subset of the parameters' space, we can easily link estimated values to the key features of a given national industrial system, as they are translated into the building blocks of a well-defined stochastic process describing firms' growth.

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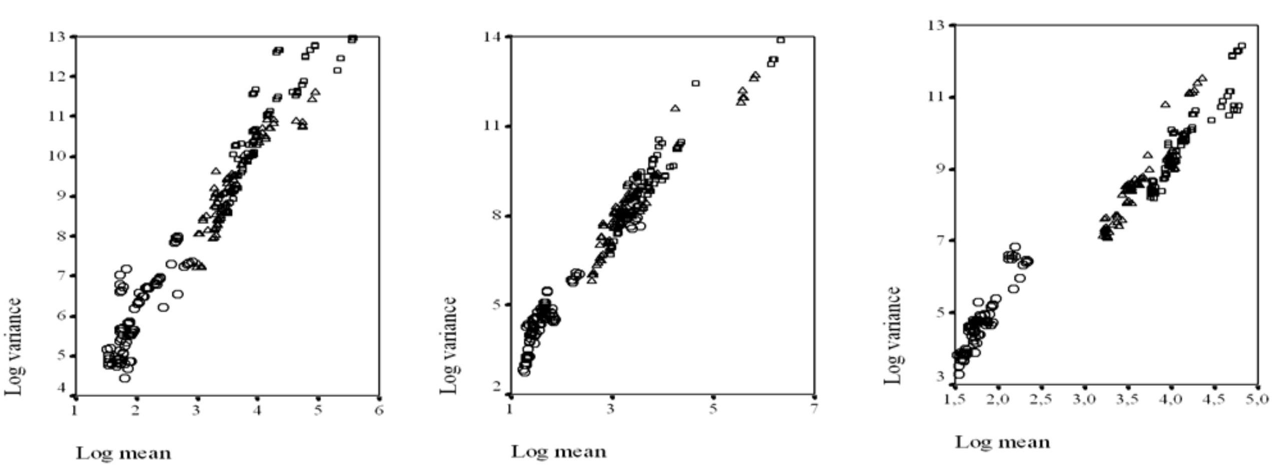
[6] In other words, upon finding one organism/individual there is an increased probability of finding another. In epidemiology, a natural interpretation is given in terms of contagion.

[7] That is, larger populations display a relatively lower probability of extinction.

Firm data cover 18 primary, manufacturing and service industries according to the 2-digit Nace Rev.1 classification from year 1996 through 2001.[8] For each country in our sample, we check for the existence of a scaling relationship between the mean and the variance of firms' size by considering three alternative measures, i.e. total assets, value added and the number of employees. Hence, for each size measurement we have 108 observations. Results of scatter plots are presented in Figure 1.



a) France *b) Italy* *c) Spain*

Figure 1. *Firms' size variance-mean plots for three European countries. Each point represents the time t (t = 1996-2001) pair [log(variance),log(mean)] for firms' size belonging to sector i (i =1,…,18) with sizes measured by total assets (circles), value added (squares) and number of employees (triangles), respectively. If the power law (1) holds, data are organized on a linear relationship with positive slope.*

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[8] The classification of industries (Nace code inside brackets) employed is: 1) Agriculture (A); 2) Manufacture of food products, beverages and tobacco (DA); 3) Manufacture of textiles and textile products (DB); 4) Manufacture of leather and leather products (DC); 5) Manufacture of wood and wood products (DD); 6) Manufacture of pulp, paper and paper products, publishing and printing (DE); 7) Manufacture of coke, refined petroleum products and nuclear fuel (DF); 8) Manufacture of chemicals, chemical products and man-made fibres (DG); 9) Manufacture of rubber and plastic products (DH); 10) Manufacture of other non-metallic mineral products (DI); 11) Manufacture of basic metals and fabricated metal products (DJ); 12) Manufacture of machinery and equipment n.e.c. (DK); 13) Manufacture of electrical and optical equipment (DL); 14) Manufacture of transport equipment (DM); 15) Manufacturing n.e.c. (DN); 16) Electricity, gas and water supply (E); 17) Construction (F); 18) Wholesale and retail trade (G).

