Available online at www.sciencedirect.com
SCIENCE DIRECT®

ELSEVIER

Journal of Forest Economics 10 (2004) 3–19

Journal of FOREST ECONOMICS

www.elsevier.de/jfe

Effects of size and age on the survival and growth of pulp and paper mills

Xiaolei Li[a], Joseph Buongiorno[a,*], Peter J. Ince[b]

[a] *Department of Forestry Ecology and Management, University of Wisconsin-Madison, Madison, WI 53706, USA*
[b] *Forest Products Laboratory, USDA Forest Service, Madison, WI 53706, USA*

Received 17 March 2003; accepted 22 December 2003

Abstract

The growth of pulp and paper mills in the US from 1970 to 2000 depended mostly on size and age. Mills grew according to Gibrat's law, and post-1970 mills grew faster than pre-1971 mills. Mills stopped growing at approximately 22 years of age. But most mills survived beyond that, thus growth was not necessary for survival, but characteristic of the early phase of the mill life cycle. Less integrated mills grew slower. So did more specialized mills and more so if they produced mostly paper. Mill location was uncorrelated with growth, but location mattered indirectly by facilitating or hindering mills with growth-conducive characteristics.

JEL classification: C5; D23; L11; M11

Keywords: Growth; Pulp; Paper; Paperboard; Econometrics; Location; Capacity; Exit-life cycle; Survival

---

Introduction

Much of the growth of industry comes from the growth of existing establishments, rather than from new ones (Kumar et al., 2001). Rajan and Zingales (1998) find,

---

*Corresponding author.
E-mail address: jbuongio@wisc.edu (J. Buongiorno).

1104-6899/$ - see front matter
doi:10.1016/j.jfe.2004.03.003

based on the data of 48 countries, that two-thirds of the growth in industries over the 1980s came from the growth in the sizes of existing establishments. Consequently, the growth of firms and plants is an important subject of industrial economics research. Here, we concentrate on the pulp and paper industry, one of the most dynamic parts of the forest sector. The objective is to better understand some of the determinants of the survival and growth of pulp and paper mills in the United States.

There are several theories of industrial establishment survival and growth. According to Gibrat's Law of Proportional Effect, the growth rate of a mill is independent of its size (Sutton, 1997), and thus the capacity change over time for individual plants is expected to be directly proportional to the capacity of the plant. However, Gibrat's law has been challenged in some studies. Hall (1987) found that it applied mostly to large firms. Jovanovic (1982) outlined a firm learning theory, which implies that Gibrat's law should be combined with an inverse growth–age relationship. Evans (1987) refuted Gibrat's law with empirical findings of negative effects of size and age on firm growth rates. Agarwal and Audretsch (2001) showed, with a Cox survival model, that the relationship between firm size and survival is shaped by technology and the stage of the industry life cycle.

Studies specific to the pulp and paper industry include Sutton's (1973), which concluded that larger pulp and paper mills tend to grow faster, because they are more profitable. However, Buongiorno et al. (1981) found that, although large mills were more productive and profitable than small mills, the effect leveled off for mills with more than 500 employees. Indeed, Gibson (1970) suggested that mills in the pulp and paper industry could stay small and be profitable by occupying appropriate niches.

In addition to size or profitability, the degree of vertical integration in the production process was determined in previous studies to be a relevant factor in capacity growth. Ohanian (1994) found, using a transaction–cost model estimated with a Tobit regression, that vertical integration (e.g. avoiding reliance on purchased market pulp by producing wood pulp on site) was a determinant of mill growth and mill survival. The influence of other factors on growth, such as age, product type, output diversity, and location, seems to have been rarely analyzed quantitatively for the pulp and paper industry.

This study focuses on some of the potential determinants of growth for individual pulp and paper mills in the United States. Special attention is given to the effects of initial size and age of a mill, since most of the previous works concentrated on these variables. In particular, recent theories propose that the size–growth relationship can be different in different life cycles of industries (Geroski, 1995; Agarwal and Audretsch, 2001). The analysis of the effects of size and age on mill growth was done while controlling for location, product type, output diversity, and vertical integration which might also affect mill survival and growth. Nevertheless, the results suggested that the main determinants of survival and growth were indeed mill size and mill age.

Methods

Data

The data were drawn from the FPL-UW database of US pulp and paper industry mill capacity, maintained by the USDA Forest Service, Forest Products Laboratory, in collaboration with the University of Wisconsin-Madison (Ince et al., 2001). The database consists of detailed annual production capacity (but not production) records for all pulp and paper mills in the United States. Annual data are available on each individual mill's capacity, location, type of production process, and mill products (newsprint, uncoated free sheet, coated free sheet, tissue and sanitary, specialty packaging and industrial paper, kraft packaging paper, linerboard, corrugating medium, solid bleached board, recycled board, and market pulp) from 1970 through 2000. Given this time span, only the age of mills that opened after 1970 could be known exactly. Mills that already existed by 1970 were designated as "pre-1971" while the rest were the "post-1970" mills.

