SURVIVAL OF FIRMS AND PLANTS IN A SUPPLY-CONSTRAINED INDUSTRY

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Abstract: We analyze the duration of firms in a supply-constrained industry — the Australian black-coal industry — using our thirty-two-year database. We test the hypothesis that the exhaustion of coal reserves of individual mines (the firm's plants) will be reflected in the firm's duration, and find negative duration dependence with the age of the firm. In contrast to the results from studies of manufacturing industries, we find no relationship between firm size and survival. For individual mines (plants) we find no dependence with age but positive dependence with size — the larger the mine, the longer it survives. We find that the exit of firms is driven by the depletion of their reserves, and by the entry of new firms seeking the supply-constrained resource.

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1. Introduction

This paper contributes to the literature on the dynamic processes governing industry structure by comparing the duration of firms in a supply-constrained industry with the duration of their plants. This is an extension of others' research, mainly of manufacturing industries, to an industry in which a necessary input is depleted over time. We draw a parallel between the plants of manufacturing firms and the mines of extracting firms, and consider the relative hazards of mines and coal-mining firms, and the underlying processes affecting each.

In 1982 Jovanovic developed a model of manufacturing firm survival and growth. He argued that as the firm's experience grew — as it aged — it would learn about its costs, as well as its product market, which would mean that it would be less likely to fail through low efficiency and consequent poor performance (the price-cost margin, simply put). Jovanovic argued that there must be a positive relationship between age and survival, and between size (as measured by the level of output produced per period) and survival. Beginning in the late 1980s, a series of researchers examined manufacturing firms in the U.S., Canada, and other countries (Fariñas and Moreno 2000) and found just such positive relationships reflected in the data: one of the most striking stylized facts regarding the dynamics of industries that has emerged from empirical studies is that the survival rates of businesses are positively related both to establishment size and age" (Audretsch and Mahmood 1995, p.95). Research with a narrower focus, on new firms, using a database from the U.S. Small Business Administration, also found these positive relationships (Phillips and Kirchhoff 1989, Audretsch 1991). These papers, for the most part, used infrequent, aggregated time series of periods up to 15 years long, although Agarwal (1997) used a database that was almost a century in length. They were not only, or perhaps primarily, concerned with survival (as reflected in changing survival rates over time, or age), but with firm growth[1]. Caves (1998, p.1949) organized "the recent profusion of stylized facts", and his paper provides an excellent review of the literature surrounding the issues then.

There is also a small literature on duration in the services sector. Audretsch et al. (2004) found that there is no relationship between survival and size in the Dutch hospitality industry, but this

[1] "Survival of firms has . . . been studied as a side issue to growth of firms" (Agarwal 1997, p.571).

industry is characterized by a large number of small firms, and, as the authors pointed out, “industry dynamics in small-scale services might not simply mirror that in manufacturing”. They concluded that this is due to the Dutch hospitality industry having minimal sunk costs, with low capital intensity and scale economies. But the Maggiolini and Mistrulli (2005) study of Italian co-operative credit banks showed a positive relationship between size (market share) and duration, and Santarelli's (2000) analysis of the Italian financial intermediation industry showed a positive relationship between size and duration of new banks. Cameron and Hall (2003) investigated the hazard rate of Australian mutual fund closure, and the variation over time in the conditional probability of fund closure, given the surviving funds. They found a hump-shaped hazard function that is consistent with learning, and is typical of lognormal duration models. Freeman et al. (1983) found that death rates of younger labour unions, electronics manufacturing firms and newspaper publishers were much higher than those of older organizations. But rather than this “liability of newness”, we here find a senescence effect, as discussed below. Some studies examined the effect of the technological regime on survival (Audretsch 1991, for example) but in our industry firms share similar technology: coal-mining and coal-preparation methods and equipment are equally available to all firms.

The industry we analyze is supply-constrained in two ways: first, the primary input, coal, is exhaustible. Second, although owning a coal deposit is necessary for production, it is not sufficient: a further requirement is permission-to-mine, as embodied in a mining permit. In New South Wales (NSW), the State Government has traditionally identified prospective coal-mining areas and will grant exploration and mining permits for these areas at periodic intervals by sealed bid auction. Rights to in-situ coal are transferable, as are permits to mine.