From (1), it is immediate to note that if the TPL holds the relationship between log variance and log mean is linear:

$$\log \sigma^2 = \log a + \beta \log \mu \qquad (2)$$

with a being a scale parameter. Interestingly enough, for all three countries, and for all the three alternative size measurements as well, a linear relationship emerges neatly. In other terms, besides being typical of natural populations, the TPL seems to characterize the relationship between the mean and the dispersion around it of firms' size.

		Total assets	Value added	# of employees
France	a	1.713	1.200	1.200
		(0.442)	(0.342)	(0.342)
	β	2.056	2.161	2.161
		(0.108)	(0.170)	(0.170)
	$\bar{R}^2$	0.903	0.815	0.815
Italy	a	-3.177	-3.427	-2.095
		(0.562)	(0.475)	(0.287)
	β	3.089	3.326	3.822
		(0.135)	(0.132)	(0.159)
	$\bar{R}^2$	0.929	0.941	0.936
Spain	a	1.191	1.820	1.327
		(0.261)	(0.27)	(0.151)
	β	1.905	1.905	1.940
		(0.068)	(0.067)	(0.084)
	$\bar{R}^2$	0.952	0.953	0.931

Table 1. *OLS estimation results of the TPL parameters, as derived from equation (2) in the text. Numbers in parenthesis are standard errors. For each equation, the total number of observations is 108.*

The linear specification (2) implies that parameters can be consistently estimated by means of OLS. Regression results are reported in Table 1. All parameters are statistically significant at the 1% level, and the goodness of fit can be considered largely satisfactory in all cases. With regards to the scaling exponent β, two results deserve to be emphasized. First, for each country size measurements are quantitatively equivalent. This result is hardly surprising, as it replicates a well known finding in the literature dealing with the firm size distribution (see e.g. Hart and Oulton, 1996). Second, the slope of the TPL in its log-linear version differs substantially across countries. The estimated β turns out to be slightly below 2 for Spain, somewhat higher than 2 for France, and well above 3 for Italy.

The main gain one can buy by applying the TPL description to firm-level data is clearly the implication these results could entail with reference to the forces shaping the dynamics of market structures and firms' growth processes. Of course, a satisfactory answer would require the specification of a fully detailed choice-theoretic model, an endeavour which goes well beyond the purpose of this paper, and that we leave for future research.

As an alternative research strategy, in this paper we limit ourselves to a simulation-based analysis, with the aim of comparatively gauging the ability of a limited set of stochastic growth models to generate TPLs consistent with real data. In particular, the benchmark we shall use to assess the accuracy of each model's predictions with empirical data is the slope of the TPL we obtain through simulations. While we acknowledge that such a criterion may be deemed as unsophisticated, we will show that it proves able to return indications neat enough to be confidently used for preliminary judgements.

3. Stochastic visions of firms' growth

Abstracting from strategic considerations, a reduced form stochastic model of firms' dynamics can be rationalized along the following lines. Let us suppose that the best a firm can do to cope with a complex environment consists in sequentially searching for local goals (Cyert and March, 1963), so that the future size of a firm - its initial size being given - depends on continually moving future targets, while its current period growth is constrained solely by its internal (e.g., managerial or knowledge) resources. In other terms, internal and external constraints and unpredictable movements of future targets imply that the long-run size of a firm is undetermined, and that its actual rate of growth appears to an external observer as a random variable.

From this perspective, alternative models of growth moving from different theoretical quarters can be conceived by simply admitting suitable distributional and parametric assumptions regarding the stochastic processes governing firms' dynamics. In particular, the incidence of multiplicative and/or additive stochastic components in reduced-form models can be associated to different assumptions on the nature and intensity of the relationship between each single firm and its environment. In this paper we deal with the following four examples.