Summary statistics calculated with these data showed the following stylized facts:

- The total US market pulp, paper and paperboard production capacity increased from 61,899 thousand short tons (1 short ton = 0.907 metric ton) per year in 1970 to 112,429 thousand short tons per year in 2000. About 78% of this growth was achieved by expansion of pre-1971 mills, while the rest was a result of new mills opening after 1970.
- From 1970 to 2000, the average surviving mill capacity increased from 107 to 225 thousand short tons per year. Concurrently, the number of surviving mills dropped from 579 to 499. Thus, capacity expanded by mills becoming much larger on average, but fewer in number.
- The growth rate of US capacity slowed down, from an average of 2.2% per year during 1970 to 1980, to an average of 1.8% per year during 1990–2000.
- The larger the mills, the higher their probability of survival and the faster they tended to grow (Table 1).
- The survival rate of pre-1971 mills was lower than that of post-1970 mills and the younger mills grew much faster than did the older mills (Table 2).
- Capacity moved to the US South region. As in Ince et al. (2001), the South consists of Virginia, Kentucky, Tennessee, North Carolina, South Carolina,

Table 1. Survival and growth of US pulp and paper mills by size, from 1970 to 2000

	Average mill capacity (10^3 short ton yr^{-1})						
	< 100	100–199	200–299	300–399	400–499	> 500	Total
Number of mills	401	97	54	40	30	41	663
Survivors (%)	63.8	88.7	87.0	97.5	100	100	75.3
Average mill growth (% yr^{-1})[a]	−1.2	3.9	2.7	4.5	4.6	3.5	0.8

[a] Average growth rate of all mills in the category.

Table 2. Survival and growth of US pulp and paper mills by vintage, from 1970 to 2000

	Number	Survivors (%)	Average mill growth (% yr^{-1})
Post-1970 mills	84	85.7	12.7
Pre-1971 mills	579	73.7	−1.0

Table 3. Survival and growth of US pulp and paper mills by region, from 1970 to 2000

	Number	Survivors (%)	Capacity share (%)		Average mill growth (% yr^{-1})
			1970	2000	
South	182	87.9	47.7	57.1	3.2
North	404	69.6	36.4	29.1	−0.3
West	77	75.3	15.9	13.8	0.6

Table 4. Survival and growth of US pulp and paper mills from 1970 to 2000, by number of products

	Number	Survivors (%)	Average mill growth (% yr^{-1})
Single-product mills	433	68.6	−0.1
Multi-product mills	230	87.8	2.5

Georgia, Alabama, Missouri, Arkansas, Oklahoma, Texas, Louisiana, and Florida. The West includes Oregon, Montana, North Dakota, Idaho, Wyoming, South Dakota, Nebraska, Colorado, Utah, Nevada, California, Arizona, New Mexico, and Kansas. The North consists of Minnesota, Wisconsin, Michigan, Vermont, Maine, New-York, New Hampshire, Maine, Iowa, Illinois, Indiana, Ohio, Pennsylvania, Rhodes Island, Connecticut, New-Jersey, Delaware, District of Columbia, Maryland, West Virginia, and Missouri.

- From 1970 to 2000 (Table 3). By 2000, the South had more than half of the total US capacity. This happened with a much faster average mill growth in the South than in other regions.
- Among 433 single-product mills observed from 1970 to 2000, only 69% of them survived by 2000 while almost 88% of 230 multi-product mills survived, and they had a higher average annual growth rate than single-product mills. Thus, the more diversified mills tended to have better survival rates (Table 4).
- For the paper mills observed from 1970 to 2000, the average growth rate was only 0.2%. Meanwhile, the paperboard mills grew at an average rate of more than 1.1%, and also had a higher survival rate (Table 5).

Table 5. Survival and growth of US paper and paperboard mills, from 1970 to 2000

	Number	Survivors (%)	Average mill growth (% yr^{-1})
Paper mills	259	71.4	0.2
Paperboard mills	404	77.7	1.1

Table 6. Survival and growth of US pulp and paper mills, from 1970 to 2000, according to their reliance on market pulp

	Number	Survivors (%)	Average mill growth (% yr^{-1})
Mills relying on market pulp	69	24.6	−5.4
Other mills	594	81.1	1.5

- The minority of mills that relied entirely on market pulp (i.e. the non-integrated mills) had a much lower survival rate and a lower average growth rate than other mills (Table 6).

Hypotheses

The summary statistics in Tables 1–6 are only suggestive of general trends because the effect of each variable, such as mill size, is not controlled for the effects of other variables. Existing theories suggest two main testable hypotheses:

1. Larger mills are more likely to survive, and to grow faster. Theoretical reasons for this include scale economies (Sutton, 1997). A special case is Gibrat's law (Gibrat, 1931) according to which the relative growth rate is independent of size, because "the probability that the next opportunity is taken up by any particular active firm is proportional to the current size of the firm" (Sutton, 1997).
2. Older mills grow slower, and are less likely to exit the industry. A theoretical explanation of this pattern is Jovanovic's (1982) learning theory. It predicts that younger firms tend to enter an industry at sub-optimal scale, and to learn their optimal scale as they age, becoming more competitive through their life cycle. A similar argument is developed by Agarwal and Audrestsch (2001). Cabral and Mata (2003) suggest a role for financial constraint to explain the entry of firms at a sub-optimal size.