Because of the exhaustion of mine reserves and the restrictions on access to reserves, the duration dependence of firms in an extractive industry is likely to differ from the dependence in manufacturing. Analysis of duration should give insights into the economics of the industry, and perhaps reveal other differences. Since the coal industry is of significant economic importance to Australia, a better understanding of the factors that influence its structure and evolution is valuable[2]. Moreover, our findings may generalize to other extractive industries, such as natural gas and other minerals in other countries with well-established property rights, and to other supply-constrained industries.

In the coal-mining industry the firm's "plants" are its mines, necessary for producing its coal from the main resource of the firm, the in-situ coal reserves. Exhaustion of its coal equates to exhaustion, and death (exit), of the mine. But a coal-mining firm may comprise more than a single mine. The lives of coal-mining firms and their plants — the mines — are decoupled, through trade in mines and trade in firms. The lives of these firms are therefore distinct from the birth and death of their mines. Although the life of a working mine is necessarily finite, a firm could in principle survive indefinitely, by opening new mines, or buying operating mines from other firms, or acquiring firms with operating mines. This implies that firm hazard should be less than mine hazard, but we report counter results below.

Are there any non-extracting industries that are supply constrained? We argue that manufacturing industries are not in general supply-constrained, but that some service-sector industries might be. Any industry — such as free-to-air broadcasting, banking or insurance — in which a government permit is necessary for operation, might in practice be supply-constrained.

We analyze the durations of NSW coal-mining firms and coalmines in operation from mid-1969 to mid-2001. We test the influence of size and age on duration. We also explore relationships between duration and control for foreign ownership and the competition from firms in Queensland (Australia's other major coal-producing region). Because coal-mining firms and mines depend on exhaustible reserves, we expect their survival to be negatively related to age (cet. par). We compare the behaviour of firms and plants in our supply-constrained industry with those in manufacturing industries, which in general are not constrained in one necessary input resource. We have developed a thirty-two-year database of the ownership and operations of coal-mining firms,

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[2] Since 1985, Australia has been the world's largest exporter of coal, and coal is Australia's largest export earner (McLennan 1999); the states of NSW and Queensland are the exporting regions and the major producing regions. While Queensland now exceeds NSW in annual exports, NSW has a longer history of substantial coal mining and coal exports.

and their mines (extending some firms back a further 10 years and some mines a further 20 years), and use these to examine whether, in this extractive industry, the clear relationships seen in manufacturing industries still hold: is coal-mining firm survival positively related to the age of the firm? Is coal-mining firm survival positively related to the size of the firm? What of mine survival? Because firms buy, sell, and develop mines, there is no reason to suppose that mine exhaustion is necessarily reflected in such firms exhibiting a negative relationship between survival and firm age. We seek empirical confirmation of this prior belief.

We test three hypotheses:

Hypothesis 1: Unlike manufacturing industries, the survival of firms and plants in the NSW coal industry is negatively related to their age;

Hypothesis 2: The hazard of plants is greater than the hazard of firms in our industry;

Hypothesis 3: Unlike manufacturing industries, the survival of both firms and plants is negatively related to their size in our industry,

The structure of the paper is as follows: Section 2 discusses the distinctions between "firms" and "plants", ways in which firms can enter and exit the extractive industry, and ways in which the firms' "plants" (i.e. individual mines) can begin, can cease, or can be bought and sold while continuing to operate. Section 3 discusses the construction of the database of Australian black-coal mines and firms. Section 4 estimates the survival functions and hazards of firms and plants, and tests the relationship between size and duration. Section 5 discusses our findings, and compares and contrasts them with the duration of firms and their plants in other industries. Section 6 concludes. The Appendix contains a discussion on left censoring.