3.1 *A demographic model*

This model considers firms' size, measured in terms of employment, as the result of independent discrete processes of arrivals and departures of employees. Define $S_i(t)$ as the size of firm i at time t. Let $H_i(t)$ be the number of people hired and $F_i(t)$ the number of people fired or who resigned, during the same period. Both new appointments and lay-offs are modelled as Poisson processes with rate parameters $\lambda_i^H(t)$ and $\lambda_i^F(t)$ dependent on size and past growth:

$$\lambda_i^J(t) = \lambda^J\left(S_i(t), \frac{S_i(t) - S_i(t-1)}{S_t(t-1)}\right), \ J = H, F \qquad (3)$$

The current size affects positively both arrivals and departures of workers, while the past growth rate affects positively entrances and negatively departures. In other terms, job flows increase with size and the growth of firms' size displays inertia. The law of motion of S_i is then:

$$S_i(t+1) = S_i(t) + H_i(t) - F_i(t). \qquad (4)$$

The reduced form (4) represents an archetype of the modelling approach used by organizational ecologists in dealing with growth (Carroll and Hannan, 2000). The model can also easily accommodate the evidence on job flows in terms of gross creation and destruction by means of suitable parameterizations of the two stochastic processes (Davis *et al.*, 1996).

3.2 *A passive learning model*

The second model we consider can be seen as a variant of Gibrat's LPE framework, suitably modified to take into account some of the most important violations highlighted by the empirical literature, in particular those relating to the influence of size on growth rates and their variability. The consensus view emerged out of a profusion of econometric studies (Caves, 1998) states that: *i*) smaller firms grow faster than larger firms, and *ii*) the variance of firms' proportional growth decreases as size increases.

In formal terms, the standard LPE results from a description of firms' growth as multiplicative random processes:

$$S_i(t+1) = S_i(t)u_i(t), \qquad (5)$$

where the random variable u_i (t) is extracted from a probability distribution $U(u)$ with positive support. Under the general conditions for the Central Limit Theorem to hold true, as t gets large the distribution of $\ln S_i(t)$ approaches a Gaussian distribution with the mean and the variance growing linearly with t.

In order to take into account the two violations of the *pure* Gibrat law cited above, in simulations the stochastic disturbance term is modelled according to:

$$u_i(t) \sim iid\ N\left(\frac{\alpha}{\sqrt{S_i(t)}}, \frac{\phi}{\sqrt{S_i(t)}}\right) \tag{6}$$

with $\alpha > 0$ and $\phi > 0$. In other terms, for each firm i both the mean and the variance of the proportional growth rate are forced to decrease with the square root of the firm's size.

The model (5)-(6) can be interpreted as an estimable reduced form from the *theory of passive learning* proposed by Jovanovic (1982). If the uncertainty surrounding the true efficiency of a firm can be resolved sequentially, risk-averse entrepreneurs enter a market at a small scale. If the true efficiency is above a critical level assuring survival, the size of their firms grows in order to close the gap between the start-up size and the maximum efficiency scale. As an implication, the smallest firms will have the higher and most variable growth rates. Learning about the true predetermined level of efficiency is passive in that it is assumed that a firm's investments cannot modify it.

3.3 *A spillover model*

In this model the pure Gibrat model is supplemented with an additive random disturbance aimed at capturing the influence on growth of factors external to the firm. For example, one can assume that each firm can be affected by technological and informational spillovers emanating from similar and/or spatially adjacent firms. The evolution of the i-th firm's size is then governed by the following equation, known as the Kesten (1973) model:

$$S_i(t+1) = \lambda_i(t)S_i(t) + \gamma\mu_i(t) \tag{7}$$

where $\lambda_I(t)$ is a uniformly distributed random variable with positive support $(\lambda_{min}, \lambda_{max})$, $\mu_i(t)$ is a uniformly distributed random variable with positive support (μ_{min}, μ_{max}), and $0 \leq \gamma \leq 1$ is a parameter.

This stochastic difference equation leads to a power law distribution for sizes if the mean of the process for the multiplicative term in logs is negative,

$\langle \ln \lambda \rangle < 0$. On the contrary, if $\langle \ln \lambda \rangle \geq 0$ the long-run distribution for sizes is a log-normal expanding in time, but with a right tail which approximates a power law. In simulations, we compel to finiteness of the theoretical moments in finite times by imposing $\langle \ln \lambda \rangle = 0$.

Finally, note that the specification (7) implies that the fraction of the growth rate due to external influences is proportionally more important for small firms than for big ones, an assumption which is consistent with much of what is observed in real data (Guiso and Schivardi, 1999).

3.4 *A competence model*

The final model can be seen as a reduced form inspired to the *competence* view proposed by Penrose (1959) and Nelson (1991). In a nutshell, the competitive advantage of each single firm is based on the possession of a set of *core competencies* substantiated in bundles of skills, practised organizational routines and tacit knowledge. This theory implies that firms should possess heterogeneous characteristics (as competencies are unique) and realize heterogeneous performances over a long period of time.