In addition, other variables may affect the survival and growth of mills, and should be controlled for in testing the effect of mill age and mill size. These additional variables include the mill location, which may reflect resource availability and access to markets (Table 3), the diversity of the output which may influence the stability of profits (Table 4), and the type of product (Table 5). Also, the more integrated mills may survive and grow better than those that rely on market pulp, due to the wide fluctuations of the price of market pulp (Ohanian (1994) and see also Table 6).

Statistical models

The complete statistical model of mill survival and growth consists of one equation to predict the probability of survival, two equations to predict the growth of mills that survived or closed, and one equation to predict the unconditional expected growth of an active mill. Consider mill *i* that has the characteristics described by the vector of variables $\mathbf{X}_i$. The mill survival rate between 1970 and 2000 is modeled as

$$\Pr(S_i = 1|\mathbf{X}_i) = h(\mathbf{X}_i\boldsymbol{\delta}), \tag{1}$$

where, S_i is a binary variable taking value 1 if the mill survived between 1970 and 2000, 0 otherwise, h is a probability function, and $\boldsymbol{\delta}$ is a vector of parameters, to be determined empirically.

The annual growth g_i of the mills that survived or closed between 1970 and 2000 is modeled as

$$E(g_i\big|S_i = 1, \mathbf{X}_i) = \mathbf{X}_i\boldsymbol{\beta}^1, \tag{2a}$$

$$E(g_i\big|S_i = 0, \mathbf{X}_i) = \mathbf{X}_i\boldsymbol{\beta}^0, \tag{2b}$$

where, $\boldsymbol{\beta}^1$ is a vector of parameters pertaining to the mills that survived, and $\boldsymbol{\beta}^0$ pertains to the mills that closed.

Then, the expected growth of an active mill, conditional on mill characteristics only is

$$E(g_i|\mathbf{X}_i) = E(g_i|S_i = 1, \mathbf{X}_i)Pr(S_i = 1|\mathbf{X}_i) + E(g_i|S_i = 0, \mathbf{X}_i)Pr(S_i = 0|\mathbf{X}_i). \tag{3}$$

In the empirical estimation, the probability of survival was estimated with a linear probability model

$$\begin{aligned}\Pr(S_i = 1|\mathbf{X}_i) = {} & \delta_0 + \delta_1 C_i + \delta_2 Y_i + \delta_3 M_i + \delta_4 D_i + \delta_5 R_{si} \\ & + \delta_6 R_{ni} + \delta_7 P_i + \delta_8 Y_i C_i + \delta_9 Y_i A_i + \delta_{10} Y_i M_i \\ & + \delta_{11} Y_i D_i + \delta_{12} Y_i R_{si} + \delta_{13} Y_i R_{ni} + \delta_{14} Y_i P_i,\end{aligned} \tag{1a}$$

where the explanatory variables are defined in Table 7. The cross products between Y_i and other variables were to differentiate the effects of different mill characteristics on the survival rate of pre-1971 and post-1970 mills. Eq. (1a) was estimated by ordinary least squares.

To check the robustness of the results with respect to the functional form, the logit and probit forms of the probability of mill survival were also estimated, with the same explanatory variables as in the linear probability model (1a). The logit model is

$$\Pr(S_i = 1|\mathbf{X}_i) = \frac{\mathrm{e}^{\mathbf{X}_i\boldsymbol{\delta}}}{1 + \mathrm{e}^{\mathbf{X}_i\boldsymbol{\delta}}} \tag{1b}$$

and the probit model is

$$\Pr(S_i = 1|\mathbf{X}_i) = \int_{-\infty}^{\mathbf{X}_i\boldsymbol{\delta}} \phi(\mathbf{X}_i\boldsymbol{\delta})\,\mathrm{d}(\mathbf{X}_i\boldsymbol{\delta}), \tag{1c}$$

Table 7. Variables used to predict the survival and growth of US pulp and paper mills from 1970 to 2000

Variable	Description	Unit
G	Growth, measured by the average annual capacity change from the first to the last year of production.	10^3 short ton yr^{-2}
S	Survival, 1 for surviving mill in 2000, 0 otherwise.	No unit
Y	Vintage, 1 for post-1970 mills, 0 for pre-1970 mills.	No unit
C	Size, measured by the average annual capacity from the first to the last year of production.	10^3 short ton yr^{-1}
A	Age, for post-1971 mills, this was the time from the first year of production to 2000. For pre-1971 mills, age was not observed.	Year
D	Output diversity, measured by the average number of products from the first to the last year of production.	No unit
M	Reliance on market pulp, measured by the ratio of market pulp capacity to the total annual mill capacity, averaged from the first to the last year of production.	No unit
R_s	1 for mills in the South, 0, otherwise.	No unit
R_n	1 for mills in the North, 0, otherwise.	No unit
P	Product type, measured by the average ratio of paper capacity to the total mill capacity from the first to the last year of production.	No unit

where ϕ is the standard normal probability density function. Eqs. (1b) and (1c) were estimated by maximum likelihood (Wooldridge, 2000, pp. 530–533).