2. Plants and Firms

We distinguish between the “plant” (the “mine” for an extractive industry[3]), which is the producing and main employment centre, and the “firm”, which is the corporate entity that owns the plant(s)[4]. Many studies of manufacturing industries, such as Dunne et al. (1989), analyze only the plant, while others, such as Evans (1987a) and Dunne et al. (1988), analyze only the firm. The plant’s survival is neither necessary nor sufficient for the firm’s survival: firms can survive the closure of some of their plants, and firms can fail while some of their plants remain profitable assets, to be sold off to new owners. Indeed, some previously unprofitable plants can be returned to profitability by the new owner, not least if their reduced purchase prices reflect write-downs on their old values, a loss borne by the owners of the exiting firm. In our study we expect the relationship between plant survival and firm survival to be weak, as a mine will only be closed when the resources are economically exhausted, not when an individual firm finds the mine unprofitable. The government may disallow the closure of a mine if it thinks extraction could be profitable under new ownership.

We analyze separately the duration of plants and firms. In this industry, unlike manufacturing, plants cannot survive indefinitely: when the resource in the mine is exhausted, the mine closes. Despite this, firms in an extractive industry might, by buying existing “plants” or by developing new “plants”, survive beyond the “plant” failures. The Australian black-coal industry relies on an exhaustible resource that is extracted from mines and sold, mainly into export markets. Its plants will one day cease operations, either because they have been physically exhausted of all resources, or because, more likely, the rising cost of operation as the coal is mined has made them unprofitable, a case of Ricardian exhaustion[5].

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[3] For manufacturing, a plant is “defined as a unified complex of production faculties on a single site — a single factory, mill, refinery, works, shop, etc.“ (Bain 1966, p.26). Our “plant“ includes the mine, coal handling and preparation facilities, indeed all the equipment to produce, condition and load the coal onto transport to leave the mine site. The firm will also have a head office, and possibly other mines.

[4] “A ‘firm’ is any independent ownership and/or control unit“ (Bain 1966, p.73).

One study has previously examined survival and hazard in an extractive industry. Merrell (2000) examined mine closure in the U.S. coal-mining industry, using a twenty-year government database of mines. That is, Merrell studied "plants," not firms. He found that favourable energy-market conditions and productivity differences tended to reduce the time to mine failure, while older mines tend to have shorter remaining life, ceteris paribus. This duration dependence of "plants" in an extractive industry is not, of course, surprising, since every unit mined will reduce future mine life, ceteris paribus. Merrell posited three forces that determine the date of mine closure (or exit): market demand, productivity, and resource exhaustion. He found that after some date in the life of the mine, exhaustion dominated the former two forces, as one would expect.

3. Data

Our data comprise 78 firms, of which14 firms (18%) are left-censored, 15 firms right censored, and 2 firms double censored. There are 171 mines, of which 55 mines are right censored, 46 mines (27%) are left censored, and one mine is double censored. For firms the period is from 1 July 1969 to 30 June 2001, and for mines it is from 1 July 1949 to 30 June 2001. We record the age of mines from the year ending 30 June1950 because that is the year in which the first "continuous mining" machinery was introduced (Eyre 1988)[6]. The year ending 30 June 1960 is used for firms as that was approximately the start of the major export market for Australian coal (which effectively started a new industry[7]) and we have earlier data on only a few firms. More details on the construction of the database are given in Lawrance and Marks (2000).

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[5] As the coal is extracted, the haulage distance to the processing plant and transport facilities increases — the increased depth of mining increases safety considerations and other costs.

[6] Before this mechanisation, annual production from most mines was very low, and many had very long durations.

[7] Prior to 1960 the market was predominantly domestic, and the Joint Coal Board controlled prices. From 1960, export sales started to become the major revenue source for NSW producers, and for many firms it was the only revenue source.

Our data are from the NSW black-coal industry, part of the Australian black-coal industry, ANZSIC[8] code 1100[9]. We define firms as those entities that control the marketing decisions of a single coalmine or a group of coalmines. In most cases, control results from greater than 50% ownership, but may result from being the largest shareholder (less than 50%, but with effective control) or by having a management agreement with other owners. The designated "firm" is the ultimate owner of the mining assets, although in many cases it is not the immediate corporate entity publicly listed as the owner. Provided a firm maintains a controlling interest in at least one coalmine, it survives: its status does not alter in our analysis if one or more of its mines closes or is disposed of. We delete the small number of firms (in electricity supply, steel manufacturing and cement manufacturing) that mine coal solely for their own consumption[10].

