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Does Gibrat's law hold for Swedish energy firms?

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Abstract Gibrat's law predicts that firm growth is purely random and should be independent of firm size. We use a random effects–random coefficient model to test whether Gibrat's law holds on average in the studied sample as well as at the individual firm level in the Swedish energy market. No study has yet investigated whether Gibrat's law holds for individual firms, previous studies having instead estimated whether the law holds on average in the samples studied. The present results support the claim that Gibrat's law is more likely to be rejected ex ante when an entire firm population is considered, but more likely to be confirmed ex post after market selection has "cleaned" the original population of firms or when the analysis treats more disaggregated data. From a theoretical perspective, the results are consistent with models based on passive and active learning, indicating a steady state in the firm expansion process and that Gibrat's law is violated in the short term but holds in the long term once firms have reached a steady state. These results indicate that approximately 70% of firms in the Swedish energy sector are in steady state, with only random fluctuations in size around that level over the 15 studied years.

Keywords Firm size; Firm growth; Random coefficient; Energy sector

JEL codes D22; L11; L25; L26

1 Introduction

Gibrat's law (Gibrat 1931) was the first attempt to explain in stochastic terms the systematically skewed pattern of firm size distribution in an industry (Aitchison and Brown 1957). A commonly accepted interpretation of the law is that the growth rate of a firm is independent of its size during a given period, so firm growth can be seen as purely random.

Gibrat's law is sometimes referred to as the law of proportionate effect because its basic underlying tenet is that the growth rate of a given firm is independent of firm size at the beginning of the examined period. In other words, "the probability of a given proportionate change in size during a specified period is the same for all firms in a given industry—regardless of their size at the beginning of the period" (Mansfield 1962, p. 1031). However, Audretsch et al. (2004) argue that the growth rate might differ among industrial sectors. For example, small firms might have a higher exit rate in a capital-intense industry characterized by economies of scale and high sunk costs, implying that small surviving firms should be characterized by higher growth rates than large firms. Because energy markets are characterized by exactly those features, it is germane to study whether Gibrat's law holds in this setting.

In addition, knowledge of the growth patterns of energy firms is also relevant to the recent deregulation of energy markets in Europe and the Nordic countries. Before the deregulation, the Swedish electricity market was characterized (as in most other countries) by vertically integrated monopolies handling the production, distribution, and retail of electricity. It was said that the deregulation would structure the markets for competition and eliminate potential market power. (A more detailed overview of the Swedish energy market will be provided in section 3.)

If some energy firms in Sweden are found to systematically and over time grow faster than others, this would mean that the market would eventually be characterized by high market concentration that could lead to the abuse of market power.

Many studies have tested whether Gibrat's law holds in different settings. Most recent studies of this sort tend to reject the hypothesis that growth is independent of firm size, instead finding that small firms grow faster than large firms (Audretsch et al. 1999; Calvo 2006; Dunne and Hughes 1994; Dunne et al. 1989; Evans 1987a, 1987b; Hall 1987). Other studies (e.g., Becchetti and Trovato 2002; Cefis and Orsenigo 2001; Geroski and Gugler 2004; Hart and Oulton 1996; Lotti et al. 2003; Mowery 1983) claim that Gibrat's law holds, but only for firms larger than the minimum efficient scale (MES) of production in a given industry. Meanwhile, still other studies (Bottazzi and Secchi 2005; Droucopoulos 1983; Hardwick and Adams 2002) do not reject Gibrat's law.

Most of the above studies are based on data from manufacturing industries, but there are some interesting sectoral studies as well. Service industries were investigated by Variyam and Kraybill (1992) and Johnson et al. (1999), credit unions by Barron et al. (1994), farming by Weiss (1998), the pharmaceutical industry by Bottazzi and Secchi (2005), and the retail sector by Daunfeldt et al. (2012). However, we are unaware of any study of Gibrat's law in the context of the energy sector.

In a recent study, Daunfeldt and Elert (2013) studied whether Gibrat's law holds in five-digit NACE industries in Sweden, performing the analysis at various levels of aggregation. Their results indicate that Gibrat's law is rejected at an aggregate level, with small firms outgrowing their larger counterparts. However, their results also indicate that, when the level of aggregation decreases, Gibrat's law is confirmed in approximately half of the studied industries. An apparent regularity in their results suggests that the more disaggregated the level of analysis, the more often Gibrat's law is confirmed. It would be germane to investigate Gibrat's law at an even lower level of aggregation, i.e., the individual firm level. This is along the lines of recent research suggesting that firm growth is determined mainly by firm-specific factors and should be investigated at the firm level (Daunfeldt et al. 2013; Reid and Xu 2010; Stam 2010).

This paper explicitly examines whether or not Gibrat's law is rejected at the firm level in the Swedish energy industry, using the three stages suggested by Mansfield (1962). We use a dataset representing all limited liability firms in the Swedish energy sector from 1997 to 2011. Unlike previous studies, all of which estimated whether Gibrat's law holds on average in the sample of firms studied, this paper uniquely seeks to apply Gibrat's test at the individual firm level to determine whether or not specific energy firms obey the law.