The empirical equations of mill growth, conditional on mill survival or mill closure, (2a) and (2b), were analogous to the linear equation of the probability of survival (1a). That is, the same factors that affected survival were deemed to also affect growth, since mill closure is just an extreme case of no growth. The equation for the growth of the mills that survived between 1970 and 2000 was

$$\begin{aligned} E(g_i|S_i = 1,\mathbf{X}_i) = {} & \beta_0^1 + \beta_1^1 C_i + \beta_2^1 Y_i + \beta_3^1 M_i + \beta_4^1 D_i + \beta_5^1 R_{si} \\ & + \beta_6^1 R_{ni} + \beta_7^1 P_i + \beta_8^1 Y_i C_i + \beta_9^1 Y_i A_i + \beta_{10}^1 Y_i M_i \\ & + \beta_{11}^1 Y_i D_i + \beta_{12}^1 Y_i R_{si} + \beta_{13}^1 Y_i R_{ni} + \beta_{13}^1 Y_i P_i \quad (2\text{a}') \end{aligned}$$

and the equation for the growth of mills that closed between 1970 and 2000 was

$$\begin{aligned} E(g_i|S_i = 1,\mathbf{X}_i) = {} & \beta_0^0 + \beta_1^0 C_i + \beta_2^0 Y_i + \beta_3^0 M_i + \beta_4^0 D_i + \beta_5^0 R_{si} \\ & + \beta_6^0 R_{ni} + \beta_7^0 P_i + \beta_8^0 Y_i C_i + \beta_9^0 Y_i A_i + \beta_{10}^0 Y_i M_i \\ & + \beta_{11}^0 Y_i D_i + \beta_{12}^0 Y_i R_{si} + \beta_{13}^0 Y_i R_{ni} + \beta_{13}^0 Y_i P_i \quad (2\text{b}') \end{aligned}$$

Table 8. Summary statistics of predictors

Variable	Mean	Standard deviation	Minimum	Maximum	Number of mills
g	2.98	10.41	-45.00	98.33	663
S	0.75	0.43	0.00	1.00	663
C	145.90	179.62	2.10	1118.68	663
Y	0.13	0.33	0.00	1.00	663
A[a]	15.51	8.81	1.00	29.00	84
D	1.31	0.57	1.00	4.16	663
M	0.13	0.32	0.00	1.00	663
R_s	0.27	0.45	0.00	1.00	663
R_n	0.61	0.49	0.00	1.00	663
P	0.38	0.46	0.00	1.00	663

[a] Age of post-1970 mills.

Eqs. (2a′) and (2b′) were estimated by ordinary least squares. The summary statistics of the variables are reported in Table 8. The data for S show that three-fourths of the mills examined survived from 1970 to 2000. The mills had a wide range of average capacity (C varied from 2 to 1119 thousand short tons per year). Only 13% of the mills started producing after 1971 (variable Y). The average post-1970 mill was about 16 years old, as shown by the variable A. On average, more than one output was produced in each mill (variable D), and variable M shows that most mills did not totally rely on market pulp. Instead, they were fully or partially integrated with their own pulping facilities, or they used recycled fiber. Most of US pulp and paper mills concentrated in the North and South (variables R_s, R_n). The variable P shows that the average mill had 38% of its capacity in paper production, the rest in paperboard, although the majority of mills produced either paper or paperboard, not both.

Table 9 shows the partial correlations between the mill characteristics. Some high correlations especially between R_s and R_n (mills were mostly either in the South or in the North) suggest that it may be difficult to measure the partial effect of each region on the probability of mill survival and growth.

Results

Probability of mill survival

The results of estimation of Eqs. (1a)–(1c) are given in Table 10. The linear probability model and the probit model had about the same explanatory power, while the logit model fitted the data better, on the basis of the pseudo R^2.

The significance of the explanatory variables differed depending on the specification. The only effects that were statistically significant at 5% level in all three model versions were mill capacity, C, and reliance on market pulp, M. Other things being equal, larger mills had a higher survival rate. In addition, the mill

Table 9. Correlations between characteristics of US pulp and paper mills, 1970–2000

	Growth	Survival	Post–1970	Capacity	Output Diversity	Age[a]	Reliance on market pulp	South	North
	g	S	Y	C	D	A	M	R_s	R_n
S	0.392								
	(0.000)								
Y	0.479	0.092							
	(0.000)	(0.018)							
C	0.498	0.302	0.059						
	(0.000)	(0.000)	(0.127)						
D	0.110	0.112	−0.096	0.542					
	(0.004)	(0.004)	(0.013)	(0.000)					
A	0.342	0.178	0.856	0.083	−0.061				
	(0.000)	(0.000)	(0.000)	(0.032)	(0.115)				
M	−0.136	−0.093	−0.033	−0.044	0.027	−0.027			
	(0.000)	(0.016)	(0.389)	(0.259)	(0.489)	(0.494)			
R_s	0.284	0.180	0.162	0.444	0.103	0.171	−0.101		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.008)	(0.000)	(0.009)		
R_n	−0.254	−0.165	−0.113	−0.458	−0.192	−0.121	0.047	−0.768	
	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)	(0.002)	(0.227)	(0.000)	
P	0.097	0.469	0.023	0.039	0.11	0.041	−0.056	−0.072	0.083
	(0.013)	(0.000)	(0.549)	(0.321)	(0.005)	(0.298)	(0.151)	(0.065)	(0.032)

Numbers in parentheses are the p-values for the test of zero correlation.

[a] Age of post-1970 mills.