Our measure of firm (or mine) size is the ratio of its annual production to the industry annual production for the same period[11]. Fig. 1 depicts the general form of the duration data of firms. The data are presented in Tables 1 and 2 for firms and Tables 3 and 4 for mines.

Fig. 1 here

Tables 1, 2, 3 and 4 here

Some earlier studies by others have suffered from: lack of longitudinal databases with clear identification of the actual start-up and closure dates of establishments (Audretsch and Mahmood, 1995); infrequent data (sometimes only every five years); aggregate data (such as four-digit SIC categories) rather than data on individual establishments (Audretsch, 1991); and the lack of data on mergers and acquisitions (Evans 1987b). Our data do not suffer from these shortcomings.

[8] Australian and New Zealand Standard Industrial Classification

[9] Data of individual mines are from Joint Coal Board internal records, Joint Coal Board (various years) annual reports and from NSW Department of Mineral Resources (various years).

[10] These are deleted because they do not participate in the open market and so are not directly influenced by competition and prices.

[11] Proportionate size rather than absolute size is used since the general sizes of mines grow as technology advances.

4. Duration Analysis

4.1 The hazard of firms

How does the hazard (and the duration) of firms in our industry change over the study period? For manufacturing firms it mostly falls (that is, older firms survive longer in the industry). We follow the analysis of Kiefer (1988) and others, to produce the Kaplan-Meier (1958) product-limit estimator of the survivor functions. We use an adjusted survivor function proposed by Turnbull (1974) to compensate for the left censoring[12] (see Appendix) in order to estimate the hazard function (the ratio of the number of mines exiting to the number at risk, see Kiefer 1988), and to calculate the integrated hazard function. With a number of tied ages, the hazard function is very irregular and the integrated hazard is easier to interpret[13].

We see from Fig. 2 that the hazard of firms in our industry generally increases over time, in contrast to the results by others for manufacturing firms.[14]. This confirms the behaviour of firms in Hypothesis 1.

Fig. 2 here

4.2 The hazard of mines

As with the firm data, the mine data are left censored. We use the suggestion by Iceland (1977) and Moffitt and Rendall (1995) of running the analysis twice: excluding the left-censored data, and including the left-censored data without adjustment (tacitly assuming that the left-censored mines started at 1960). Both methods produce increasing hazards, and we average the results. (See the

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[12] We distinguish between left censoring and left truncation. As Guo (1993, p.220) explains, “left truncation arises when sampling from an incomplete population. Left-truncation event-history data are incomplete because they do not include those subjects that have survived long enough to be observed“. He refers to the “event“ having occurred before the start of the study, this being an incident such as a heart attack. Our duration is the total age of the firm (in the industry) so the “event“ is the exit of a firm, and we use Kiefer’s (1988) interpretation of left censoring.

[13] The hazard may be viewed as the instantaneous probability of failure at a specific time, conditional on having reached that time (Lawless 1982). The integrated hazard (which = –ln[survivor function]) is not a probability.

Appendix for discussion of left censoring.) We find that the hazard trend for mines rises slightly, but the integrated hazard is approximately linear, which is consistent with a fairly constant hazard, contrary to our expectation of the behaviour of plants (Hypothesis 1).

Given the inevitable economic exhaustion of individual mines and the firms' freedom to buy, sell and (to a limited extent) open new mines, Hypothesis 2 states that mines will fail first, and that the hazard of mines will exceed that of firms. But, contrary to our expectations, we find that the hazard for firms is much greater than that of mines, except for very young mines which have a slightly higher hazard than firms of the same age (Fig. 2). We use a log rank test of the integrated hazards of firms and mines (Diaz 1999, Bland and Altman 2004) and find that the difference between the two hazards is highly significant (a test statistic of 14 with one degree of freedom).