An easy way to model this is to suppose that the size of firm *i* depends on an aggregate growth shock $g(t)$ and an index of its competence level $\theta_I(t)$:

$$S_i(t+1) = S_i(t)[1 + g(t) + \theta_i(t)], \qquad (8)$$

where competences are assumed to evolve over time according to:

$$\theta_i(t) = \eta \theta_i(t+1) + \varepsilon_i(t) \qquad (9)$$

with $g(t)$ and $\varepsilon_i(t)$ identically and independently distributed according to a Gaussian with mean 0 and standard deviation σ_g and σ_ε, respectively. We further assume that $\eta < 1$, so that (9) describes a process in which increments in individual competences depend on the previously acquired abilities, but competence levels gradually revert to some long run mean level.

In this model, firms which possess a competitive advantage ($\theta > 0$) gain larger market shares, firms with no particular competences ($\theta = 0$) grow at the common growth rate $g(t)$, while those firms which are incompetent ($\theta < 0$) grow even slower.

3.5 *Summing up*

Although the four models we presented are all grounded on common ingredients and a common view — the one according to which the driving forces of corporate growth are largely unobservable, and thus from an empirical viewpoint one cannot do more than use random processes in modelling them — it appears that alternative combinations of few building blocks allow us to generate reduced forms compatible with a large range of theoretical accounts. In order to increase the explanatory power of the stochastic models sketched above, however, several additional features should be added, in particular as regards entry and exit processes. While we concede that these issues are of primary importance, in this paper we decide to bypass them. The main reason is that we prefer instead to focus on the barebones of firms' dynamics – in this case, the properties of the random forces leading to the decline and the increase in the size of operating firms - under the contention that the simpler the model, the easier it is to concentrate on the microeconomic mechanisms underlying the emergence of aggregate regularities.

4. Simulation results

The four models described in the previous Section are used to generate simulated industry histories through computerized simulations. Artificial data are then employed to calculate the long-run firms' size distribution; to inspect the emergence of a TPL, its slope and the appropriateness of a linear fitting to mean-variance relationships; and, in principle, to check the sensitivity of results to parameter values.[9]

Since the object of our analysis consists in examining the emergence of a stylized fact in extremely general models, no serious attempts of calibration have been made. The value of the parameters used in baseline simulations are reported in Table 1. All simulations for the alternative scenarios are based on four common initial conditions:

1. The number of operating firms per scenario is invariably 1000;
2. Each history lasts 1000 periods;
3. Each firm is assigned an opening size of 100 units. Artificial industrial systems are then allowed to *grow* according to the assigned stochastic laws of motion, without any additional external intervention.

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[9] Results regarding robustness checks *via* Montecarlo simulations in the 10 parameter spaces are not reported due to space constraints, but are available upon request. It must noticed, however, that for reasonable variations around the mean value considered in benchmark simulations our results are not qualitatively affected.

4. Each scenario is replicated 100 times through independent (Montecarlo) simulations. For the sake of comparison, the four scenarios share the same seeds of the pseudo-random generator each time a replication is run.

$\alpha = 5$	$\mu_{\min} = 0$
$\phi = 10$	$\mu_{\max} = 1$
$\lambda_{\min} = 0$	$\sigma_g = 1$
$\lambda_{\max} = 2$	$\sigma_\varepsilon = 1$
$\gamma = 1$	$\eta = 0.8$