Table 10. Effects of mill characteristics on the survival rate of US pulp and paper mills from 1970 to 2000

	Model		
Independent variable	Linear (1a)	Logit (1b)	Probit (1c)
Constant	0.59	−1.38	−0.70
	(0.07)***	(1.65)***	(0.67)***
C	0.0006	0.01	0.007
	(0.0001)***	(0.003)***	(0.0005)***
Y	0.01	−2.00	−1.38
	(0.21)	(353606.00)	(267879.00)
M	−0.38	−5.55	−3.06
	(0.04)**	(1.29)***	(0.34)***
D	−0.004	0.56	0.26
	(0.03)	(0.45)	(0.23)
R_s	0.03	0.78	0.47
	(0.05)	(0.50)	(0.39)
R_n	−0.06	0.25	0.12
	(0.05)	(0.44)	(0.005)***
P	0.45	176.00	28.79
	(0.03)***	(4007.00)	(1008.00)
$Y \times C$	−0.0001	0.02	0.01
	(0.0003)	(0.02)	(0.009)
$Y \times A$	0.01	0.08	0.05
	(0.00)	(0.06)	(0.05)
$Y \times M$	−0.04	−39.00	−146.33
	(0.14)	(353606.00)	(299969.00)
$Y \times D$	−0.05	−1.50	−0.75
	(0.12)	(2.01)	(1.07)
$Y \times R_s$	0.11	2.04	1.26
	(0.16)	(2.45)	(1.12)
$Y \times R_n$	0.15	2.47	1.43
	(0.17)	(2.23)	(1.05)
$Y \times P$	−0.18	9.00	−7.43
	(0.09)**	(9901.00)	(6789.00)
Observations	663	663	663
R^2	0.39	0.54[a]	0.37[a]
Percent correctly predicted		93.6%	92.4%
Log-likelihood value		−170.29	−336.31

, * Coefficients significant at 0.05 level, 0.01 level.

[a] Pseudo R^2 (Wooldridge, 2000, p. 536).

survival rate from 1970 to 2000 was lower for the mills that relied more on market pulp.

The parameters of the linear probability model are the simplest to interpret. They show that a 6% difference in survival rate corresponded to a capacity difference of

100 short tons per year. In addition, a 3.8% difference in survival corresponded to a 10% difference in reliance on market pulp. The linear model also suggests that mills with a higher proportion of paper production, P, had a higher survival rate, but this was not supported by the other model forms.

Most strikingly, there was no significant difference between the survival rates of pre-1971 and post-1970 mills after controlling for the other variables, apart from the significant effect of the product $Y \times P$ in the linear model only (suggesting lower survival rates for the post-1970 mills that produced mostly paper).

Neither the diversity of product output nor the age of post-1970 mills affected significantly their survival rate. The probit model suggested that mills in the North had higher survival rates, but this was not confirmed by the other models.

Growth of mills that survived between 1970 and 2000

The results in Table 11 show that Eq. (2a′) explained 74% of the variation in growth of the US pulp and paper mills that survived between 1970 and 2000. Given survival, growth (in 10^3 short ton yr^{-2}) was affected significantly by mill size, age, output diversity, and product type.

In agreement with Gibrat's law, the capacity growth of surviving mills was proportional to their initial capacity, C. Also, mills that opened after 1970 tended to grow faster, as shown by the positive and significant signs of coefficients of Y and $Y \times C$. To each additional 100 short tons per year of capacity corresponded an additional annual growth of 2 short tons per year of capacity for pre-1971 mills and 8 short tons per year for post-1970 mills. Furthermore, among the post-1970 mills, the younger mills (smaller $Y \times A$) also grew faster. Other things being equal, a 10-year younger mill added annually 9.4 tons per year more capacity. The more specialized mills (those with a low D) grew faster. To one more product in the product line corresponded a lower annual growth of about 1 short ton per year, other things being equal. There was no statistically significant difference in growth rate by region. The negative and significant effect of $Y \times P$ indicates that the post-1970 survivor mills that produced mostly paper grew slower. Other things being equal, a post-1970 mill specializing in paper production added annually 3.3 short tons per year less capacity than one specializing in paperboard.

Growth of mills that closed between 1970 and 2000

For mills that closed between 1970 and 2000, the mean annual growth was negative (−4.1 thousand short tons per year). The results of estimation of Eq. (2b′) are given in the last column of Table 11. The adjusted R^2 shows that this model explained 42% of the variation in the growth of the mills that closed. Only two variables were statistically significant at 5% level. Among the mills that closed, the larger mills (high C), grew significantly slower than the other mills.

Because of the high correlation of R_s and R_n, these two variables together with $Y \times R_\text{s}$ and $Y \times R_\text{n}$ were tested jointly in all the models. The results failed to show a significant effect of the region on mill growth or survival.