4.3 Factors affecting firm duration

What factors affect firm duration? We use a Cox (1972) proportional-hazards regression model with covariates firm size, foreign competition, and interstate (Queensland) competition to answer this. In 1995 Audretsch & Mahmood were the first to estimate a Cox proportional-hazard duration model of firm and plant survival. Previously, database restrictions had precluded this. This technique is especially suitable for censored data[15]. We cannot use the Turnbull (1974) correction method for left-censored data because it creates non-integral numbers of firms (this is not a problem with the Kaplan-Meier product limit estimator.) We have the choice of the treatment by Allison (1984, p.56), who advises that left censoring for time-to-event data should be handled by "treating the initial censored interval as if it began at the beginning of the observation period" if the hazard rate depends on age, or of ignoring the left-censored data (see the Appendix). We choose to ignore the left-censored data because from 1960 the export market expanded rapidly, encouraging the growth of firms — so pre-1960 firms would have behaved differently from firms post-1960. We find, moreover, that the correction made in the Kaplan Meier survivor function by the Turnbull method is not very different from the survivor function when the left-censored data are ignored.

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[14] An integrated hazard convex to the origin means the hazard is increasing.
[15] See Santarelli, (2000), Leung et al. (2003) and Maggiolini and Mistrulli, (2005) for applications of the proportional hazards model.

Without evidence of economies of scale, an activity will not exhibit size-dependence of duration. The coal industry is characterized by highly capital-intensive entry, but Lawrance (2002) has shown that there is no evidence of economies of scale for firms (as distinct from individual mines) in the NSW coal industry. Moreover, Lawrance and Marks (2008) find that the Gibrat proportional growth rule applies to firms in this industry, which is consistent with absence of economies of scale. A large firm may own mines smaller than the single mine of a small firm, and the multiple mines of a large firm may be widely separated geographically, which means that equipment cannot be shared. Moreover, the economies of scale in head-office administration of a large firm may be countered by the use of rapid communication in a small firm. Frequently a small firm will have better industrial relationships with its workforce and may obtain some preferential treatment from export customers who wish to maintain negotiating pressure on the larger suppliers[16]. One would expect selling prices to affect duration and we discuss this below. Under the Hotelling (1931) principle we should see prices rising, but there is a clear trend of falling prices, indicating there is no evidence of increasing scarcity over the period.

We use a static duration model of survival for the Cox proportional-hazards model, in which there are different hazards for different covariates[17]. We assume that the variables have a multiplicative effect on the hazard function, which implies that these hazard functions are proportional to one another (Lawless, 1982). The reference hazard function is that produced by the null covariate vector and is the "baseline" or "observed" hazard (Leung et al. 2003). We test for a negative correlation between size of the firm and duration in the NSW coal industry from 1970 to 2001, controlling for competition from Queensland and for foreign ownership[18]. Contrary to our expectations (Hypothesis 3), we find no relationship between firm size and firm survival. As a control for changed economic conditions, we test for any change in hazard between the first half and the second half of our data period — 1970–1985 and 1985–2001— but find no significant

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[16] See Fitzgerald (2002) for an example of this.

[17] Examination of the data shows that, while the trend of real prices is downward, the apparently random short-term fluctuations of prices do not permit a time-dependent analysis.

[18] In 1990 foreign firms controlled 48% of NSW export coal producers (excluding the captive mines of the major steel producer and the State Government), while in 2001 the proportion had risen to 83% (NSW Department of Mineral Resources, various years).

effect. Empirical results by others for manufacturing companies show a positive relationship between size and duration, but we find no relationship for our data (Table 5).

Table 5 here

The Cox model assumes that the hazards are proportional and, to test the validity of this assumption, we compare the survivor function derived from the multiple covariates with the base survivor curve (that produced by no modifying variables). The survivor curves are very similar (Chi-squared statistic 0.08 with 12 d.f.), which validates the proportional hazards assumption (Kleinbaum 1996).