A random coefficient model in which distributional assumptions are made regarding the firm-specific coefficients is therefore constructed to test Gibrat's law at the individual firm level. This modeling approach estimates the coefficient of an average unit to determine, for example, whether or not the average firm obeys Gibrat's law, while estimating the covariance matrix measures the degree of heterogeneity for each firm, making it possible to estimate whether or not a firm obeys Gibrat's law at the individual firm level.

This paper contributes to the literature in the following ways. First, to our knowledge, this is the first paper investigating whether Gibrat's law holds on average in the Swedish energy sector. Second, as previous studies have demonstrated that the level of aggregation affects results touching on Gibrat's law, with the law being rejected more often at higher levels of aggregation, it is important to study the issue at the lowest possible level of aggregation, i.e., the individual firm level.

The present results indicate, in line with those of Daunfeldt and Elert (2013) and Lotti et al. (2009), that small firms in the Swedish energy sector, on average, grow faster than larger firms. However, this finding is weakened when studying only surviving firms and firms above the industry MES. In addition, in about 70%

of cases when either revenue or employment is used as the indicator of firm size, Gibrat's law holds at the individual firm level, meaning that, during the studied period, the growth rate of these firms represents purely random variation around a certain steady-state firm size. The results are even stronger when studying firms above the industry MES in terms of revenue or employment. In approximately 86% (revenue) and 79% (employment) of these cases, Gibrat's law cannot be rejected at the firm level. Three conclusions can be drawn from this. First, the pattern found by Daunfeldt and Elert (2013), i.e., that Gibrat's law holds more often in more disaggregated samples, is confirmed by the present study. Second, the present results also seem to confirm those of Lotti et al. (2009, p. 31), that "a significant convergence toward Gibrat-like behavior can be detected ex post". This finding indicates that market selection "cleans" the original population of firms, so that the resulting industrial "core" does not depart from a Gibrat-like pattern of growth. Third, the results are consistent with models based on passive and active learning, which can be seen as defending the validity of the "law" in the long term.

An overview of the theoretical background to Gibrat's law is presented in section 3, while section 4 examines the Swedish energy market. The data and econometric model are presented in section 4, while the results are presented in section 5. Finally, section 6 summarizes the study and draws conclusions.

2 Gibrat's law: background

Debate regarding the validity of Gibrat's law has been protracted. Initial results regarding the relationship between firm growth and firm size confirmed Gibrat's law (see, e.g., Ijiri and Simon 1974, 1977; Mansfield 1962; Wagner 1992, 1994), which predicts that the vast majority of active small firms will remain small and that there will be a scarcity of large firms in the market. Until the 1970s, the law was popular among both applied and theoretical industrial economists for two main reasons.

First, as Simon and Bonini (1958) pointed out, if one "incorporates the Law of Proportionate Effect in the transition matrix of a stochastic process … then the resulting steady-state distribution of the process will be a highly skewed distribution" (p. 609). This is a clear empirical pattern in most economic sectors, which are characterized by a lognormal size distribution with a large number of small- and medium-sized firms and a small number of large ones. The theoretical consistency between Gibrat's law and the observed size distribution across industrial sectors was also proposed by Steindl (1965).

Second, from a purely theoretical perspective, Gibrat's law has proven generally consistent with classical economic models of firm size distribution. For example, Viner (1932) suggested that business size distribution is the outcome of cost-minimizing firms, which are characterized by U-shaped long-term average cost functions when facing a given market demand. From the modern organizational theory perspective, Lucas (1978) postulated different size distributions to solve the problem of allocating productive factors over managers' various "talents" so as to maximize aggregate output. In his view, firms can be seen as collections of assets that managers can change arbitrarily from period to period. Taking this managerial perspective argument still further, more recent evidence from Vivarelli (2013) calls for an even more rigorous definition of the manager. He claims that, instead of "entrepreneur", "founder" is a more suitable term, as any set of entrepreneurial ventures can be seen as a fairly heterogeneous aggregate in which real and innovative entrepreneurs are found together with passive followers and overoptimistic gamblers. None of these theories contradicts the independence of firm growth and size, i.e., Gibrat's law.

However, in a seminal work, Mansfield (1962) investigated the US steel, petroleum, and tire sectors in different time periods, and rejected Gibrat's law in most cases. Later, he further demonstrated that if all firms from all sectors are included in the sample, Gibrat's law is also rejected; however, if only firms that survived the whole observed period are included, his results suggested no conclusions about Gibrat's law. Mansfield's results indicated that Gibrat's law holds when the included firms exceed the industry MES, so firms behave differently depending on the stage at which they are tested. Mansfield was the first researcher to question the existence of Gibrat's law; since then, others have challenged its overall validity.