Table 11. Effects of mill characteristics on the annual growth of US pulp and paper mills from 1970 to 2000

Independent variable	Mills that survived	Mills that closed
Constant	0.76	3.72
	(1.51)	(2.06)
C	0.02	−0.08
	(0.00)***	(0.01)***
Y	16.03	−3.72
	(4.46)***	7.82
M	−0.48	−0.27
	(1.19)	(0.95)
D	−1.03	−1.37
	(0.51)**	(1.33)
R_s	0.27	−4.49
	(0.92)	(1.76)**
R_n	−0.04	−2.78
	(0.84)	(1.45)
P	0.08	—[a]
	(0.59)	
$Y \times C$	0.06	0.08
	(0.00)***	(0.05)
$Y \times A$	−0.94	0.00
	(0.08)***	(0.25)
$Y \times V$	1.01	0.27
	(3.23)	(3.79)
$Y \times D$	0.21	1.37
	(2.08)	(6.01)
$Y \times R_s$	4.02	4.49
	(3.03)	(7.00)
$Y \times R_n$	5.59	2.78
	(3.21)	(4.56)
$Y \times P$	−3.32	—[a]
	(1.61)**	
Observations	499	164
R^2 (adjusted)	0.74	0.42

, * significant at 5% and 1% level.

[a] Mills that closed produced only paperboard products.

Expected mill growth

Eq. (3), with the parameters in Tables 10 and 11 was used to calculate the expected growth of a mill between 1970 and 2000, based on its mill characteristics only. This procedure takes into account that a mill could have survived or closed during that interval (the linear model was used to calculate the probability of survival). This equation was then applied to calculate the effect of each one of the significant variables, while holding the other variables constant at their means.

Fig. 1 shows the effect of initial capacity level, *C*, on expected annual mill growth, other variables being held constant. The effects are shown separately for post-1970 and pre-1971 mills. For both groups of mills, the range of capacity was very broad. Some pre-1971 mills were larger than post-1970 mills, but the average pre-1971 mill was smaller than the average post-1970 mill. For a given capacity, post-1970 mills had a higher expected growth than pre-1971 mills. The difference in expected annual growth between the two groups of mills increased as the capacity of the mill increased. For post-1970 mills, the growth was almost directly proportional to the capacity level, in accordance with Gibrat's law. Among pre-1970 mills, only those with a capacity above 300,000 short tons per year had a positive expected growth, but on average, their expected growth was slightly negative.

The partial effect of age, *A*, on the expected annual capacity growth of post-1970 mills is shown in Fig. 2. Mill age ranged from 1 to 30 years, with an average of about 16 years. Other things being equal, expected annual growth decreased almost linearly with age, a 10-year difference in age corresponding approximately to a 6000 short tons per year difference in annual capacity growth.

Fig. 3 shows the partial negative effect of reliance on market pulp, measured by the ratio of market pulp capacity to total capacity, *M*. The range of *M* was the same for post-1970 and pre-1971 mills, but on average, post-1970 mills relied less on market pulp than pre-1971 mills. The marginal effect of reliance on market pulp on growth was the same on post-1970 mills as on pre-1971 mills. The expected annual growth of mills that totally relied on market pulp was about 6000 short tons per year lower than that of mills completely independent of market pulp. But, for pre-1971

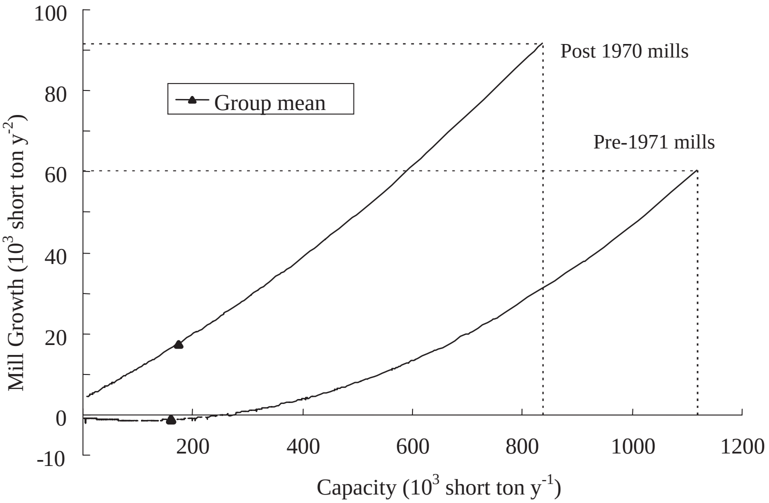

Fig. 1. Effect of capacity on the expected growth of pulp and paper mills in the USA from 1970 to 2000.

mills, even the mills totally independent of market pulp had a negative expected growth.

The partial effect of output diversity, measured by the number of products D, on expected annual capacity growth is shown in Fig. 4. The figure covers the range of the data and shows that post-1970 mills tended to produce fewer products than pre-1971 mills. The marginal increase in growth associated with more specialization was

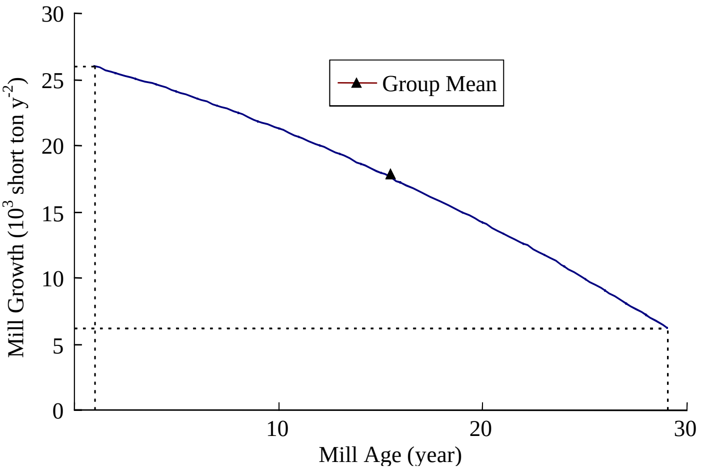

Fig. 2. Effect of age on the expected growth of post-1970 pulp and paper mills in the USA from 1970 to 2000.