The entry of a new firm is usually only made possible by the exit of an existing firm (or by the sale of some of an existing firm's assets), and a firm wishing to enter the industry looks to purchase the asset(s) of an existing firm, that is, it has a call option on the asset of a willing seller: the investment will represent an irreversible expenditure and the decision to exercise the option can be delayed (Pindyck 1991). Since there are barriers to exit — a firm abandoning a mine may have substantial liabilities for mine rehabilitation and workers' entitlements, and, moreover, the government will not allow a mine to be abandoned (and the coal to be "sterilized"[19]), if it thinks extraction is still economically feasible — an exiting firm must find a willing buyer. Rather than a liability of newness, we expect a liability of obsolescence or of senescence for incumbent firms.

There is no direct duration dependence of NSW firms on other factors, such as the competition from Queensland firms, although this may be reflected in the price. With Kimura and Kiyota (2007) we find no evidence of "footloose" behaviour by foreign ownership — there is no relationship between the foreign or domestic ownership status of firms and their survival.

4.4 Factors affecting mine duration

What factors affect mine duration? Again we use a Cox proportional-hazards regression model. Because of the strong government control over the closure of mines, we do not think it useful to include variables other than size and type of mine (viz. surface or underground) in the Cox analysis. Unlike the result for firms, and contrary to Hypothesis 3, we find (Table 6) that there is a positive relationship between mine survival and mine size (the negative coefficient shows a decrease in hazard with age), which is consistent with Merrell's (2000) results. Our post-hoc

[19] Rendered impossible to extract in the future.

conclusion is that the usual causal relationship is reversed, with mine size resulting from (potential) longevity rather than the other way around. A mine that has a large resource deposit will be equipped with the technology that produces high output, and this expensive equipment will only be installed if there is a long life over which to depreciate it. Coal-mining firms typically use a twenty-year discounted cash flow analysis for any major capital expenditure, and so a mine with a small resource deposit will not generally be equipped with expensive, high-output equipment.

Our test for type of mine — surface or underground — finds significance when the left-censored data are included, with a negative relationship between duration and hazard for underground mines. When, however, the left-censored data are deleted, there is no such significance. This results from 45 of the left-censored mines being underground, and all the left-censored mines having an average life (after 1 July 1950) of 37 years, while uncensored mines have an average life of 17 years. As 20 of these 37 years are from 1950 to 1970, we can deduce that, since 1970, there is no significant difference in the size/duration dependence between surface and underground mines.

Table 6 here

5. Discussion

While we anticipated that firm hazard would increase with age (Hypothesis 1), we assumed that the coal-mining firm's ability to buy and sell existing mines, to develop new mines, and even to acquire existing coal-mining firms would offset the positive influence on hazard of resource depletion exhibited by individual mines (Merrell, 2000), which would lead to firms having a lower hazard than their mines. As we argue above, there is no reason for the inevitable exhaustion of its individual plants to necessitate the exit of the firm. Our results, however, show that, in general, the hazard of firms is positively related to age, over the past forty-odd years, in the NSW coal-mining industry, while the hazard for mines rises only slightly over time. That is, the duration dependence of the firm does not have the same duration dependence of the "plant," here the mine. The duration dependencies between firm and plant for manufacturing was found by Dunne et al. (1989) and Audretsch and Mahmood (1995) to be the same, although their results for firms was the reverse of ours: the older the manufacturing firm, the less likely is its imminent failure. But in our analysis, contrary to Hypothesis 2, the hazard of mines is significantly lower than that of firms (except for very young mines and firms, where the hazard of mines slightly exceeds that of firms), emphasizing the nature of the coal industry where the mine, not the firm, is the basis of the industry. Some firms sell their mines to other firms, which prolong the life of the mines beyond that of the firm. The higher hazard of mines in the early years may result from a number of very small mines, with limited coal reserves, which have a short life. An established miner may open a short-term mine to exploit a small deposit.