The law was first challenged on a purely theoretical basis by Jovanovic (1982), who proposed a Bayesian model of noisy selection according to which only efficient firms can grow and survive. In his model of passive learning, new firm founders are seen as risk-taking agents endowed with unknown, time-invariant characteristics. During the selection process, each firm learns whether it is more efficient than the others and takes optimal action based on the evidence ex post the prior distribution. This model appears consistent with the empirical rejection of Gibrat's law in the short term (Jovanovic 1982, p. 650), but after noisy selection has been completed, there is no reason to reject the law.

The active learning model proposed by Ericson and Pakes (1995), using Jovanovic's (1982) line of reasoning, assumes that firms maximize the expected discounted value of the future net cash flow, conditional on the current information set. It assumes that the firm knows the current value of the parameter determining its profit distribution, but that this value changes over time in response to the stochastic outcomes of the firm's own investments.

Those two models based on passive and active learning suggest that the firm expansion process reaches a steady state. Gibrat's law is violated in the short term when smaller firms accelerate their growth in comparison with their larger and more experienced counterparts, but holds in the long term when firms reach their steady state.

In the late 1990s, Gibrat's law was largely defended as a general law, valid after firms achieve a MES level of output, that does not apply to smaller firms operating at sub-optimal scales (Geroski 1995) (see empirical evidence cited in section 1).

However, the more recent work of Lotti et al. (2009) found that, while Gibrat's law is likely to be rejected ex ante, convergence toward Gibrat-like behaviour over time is detected ex post; in other words, the reshaped and shrunken population of surviving and therefore most efficient firms exhibits within itself patterns of growth consistent with Gibrat's law. In this context, Fotopoulos and Giotopoulos (2010) find that, for Greek manufacturing firms, Gibrat's law is rejected for micro, small, and young firms, while it holds for medium, large, and old firms. Moreover, Daunfeldt and Elert (2013) demonstrated that the more disaggregated the data analysed, the more likely Gibrat's law was to be confirmed.

In addition, some investigations of Gibrat's law have focused on the sector level. For example, Teruel-Carrizosa (2010) provides evidence supporting the proposition that market structure affects the capacity of firms to grow, mainly due to the distinct levels of MES of different economic sectors. For this reason, studies of individual sectors would seem to be crucial.

Other studies suggest that we should move beyond Gibrat's law to empirical studies of growth processes that take account of firm-specific capabilities. Specifically, Stam (2010) argues that the historical accumulation of resources might explain the different reactions and performances of firms facing similar external shocks to firm growth. Following this line of reasoning, it is also noteworthy that Reid and Xu (2010) move beyond Gibrat's law to try to create a "comprehensive" growth model incorporating both firm-specific factors and the business environment as additional determinants of firm growth. Finally, Daunfeldt et al. (2013) investigate the growth processes of retail and wholesale firms, incorporating firm-, industry-, and region-specific variables in their empirical model. Their main finding is that firm-specific heterogeneity explains much of the variation in growth between firms.

3 The Swedish energy market

As in most European countries, the national energy market in Sweden was formerly dominated by a state-owned "national champion", Vattenfall, with a market share of more than 50%. To provide more efficient allocation of this essential service (i.e., electricity), designing and implementing electricity market reform was an urgent matter in the Nordic countries. Deregulation of European electricity markets started in 1990, and by 2006 most OECD countries had to some extent liberalized their electricity markets (Al-Sunaidy and Green 2006). In Sweden, the electricity market was deregulated in 1996, when Sweden also joined NordPool, the first international power exchange (Lundgren 2012).

Meanwhile, inspired by the 1989 electricity reform in England and Wales, the EU electricity market directive came into force in 1997, guided by the belief that competition could produce better efficiency and lower prices than could traditional regulation. So far, the electricity market reform in Sweden has been farther reaching than the EU electricity market directive prescribes.

Nevertheless, given the new regulatory framework, the major legacy companies could still exercise considerable market power on their respective home markets and jeopardize the competitive electricity markets that the reforms were intended to create. The strategy adopted to solve this problem was market integration: between 1991 and 2000, the electricity markets of Denmark, Finland, Norway, and Sweden were opened up for competition in generation and retailing and were integrated into a single Nordic electricity market.

Moreover, thanks to the large share of hydropower, in conjunction with the uneven distribution of hydropower resources between the four Nordic countries, inter-connector capacities were already quite large. The barriers to cross-border trade were institutional rather than physical.[1] By abolishing border tariffs and adopting a system of distance-independent transmission prices, the relevant market was significantly enlarged and the market power of the major generators should be gradually diluted, particularly the market power of Vattenfall in the Swedish energy market. In fact, although some major energy firms in Sweden have been continually accused of exercising market power, convincing proof is lacking (see Nylund 2013, pp. 1–2, and references therein). At the same time, power industry productivity has increased and retail electricity prices (before tax) have become strongly linked to wholesale electricity prices (Bergman 2005).