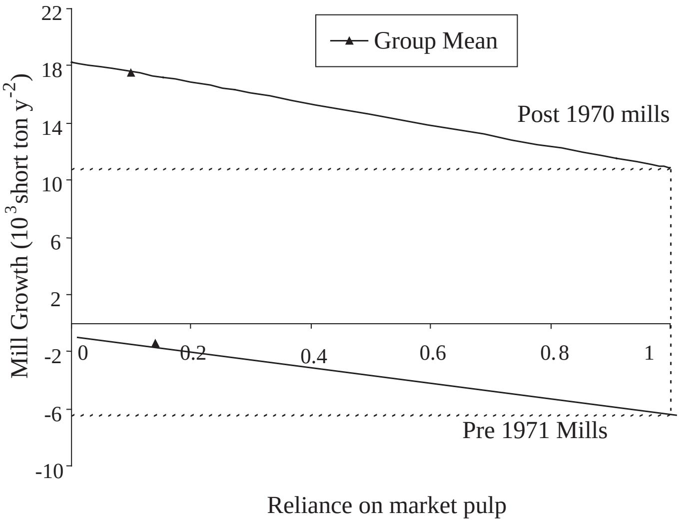

Fig. 3. Effect of reliance on market pulp on the expected growth of US pulp and paper mills from 1970 to 2000.

similar for pre-1971 and post-1970 mills, but even the most specialized pre-1971 mills had negative expected growth.

Fig. 5 shows the partial effect of the mill product type, measured by the proportion of paper products in total production, *P*. The range of *P* in the data was the same for pre-1971 and post-1970 mills, but on average, post-1970 mills tended to produce more paper. The marginal effect of the proportion of paper production on the growth of post-1970 mills was small, as reflected by the almost horizontal graph. This marginal effect was somewhat larger for pre-1971 mills. Although on average they had a negative growth, pre-1970 mills that produced only paper had an expected annual growth of about 3000 short tons per year.

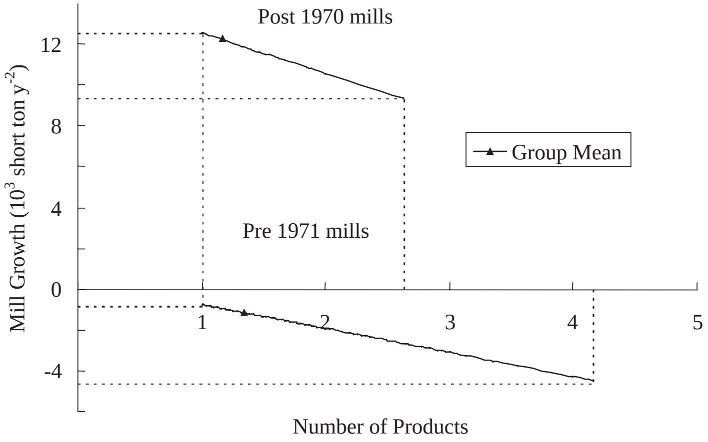

Fig. 4. Effect of output diversity on the expected growth of pulp and paper mills in the USA from 1970 to 2000.

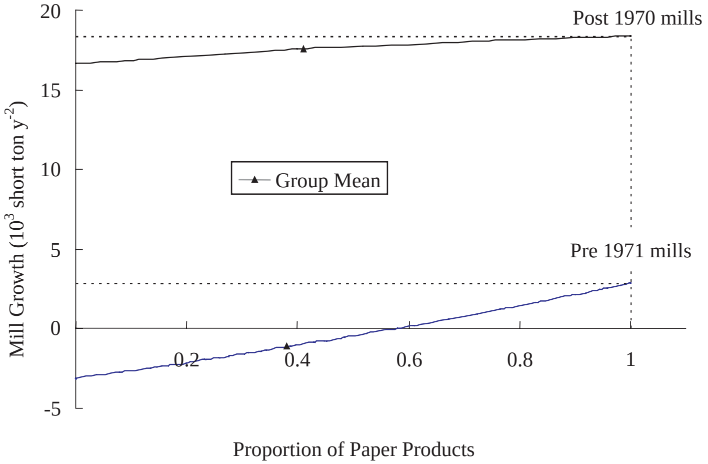

Fig. 5. Effect of product type on the expected growth of pulp and paper mills in the USA from 1970 to 2000.

Discussion

We examined the capacity growth of individual mills in the United States pulp and paper industry from 1970 to 2000. The growth process was modeled with three equations to predict the survival rate during the period of observation, the growth of the mills that survived or closed, and the resulting expected growth of a mill. Among the many possible variables that could affect mill survival and growth, this paper investigated the effects of mill size, age, vertical integration, diversity of output, location, and type of product.

We found that expected mill growth was affected most strongly by mill size, measured by capacity, and by the age of the mill. For the post-1970 mills, after controlling for the effects of other variables, the expected annual growth was directly proportional to capacity level, in accord with Gibrat's law.