Table 2. *Parameter values used in baseline simulations*

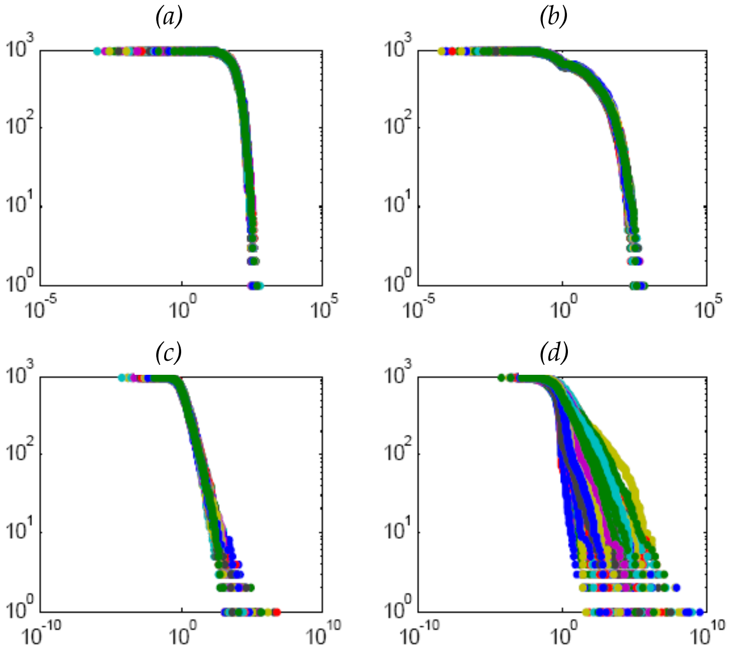

Figure 2. *Log-log plots of the firms' size distributions. Each panel reports results for 100 Montecarlo replications. (a) Demographic model; (b) Passive learning model; (c) Spillover model; (d) Competence model.*

Panels (*a*)-(*d*) of Figure 2 displays the plots of the firms' size distributions in double-logarithmic paper resulting at the 1000th period of Montecarlo simulations for each model. In line with empirical observations, in all cases the distribution is right skewed and almost stationary. While for the demographic (Panel (*a*)) and the passive learning (Panel (*b*)) models the firms' size distribution is consistent with a log-normal fit, the upper tail for the spillover (Panel (*c*)) and the competence (Panel (*d*)) models may be approximated by the Pareto law. The competence model is the one that displays the largest dispersion in long-run outcomes.

Our key findings are reported in Figures 3 and 4. Panel (*a*) of Figure 3, in particular, indicates that a TPL — that is a positively sloped linear relationship between populations' mean and variance — does not materialize as a general feature of stochastic growth models. In fact, the demographic model generates an almost vertical aggregate (i.e., obtained by pooling outcomes from 100 replications) linear relationship, a result which is in strong conflict with empirical observations. In all other cases, a TPL appears neatly. The goodness of fit to a linear relationship — measured by the OLS adjusted R^2 — for each replication and for pooled outcomes is always higher than 0.92.

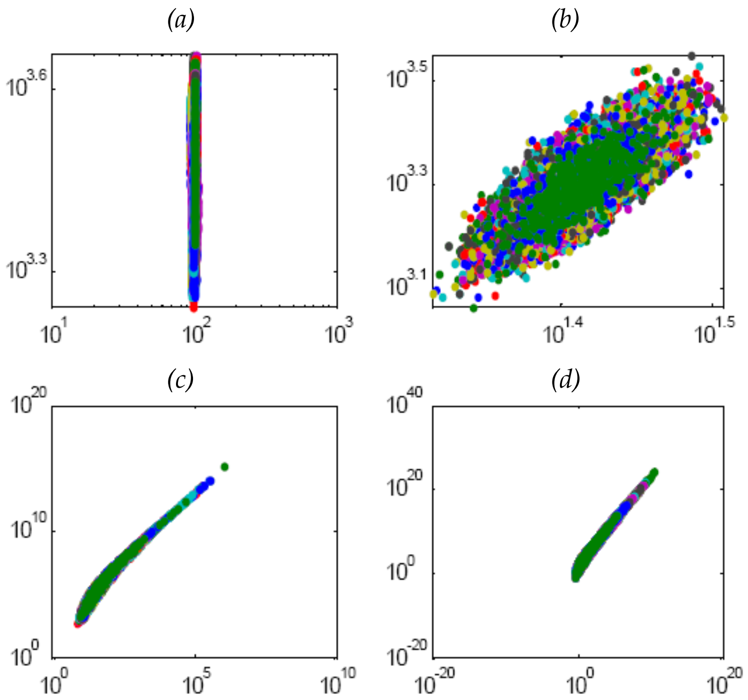

Figure 3. *TPLs emerging from simulations. Each panel reports results for 100 Montecarlo replications. (a) Demographic model; (b) Passive learning model; (c) Spillover model; (d) Competence model.*