Bergman (2002) concluded that the benefits of increased competition on the electricity market are likely to be greater in the medium and long terms than in the short term. These gains will not be realized unless competition is maintained. However, as the energy market is complex, the prospects for ongoing efficient competition are not entirely positive in view of the barriers to entry, mainly in generation, and ongoing horizontal and vertical integration processes.

4 Data and empirical model

4.1 Data

To conduct the empirical analysis, we use unbalanced longitudinal firm data on Swedish limited liability firms in the energy sector during the 1997–2011 period,

[1] As the Nordic energy market is expanding, there is still a need for more interconnections between the Nordic countries. How to finance such cross-border investments and how to make transmission systems more efficient is considered by Nylund (2013) in papers 1–3.

for a total of 2185 firms and 18,137 firm-years. In Sweden, all limited liability firms are legally obliged to submit their annual financial reports to the Swedish Patent and Registration Office. The financial report data are an effective source of information on the economic well-being of firms, as they contain comprehensive information related to firm economic performance, for example, revenue, profit measures, number of employees, salaries, and fixed costs, along with a NACE code indicating the firm's main economic activity. In the data, firms are classified into the energy sector and various sub-sector industries according to the EU's NACE standard, an activity-based classification commonly employed by Statistics Sweden (SCB).

Given the panel dataset on Swedish energy sector firms, the next step in the empirical analysis was to identify the measures of firm growth needed to test Gibrat's law. A main challenge in empirical research into firm growth is to homogenize the criteria for classifying the units of observation. A large range of indicators is used in growth studies, the number of employees and revenue being the most common (Delmar 1997).

As Kimberley (1976) stated, the number of employees was the most widely used measure of firm size at the time. The number of employees reflects how internal processes are organized and adapts to changes in activity. Moreover, employment is not sensitive to inflation or currency exchange rates. This is especially useful for multi-sector analyses, in which sector-specific deflators need not be sought (Coad 2009, p. 9). Scholars agree that this variable is a direct indicator of organizational complexity and is suitable for analysing the managerial implications of growth (Penrose 1959).

However, Delmar et al. (2003, p. 331) have argued that the number of employees does not reflect "labor productivity increases, machine-for-man substitution, degree of integration, and other make-or-buy decisions". In addition, Gibrat's law, or Gibrat's law of proportionate growth, as it is sometimes called, gives rise to a continuous lognormal distribution while employment as a firm size indicator is a count data variable. Revenue, given these considerations, is then naturally taken as a better indicator of firm growth. In addition, compared with using revenue as the size variable, number of employees suffers from indivisibility, especially for small firms with only a few employees.

As they have both become common measures in the literature, and for purposes of comparison with other studies, both revenue and employment are used here to measure firm growth. However, for the reasons mentioned above, the estimated coefficients for employment should be interpreted with some caution.

Table 1 presents summary statistics for the average annual change in an energy firm's employment and revenue between 1997 and 2011. Following Mansfield's (1962) classification,[2] the dataset can be subdivided into three groups, as follows:

Type 1 – Surviving and non-surviving firms regardless of their initial size.

[2] The rationale for the classification is discussed in detail in section 4.2.

Type 2 – Surviving firms only, i.e., firms that did not survive the entire study period were dropped.

Type 3 – Surviving firms that exceed the industry MES. MES has been measured in many ways in the literature. For example, Audretsch (1995) adopts the standard Comanor and Wilson (1967) proxy for measuring MES, i.e., the mean size of the largest plants in each industry accounting for one-half of the industry's value of shipments. The most common proxies for MES are the size of the industry's median plant and the ratio of that plant's output to the industry total (Sutton 1991). In the present paper, the industry MES is measured not only as all firms' average revenue and number of employees, but also as the median of these measures during the study period.

[Table 1 about here]

4.2 Empirical model

As demonstrated by Mansfield (1962), Gibrat's law can be empirically tested in at least three ways. First, one can assume that, on average, it holds for all firms in a given industry, including those that have exited the industry during the examined period. Second, one can assume that it holds only for firms that survive the entire examined period. If survival is not independent of a firm's initial size, that is, if smaller firms are more likely to exit than are their larger counterparts, this empirical test can be affected by sample selection bias and estimates must take account of this possibility. This applies in particular to new and small firms, for which the hazard rate is generally high. Third, one can assume that Gibrat's law applies only to firms large enough to have overcome the MES of a given industry; for example, Simon and Bonini (1958) found that the law was confirmed for the 500 largest US industrial corporations. Small firms operating in industries with a high MES, such as firms in the energy sector, should have a greater propensity to grow, as crossing the MES threshold ensures that the firm is large enough to survive. In previous studies, these three different subsamples have been used to study whether Gibrat's law on average holds in the studied datasets.