Other things being equal, post-1970 mills had a higher expected growth than pre-1971 mills, and within post-1970 mills, the expected individual mill growth declined and stopped at about 22 years. Nevertheless, most mills survived well beyond that age. Thus, growth does not appear to be a necessary condition of mill survival. Growth occurs largely in the early phase of a mill life cycle, after which a mill probability of survival is mostly affected by the size it has achieved.

Lesser variables that influenced the expected growth included reliance on market pulp, specialization, and type of product. Other things being equal, the more integrated mills (those that relied less on market pulp) grew faster. So did the more specialized mills, and more so if they produced mostly paper products.

After controlling for the other variables, there was no regional effect on mill survival and growth. However, there was substantial positive partial correlation between mill capacity and the dummy variable for the South (>0.4), suggesting that several of the large mills were in the South. Thus, location may matter very much if it facilitates or hinders mills that are larger, newer, less dependent on market pulp, and specialized in a few paper products.

The bigger effect of initial capacity on the growth of younger (post-1970) mills is in agreement with previous learning and lifecycle theories (Geroski, 1995; Agarwal and Audretsch, 2001; Jovanovic, 1982). Furthermore, the significant negative effect of the reliance on market pulp on growth supports Ohanian's (1994) proposition that vertical integration improves the competitiveness of pulp and paper mills, but it also suggests that mills that have increased the use of recycled fiber have gained an advantage.

This paper is only a partial look at the process of capacity changes in the US pulp and paper industry. In particular, it examined only the survival and growth of existing mills. About 22% of observed capacity growth for the industry (1970–2000) is in the establishment of new mills. Mill entry can also be modeled in parallel with mill growth and exit, to explain overall regional industry growth as a function of prices and costs, possibly by exploiting the panel data structure (Chavas and Magand, 1988; Kaltenberg and Buongiorno, 1986). Furthermore, other variables such as resource availability, corporate tax policies and environmental regulations should also be investigated, as potential determinants of growth or decline in the US pulp and paper industry.

Acknowledgements

The research leading to this paper was supported, in part, by the USDA Forest Service, Forest Products Laboratory, by McIntire-Stennis Grant 4456, by USDA-CSREES Grant 2003-35400-13816, and by the School of Natural Resources, University of Wisconsin, Madison.

References

Agarwal, R., Audrestsch, D.B., 2001. Does entry size matter? The impact of the life cycle and technology on firm survival. The Journal of Industrial Economics 49(1), 21–42.

Buongiorno, J., Stier, J.C., Gilless, J.K., 1981. Economics of plant and firm size in the United States pulp and paper industries. Wood and Fiber 13 (2), 102–114.

Cabral, L.M.B., Mata, J., 2003. On the evolution of the firm size distribution: facts and theory. American Economic Review 93 (4), 1075–1090.

Chavas, J.P., Magand, G., 1988. A dynamic analysis of the size distribution of firms: the case of the US Dairy Industry. Agribusiness 4 (4), 315–329.

Evans, D.S., 1987. Tests of alternative theories of firm growth. Journal of Political Economics 95 (4), 657–674.

Geroski, P.A., 1995. What do we know about entry? International Journal of Industrial Orgnization 13, 450–456.

Gibrat, R., 1931. Les inégalites économiques; applications: aux inégalités des richesses, a la concentration des enterprises, aux populations des villes, aux statistiques des familles, etc., d'une loi nouvelle, la loi de l'effet proportionnel. Librairie du Recueil Sirey, Paris.

Gibson, E.J., 1970. Future of British forestry. Timber Trades Journal 279 (4965), 47.

Hall, B.H., 1987. The relationship between firm size and firm growth in the US manufacturing sector. Journal of Industrial Economics 35 (4), 583–606.

Ince, P.J., Li, X.L., Zhou, M., Buongiorno, J., Reuter, M., 2001. United States paper, paperboard, and market pulp capacity trends by process and location, 1970–2000. Research Paper FPL-RP-602, United States Department of Agriculture, Forest Service, Madison.

Jovanovic, B., 1982. Selection and evolution of industry. Econometrica 50, 649–670.

Kaltenberg, M.C., Buongiorno, J., 1986. Growth and decline of the paper industry: an econometric analysis of US regions. Applied Economics 18, 379–397.

Kumar, K.B., Rajan, R.G., Zingales, L., 2001. What determines firm size? NBER Working Paper No. w7208, Cambridge.

Ohanian, N.K., 1994. Vertical integration in the us pulp and paper industry, 1900–1940. The Review of Economics and Statistics 76 (1), 202–207.

Rajan, R., Zingales, L., 1998. Power in a theory of the firm. Quarterly Journal of Economics 113, 387–432.

Sutton, J., 1973. The importance of size in forestry and the forest industries. Journal of Forest 18 (1), 63–80.

Sutton, J., 1997. Gibrat's legacy. Journal of Economic Literature 35, 40–59.

Wooldridge, J.M., 2000. Introductory Econometrics: A Modern Approach. South-Western College Publishing, Mason.

Li, Xiaolei, et al. -- Effects of size and age on the survival and growth of pulp and paper mills. Journal of Forest Economics, vol.10, no.1: 3-19 p. (2004)