The issue of quantitatively comparing simulation results with empirical records regarding the slope of the TPL is addressed in Figure 4, where we report the distribution of the parameter β for each model. Montecarlo replications show that the sampling distributions associated with the three models which prove capable of generating significant mean/variance relationships are defined on slightly overlapping supports, with the bulk of each distribution being confined into well-defined ranges for β. In particular, the passive learning model can generate TPLs with slope between 1.5 and 2 (Panel (*b*)); the competence model returns TPLs with slope comprised between 2 and 2.4 (Panel (*d*)); and finally, slopes in the range 2.3 – 3.5 can be produced by the spillover model (Panel (*d*)). Panel (*a*) of Figure 3 confirms that the demographic model does not yield any useful insight from a quantitative viewpoint either: the distribution of βs is bimodal, centred around 0, and extremely dispersed.

The main conclusion we draw from our computational investigations is that there exists a very high probability to detect an almost univocal correspondence between empirically-based TPL estimates on the one hand, and a unique stochastic growth model out of a set of several competing alternatives on the other. In our case, for instance, data for Spain return a TPL slope between 1.91 and 1.94, that is values consistent only with a passive learning model; France has a TPL with slope in the range 2.1 – 2.2, which is part of the support we obtained by simulating the competence model; and finally, estimates for Italy return values of the TPL slope higher than 3, a result in line with the spillover model.

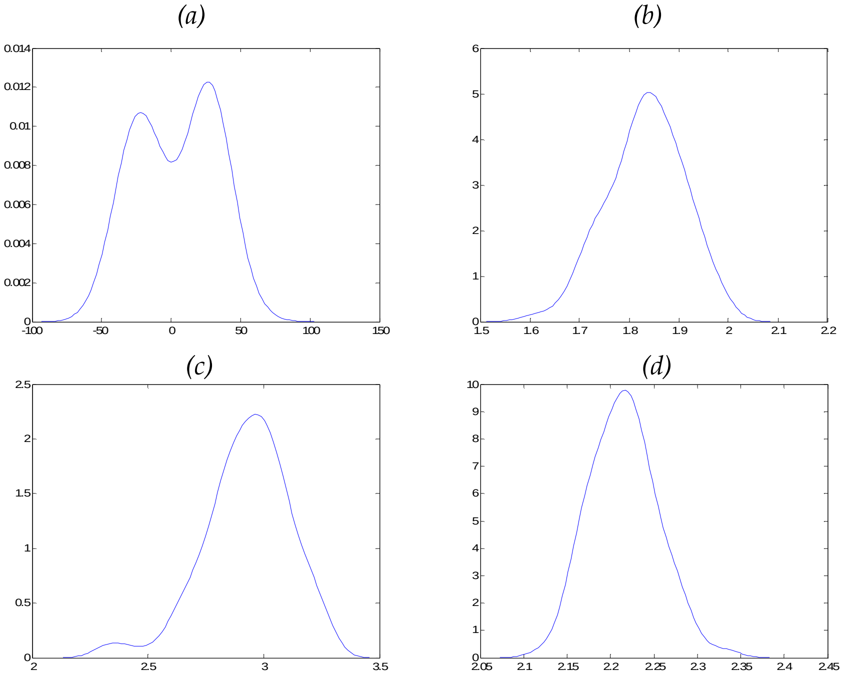

Figure 4. *Kernel estimates of . Each panel reports results for 100 Montecarlo replications. (a) Demographic model; (b) Modified-Gibrat model; (c) Spillover model; (d) Competence model.*

Do the pairings we propose between estimates of the TPL slope obtained for different countries and reduced form stochastic growth models make any sense?

A look at the empirical literature discussing the characters and the relationships among structure, conduct and performance of productive systems at a national level seems to lend an informal support to our intuition. While a comprehensive treatment of this issue is well beyond the scope of this paper, it seems useful to briefly discuss how dispersed evidence on country-specific institutions and regulations can be usefully exploited as a guide for analysis.