An alternative perspective on this type of growth modeling is to recall that each firm appears to have its own growth trajectory or inherent growth trend (as suggested by Daunfeldt et al. 2013; Reid and Xu 2010; Stam 2010) instead of focusing directly on the response of mean growth to initial size. However, if we wish to investigate whether Gibrat's law holds at the individual firm level, this means that we would have to model firm heterogeneity in the coefficient related to the test of Gibrat's law, i.e., the coefficient related to the variable for firm size in the previous year.

To do this, one might use a fixed-coefficient approach in which the firm's individual intercepts are interacted with the variable for firm size in the previous year. This requires no assumptions regarding the distribution of the firm-specific coefficients, but suffers from an overparametrization problem in which the degrees of freedom are too few to permit reliable inference. The empirical idea proposed here is that if we instead make distributional assumptions about the random effects and random coefficients included in the model, this will also make it possible to study Gibrat's law at the individual firm level without encountering overparametrization.

In the modeling approach used here, the estimated coefficient of an average unit, for example, whether or not the average firm in our sample obeys Gibrat's law, gives us the same type of coefficient as does the general regression approach used in previous studies (e.g., Audretsch et al. 1999; Becchetti and Trovato 2002; Bottazzi and Secchi 2005; Calvo 2006; Daunfeldt and Elert 2013; Daunfeldt et al. 2012; Geroski and Gugler 2004; Lotti et al. 2003). However, unlike in previous studies, the modeling approach used here also allows us to use the estimated covariance matrix to obtain precise measures of the firm-specific heterogeneity related to the coefficient for testing Gibrat's law. The following random coefficient model is used in the estimations:

$$Ln\, S_t^i = \alpha_0 + \alpha_1 Ln\, S_{t-1}^i + \theta'_{ik} T_t + \gamma_{it} \quad (1)$$

where S_t^i is the size of firm *i*, measured as either number of employees or as revenue, in the Swedish energy industry in time period *t* (*t* = 1997 … 2011). T_t is a vector of time-specific fixed effects that is included to capture time-variant heterogeneity in growth rates. The residual (or heterogeneity) term is specified as

$$\gamma_{it} = \delta_{i1} + \delta_{i2} Ln\, S_{t-1}^i + \varepsilon_{it} \quad (2)$$

where $\delta_{i1} \sim N(0, \sigma_1)$ can be considered a "random parameter" or firm-specific random intercepts not estimated along with the fixed parameter α_0; therefore, the growth rates of the same firm are not necessarily independent given the observed covariates, which are the firm size one year before, $Ln\, S_{t-1}^i$, and the time-specific effects, T_t. Meanwhile, we also included firm-specific random coefficients or slopes, $\delta_{i2} \sim N(0, \sigma_2)$, to allow the effect of the covariate to vary over each independent firm. We assume that the covariates $Ln\, S_{t-1}^i$ and T_t are exogenous with $E(\delta_{i1} \mid Ln\, S_{t-1}^i, T_t) = 0, E(\delta_{i2} \mid Ln\, S_{t-1}^i, T_t) = 0$ and $E(\varepsilon_{it} \mid Ln\, S_{t-1}^i, T_t, \delta_{i1}, \delta_{i2}) = 0$. In addition, both random intercepts and random coefficients are assumed to be independent across firms and years. The most general model estimated thus can be written as

$$Ln\, S_t^i = (\alpha_0 + \delta_{i1}) + (\alpha_1 + \delta_{i2}) Ln\, S_{t-1}^i + \theta'_{ik} T_t + \varepsilon_{it} \quad (3)$$

or

$$Ln\, S_t^i = \beta_{i0} + \beta_{i1} Ln\, S_{t-1}^i + \theta'_{ik} T_t + \varepsilon_{it} \quad (4)$$

where $\beta_{i0} = \alpha_0 + \delta_{i1}$ and $\beta_{i1} = \alpha_1 + \delta_{i2}$. Given the above assumptions, the index parameter, α_1, will give an unbiased estimate of the average effect of firm size on firm growth in the energy industry. Gibrat's law holds on average for the Swedish energy sector if α_1 equals one.

Significantly, including the firm-specific random coefficients makes it possible to determine whether Gibrat's law holds at the firm level. In other words, the adopted methodology for the first time enables us to empirically test Gibrat's law for each individual firm in the sample, i.e., Gibrat's law holds for firm *i* if the total slope of the firm, β_1 , equals one, in which case the firm has reached a steady state around which firm size varies randomly. Consequently, we can not only describe the average firm growth pattern in the Swedish energy sector, but also provide empirical evidence regarding whether each energy firm does or does not satisfy Gibrat's law.

A firm's specific total slope can be estimated by first estimating the parameters a_0 and a_1 using the method of maximum likelihood. The total residuals, $\hat{\varepsilon}_{it} = Ln\, S_t^i - (\hat{\alpha}_0 + \hat{\alpha}_1 Ln\, S_{t-1}^i + \widehat{\theta'_{ik}} T_t)$, are obtained immediately afterwards. Then we fit individual regressions of $\hat{\delta}_{i1}$ and $\hat{\delta}_{i2}$ for both random intercepts and random coefficients on $Ln\, S_{t-1}^i$ for each firm, using the ordinary least squares (OLS) method. Each firm's total slope is therefore obtained by summing two estimated parts, i.e., $\widehat{\beta_{i1}} = \hat{\alpha}_1 + \hat{\delta}_{i2}$ (Rabe-Hesketh and Skronadal 2005, p. 161).

Following Mansfield (1962), the empirical analysis is then conducted by dividing the sample in three different ways: 1) including all firms, 2) according to whether they survived or failed during the observed period, and 3) according to whether they exceeded the MES of the Swedish energy industry. We focus on the firm-specific total slope, considering Gibrat's law at the firm level.

As the individual firms' estimated total slopes rarely equal exactly one, to determine whether the growth pattern of each firm in the Swedish energy industry is in accordance with Gibrat's law, one must assign a value to each firm's total slope. As seen from the above model, a firm's total slope consists of two parts, i.e., an unbiased estimate of the average effect of firm growth in the industry, a_1, and a firm-specific random coefficient, δ_{i2} , which is also each firm's deviation from the average effect. We say that Gibrat's law holds for a specific firm only if its individual total slope equals one, i.e., it is in its steady state, with random variation around this level during the studied period.

As the first part of the estimation gives the estimated index parameter, $\hat{\alpha}_1$, testing the null hypothesis that $\alpha_1 + \delta_{i2} = 1$ is equivalent to testing $\delta_{i2} = 1 - \alpha_1$ ($H_0: \alpha_1 + \delta_{i2} = 1 \Leftrightarrow \delta_{i2} = 1 - \alpha_1$; $H_1: \alpha_1 + \delta_{i2} \neq 1 \Leftrightarrow \delta_{i2} \neq 1 - \alpha_1$). Using the standard error of the estimated random coefficient of each firm, which comes from the second part of the estimation, we can easily calculate the *t*-statistic for each firm; this indicates the probability of the true value of δ_{i2} equalling the hypothesized value $1 - \alpha_1$. Hence, we say that a firm's total slope equals one if its converted *p*-value from the *t*-statistic is greater than or equal to 0.05.

5 Results

We start by estimating equation (3) for the three models corresponding to Mansfield's (1962) three stages of Gibrat's law for the entire Swedish energy industry, using both revenue and number of employees as measures of firm size. Meanwhile, the results of OLS estimations are also provided for comparison.

[Table 2 about here]

The results concerning whether Gibrat's law holds on average for the Swedish energy industry are generally in accordance with those of most previous studies rejecting Gibrat's law. As shown in Tables 1 and 2, the results of both the OLS regression and the random coefficient model indicate that a1 < 1 irrespective of whether we use number of employees or revenue as our firm size variable, and also irrespective of whether all firms, only surviving firms, or only firms above the industry MES are included. This implies that small firms in the Swedish energy industry, on average, grow faster than do large firms and thus that firm growth is, on average, dependent on firm size.

In addition, Table 2 shows that the average firm in the Swedish energy industry converges toward satisfying Gibrat's law (i.e., $\hat{\alpha}_1$ is increasing towards 1) when going from model (1) to model (3), especially when using the random coefficient model in the estimations and when firm size is measured by revenue. This means that Gibrat's law is more likely to hold when studying surviving firms or firms that exceed the MES of the Swedish energy industry.

Another way to interpret the results is to estimate each firm's specific total slope and determine the proportion of firms for which it can be considered to equal one. In this paper, firms' specific total slopes are assigned a value of one when their estimated total slopes are not statistically significantly different from one. We expect that Gibrat's law will hold for these firms even if the exact estimates of their specific total slopes do not exactly equal one. Here, the results indicate that 71.31% of the firms have an assigned value equalling one when firm size is measured by revenue with all firms included in the sample. Meanwhile, in 70.65% of the cases, Gibrat's law holds when firm size is measured by employment (see Fig. 1). For the models including only surviving firms and firms exceeding the industry MES, the rate at which Gibrat's law holds is even higher, especially when MES is measured as the average revenue for all firms (see Figs. 1–3).

It should be noted that the present results are in line with those of Lotti et al. (2009), who considered the effects of market selection on the evolution of the firm size distribution. In particular, Gibrat's law tends to be confirmed more often ex post after market selection has "cleaned" the original population of firms. In addition, the present results are also in line with those of Daunfeldt and Elert (2013), who demonstrated that the more disaggregated the data, the more likely

Gibrat's law was to be confirmed. However, while Daunfeldt and Elert (2013) investigated this by analysing different NACE-code level data, in the present paper we can investigate this at the individual firm level.