As regards the Spanish industrial structure, the description of firms' dynamics in terms of a passive learning model can be motivated on the basis of the allegedly limited exploitation of scale economies occurred during the last 15 years, as reported by several sources. Starting from the beginning of the 1990s, the principal cause of increases in value-added has been employment rather than productivity growth (Molero, 2001). The structural limits in productivity improvement has been sharpened by the large — if compared to the EU average — use of temporary workers (Polavieja, 2006), that has led to a generalized deskilling of the workforce (Acemoglu, 2001). Two testable predictions of the passive learning model are that the growth rates of firms' size should display reversion to the mean and convergence in levels across sectors and regions. Both of them are largely confirmed by the available evidence at the firm level (Cuadraro-Roura *et al*., 1999; Correa *et al*., 2003; Peña, 2004; Calvo, 2006).

The key inspiration for the literature on core competencies and organizational capabilities is to explain persistent differences in profitability and growth performance among firms. The relationship we suggest between the French productive system and the competence model appears to be consistent with empirical results from a copious literature on the national and regional innovation systems on the one hand, and on recent institutional and regulatory developments on the other. Bergeron *et al*. (1998), for instance, use data regarding the adoption of US patents by French firms to find evidence of clusterized systems of innovation, with the emergence of well defined *technological competencies* (Patel and Pavitt, 1996). The competencies developed by firms operating in industries with higher performance in terms of knowledge production (namely: chemicals, electronic and communication, transport and mechanical engineering) appear to be rather homogenous, in comparison to the more diversified stock of know-how and experience available in other parts of the productive system. The existence of complex relationships among these technological specialized clusters somehow facilitates the circulation of knowledge outside the traditional buyer-customer relationship and, by this way, a diffusion of a core of technical knowledge from highly developed industries to the others. Knowledge spillovers, however, has driven so far to much weaker localization effects if compared to Italy (Combes, 2000). Persistent differences in growth performance have been supported also by a set of institutional reforms concerning the credit market. In particular, the deregulation of banking sector in

1985 has led to an increased sensitivity of lending to firm performance. The removal of any government interference on lending decisions has implied an intensification in risk aversion of borrowers, and a consequent increase in the cost of capital faced by poorly performing firms (Bertrand *et al.*, 2007).

The Italian post-war economic performance has been frequently associated with an observed peculiarity of its productive system, namely the emergence of many clusters of small and medium-sized firms specialized in the production of a particular goods, such as textile and clothing, furniture and machinery (Pyka *et al.*, 1990; Dei Ottati, 1994; Rabellotti, 1997). From a theoretical viewpoint these local systems, also known as *industrial districts*, have been conceptualized as complex networks of formal and informal interactions among small, geographically adjacent, functionally integrated and complementary firms. Their evolution and success are conditioned to the exploitation of strong local agglomeration economies due to technological and informational spillovers, and the promotion of institutions supporting the supply of public goods like trust and reputation systems. The additive component of the Kesten stochastic equation we used as reduced form of a spillover model is aimed precisely at capturing external influences on new opportunities for the growth of firms. Recent empirical work (Cingano and Schivardi, 2004; Guiso and Schivardi, 2007) has shown that dynamic externalities at the local level are in fact an important factor in explaining the experience of the Italian productive system during the last two decades, both in terms of TFP growth and of employment adjustments.

5. Conclusions

The purpose of this paper is twofold. First, we show that an empirical regularity originally introduced in biology and ecology to study the correspondence between mean abundances and dispersions of natural species – the so-called Taylor power law — holds true also for populations composed by economic agents. We employ micro-level data for a small sample of European countries to show that a positively sloped linear relationship between the (log) cross-section average and the (log) associated variance of firms' size emerges neatly, and that the slope of the relationship varies significantly among countries.

Second, we make use of simulations to illustrate how cross-country variations of the estimated TPL slope can be exploited to discriminate among alternative candidate explanations of industrial dynamics. In particular, we compare the ability to generate empirically-observed TPLs of four random growth models we read as estimable reduced form from more general, choice-theoretic models. We find that the emergence of a TPL pattern can not be seen as a general by-product of stochastic growth models. This implies that a first advantage of the stylized fact introduced above consists in allowing researchers to qualitatively discriminate among acceptable and unacceptable explanations of how firms grow. Moreover, computational exercises for plausible models result in a partitioning of the space of outcomes for the TPL slope into almost disjoint subsets. The candidate model retaining the higher probability to replicate actual firms′ growth rates changes as the value of the empirical slope of the TPL shifts over its admissible support.

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