[Fig. 1 about here]

[Fig. 2 about here]

[Fig. 3 about here]

[Fig. 4 about here]

6 Summary and conclusions

Firm growth has long been widely studied in the economic literature. However, classical economists found it difficult to explain the presence of firms of heterogeneous sizes in the same industry. In this sense, Gibrat's law, which states that firm growth is a purely random effect resulting in firm sizes following a lognormal distribution, fits the empirical evidence well. However, most research investigating whether Gibrat's law holds has used the ordinary least squares method to test whether or not the law holds on average in different industries. From the modelling perspective, such research ignores a firm's internal characteristics and growth trajectory.

We attempt to solve this problem empirically by using a random coefficient model to study whether Gibrat's law holds for individual firms in the Swedish energy industry. The results reject Gibrat's law from an "average" point of view: on average, small firms grow faster than do their larger counterparts in the Swedish energy industry.

However, when examining each firm individually, we find that many Swedish energy firms behave in accordance with Gibrat's law. We reemphasize that those firms are considered to be in their steady state, in which the stochastic process generating the firm size could be characterized by the behaviour described in most passive or active learning models. In addition, when the selection effect discussed by Lotti et al. (2009) is taken into account, Gibrat's law holds for an even larger share of firms.

Our data reflect the process immediately after the Swedish electricity market was deregulated in 1996. The rationale for the deregulation was to help develop a more competitive Nordic electricity market. The present results indicate that the Swedish energy market seems to have worked fairly well during its nearly 20 years of operation and that. On average, the results indicate that smaller firms grow faster than larger firms in the Swedish energy sector and that, when examining individual firms, the proportion of large firms growing faster than small firms is quite small.

In conclusion, the main finding of this study is consistent with recent theoretical models of market selection and confirms the validity of Gibrat's law at the firm level. When selection has been completed, a steady state is reached by most firms in the energy industry.

Finally, this study has certain limitations that highlight some interesting avenues for future research.

First, notwithstanding the ability to apply Gibrat's test at the level of individual energy firms using the adopted methodology, the present paper does not explain what firm-specific capabilities lead to different levels of firm growth when firms face similar external environments. A more comprehensive growth model may serve as a workable alternative when further investigating the determinants of firm growth in the Swedish energy sector.

Second, most firms in the Swedish energy sector seem to have reached their steady-state operational size. There is a literature that discusses whether there is an optimal firm size, and the firms studied here are at their optimal size at least in the sense that it is the firm size desired by their owners, boards of directors, and CEOs. However, is this size also optimal in the sense that firms that have reached their steady state are more profitable than other firms?

Third, and finally, the methods suggested here could also be used to study whether Gibrat's law holds at the firm level in other industries and/or geographical areas. The answers to these three questions are outside the scope of the present paper but could be interesting topics for future research in the field of firm growth studies.

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Table 1 Average summary statistics in natural logs.

All firms

VARIABLES	(1) *n*	(2) Mean	(3) Sd	(4) Skewness	(5) Kurtosis
ln(revenue)	18,137	8.623	2.556	0.138	3.025
ln(employment)	11,270	1.860	1.591	0.846	3.210

Surviving firms

VARIABLES	(1) *n*	(2) Mean	(3) Sd	(4) Skewness	(5) Kurtosis
ln(revenue)	10,178	8.916	2.554	0.0862	2.963
ln(employment)	6901	2.003	1.616	0.752	3.065

Firms exceeding the industry MES (mean)

VARIABLES	(1) *n*	(2) Mean	(3) Sd	(4) Skewness	(5) Kurtosis
ln(revenue)	1995	13.081	1.098	1.247	4.072
ln(employment)	2536	4.253	0.965	1.274	4.129

Firms exceeding the industry MES (median)

VARIABLES	(1) *n*	(2) Mean	(3) Sd	(4) Skewness	(5) Kurtosis
ln(revenue)	7849	10.715	1.098	0.770	3.439
ln(employment)	7932	2.342	1.451	0.920	3.361

Table 2 Comparison of OLS and the random coefficient model.

SIZE	Model (1): All firms				Model (2): Surviving firms only				Model (3): Firms exceeding the industry MES (mean)				Model (4): Firms exceeding the industry MES (median)			
VARIABLES	OLS	RC	OLS	RC	OLS	RC	OLS	RC	OLS	RC	OLS	RC	OLS	RC	OLS	RC
$\ln(\text{revenue})_{t-1}$	0.944***	0.818***			0.969***	0.842***			0.966***	0.956***			0.972***	0.799***		
	(0.003)	(0.006)			(0.003)	(0.007)			(0.007)	(0.011)			(0.003)	(0.011)		
$\ln(\text{employment})_{t-1}$			0.979***	0.926***			0.985***	0.984***			0.970***	0.952***			0.974***	0.944***
			(0.002)	(0.007)			(0.002)	(0.003)			(0.005)	(0.008)			(0.003)	(0.008)
Constant	0.525	1.487***	0.057	0.08	0.307***	1.254***	0.042***	0.044***	0.497***	0.628***	0.138***	0.207***	0.345***	2.129***	0.079***	0.152***
	(0.025)	(0.055)	(0.006)	(0.025)	(0.027)	(0.061)	(0.006)	(0.007)	(0.093)	(0.136)	(0.021)	(0.033)	(0.032)	(0.115)	(0.007)	(0.019)
Observations	18,137	18,137	11,270	11,270	10,178	10,178	6,901	6,901	1,995	1,995	2,536	2,536	9,069	9,069	9,082	9,82
R^2	0.88		0.95		0.92		0.96		0.92		0.95		0.93		0.95	
Adj. R^2	0.88		0.95		0.92		0.96		0.92		0.95		0.93		0.95	

Standard errors shown within parentheses.

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Results of random coefficient model testing Gibrat's law (percent)

Fig. 1 All firms

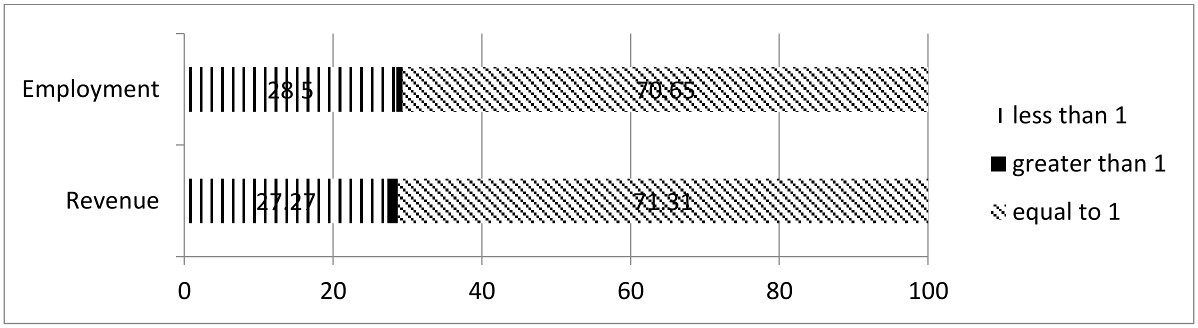

Fig. 2 Surviving firms only

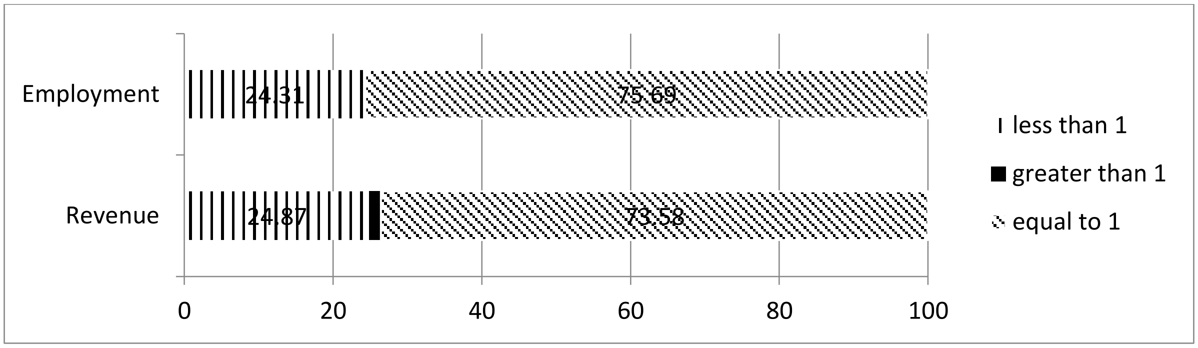

Fig. 3 Firms exceeding the industry MES (mean)

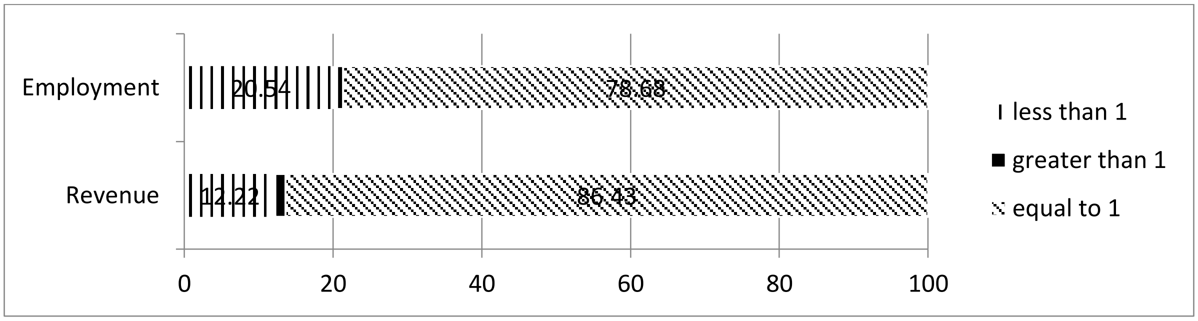

Fig. 4 Firms exceeding the industry MES (median)