Contrary to Hypothesis 3, we find no relationship between the size of coal-mining firms and their survival (in contrast to the results by others for manufacturing firms), but a positive relationship between size and survival for the plants (as also with manufacturing plants). To this extent, the coal-mining firm does behave differently from its plant, for which size is negatively related to hazard. Mines are expected to show economies of scale, and size/duration dependence can follow from this (as well as from the need for a large resource for a long life as discussed above), but, as mentioned above, the work of Lawrance (2002) and Lawrance and Marks (2008) indicates no economies of scale for coal-mining firms.

We conclude that the exit of firms from the extractive industry studied is strongly influenced by the depletion of reserves, and the associated higher costs and lower profitability. This is a senescence effect, or a liability of aging, which should also be evident in industries in which the core capital is depleted over time.

In many previous studies, mergers are not recognized, which is an acknowledged disadvantage in their analysis (Evans 1987b). In our study, of 63 firm exits, only 12 were the result of mine exhaustion; the other 51 exits occurred by merger or by sale of all mines. Fifty-four percent of new entrants resulted from mergers with existing firms (resulting in the exit of the selling firm), and 14% of new entrants resulted from buying part of an existing firm. As mergers and acquisitions are the predominant cause of exits here, we do not believe it is useful to examine models with different modes of entry and exit, as others have done.

Prices and price changes must influence duration, but there is no discernable pattern to coal prices over the period of the study. Coal prices fluctuate from year to year, and are dependent on world supply and demand, on the exchange rate, and on the price of substitutes such as oil and natural gas. From 1969 through 2001 the real price of coal fell by 24% — there were 20 years of price falls and 12 years of price rises. While falling prices will influence exits, they do not necessarily inhibit entries. Because firms cannot abandon their legal responsibilities of the mine site (such as rehabilitation) and because economic reserves may remain, almost always one firm's exit is accompanied by another firm's entry to the industry, or by an existing firm buying the firm or its mines as a going concern.

6. Conclusion

We have analyzed the durations of firms and their plants in an extractive industry that is supply-constrained. Our analysis shows that the survival of coal firms and plants in the NSW export coal industry is inversely dependent on age, as proposed in Hypothesis 1. This result is consistent with the increasing cost of extraction as reserves are depleted. Contrary to Hypothesis 2, the hazard of firms is greater than the hazard of plants. We can conclude that coal-mining firms exhibit different age dependence in duration than do their plants: the older the firm, the more likely to exit soon, despite the possibility of the firm surviving any single mine’s exhaustion. This is in contrast to manufacturing firms and their plants.

Hypothesis 3 proposes a negative relationship between size and survival. We find no relationship between coal-mining firm size and hazard, while both coalmines and manufacturing plants exhibit a negative relationship between size and hazard. We propose a reverse causal relationship — their owners only allow mines that can survive for a long time to become large.

We find that the coal-mining firm and its plants are distinct and have different survival characteristics. While there is evidence that the depletion of reserves controlled by the firm influences its duration, the complete exhaustion of a mine is linked to exit of the firm in only 19% of our cases. Individual mines are frequently owned by a succession of firms, which is consistent with the observed lower hazard for mines than for firms. While firms may cease operations and leave the industry, the coalmine itself may remain open and so remain in the industry.

Our study is conducted on firms that are supply-constrained and are price takers — they are at the extreme of a continuum of these two conditions. Future research could usefully explore any trade-off between the degree of supply-constraint and the degree of market power on survival dependence. We expect that further research will reveal that other extractive mineral industries, and other industries in which "capital" of some sort is exhausted over time, will exhibit similar characteristics, since there is no reason to believe that our extractive industry is unique.

Appendix

Turnbull (1974) described a method of correcting for left censoring[20], and Klein and Moeschberger (1997) gave a simple algorithm for this procedure, with the durations arranged into groups (producing a new time grid t_j). The Kaplan-Meier product-limit estimator for this time grid is found by ignoring left-censored data occurring at t_i. Modified Kaplan-Meier survivor functions are found by progressive iteration, which "estimates the probability that the event occurs at each possible time t_i less than t_j" using the idea of "self-consistency" (Klein and Moeschberger 1997, p.127), based on the initial product-limit estimator. We use this method in our analysis of firms and find that the third iteration (which adjusts for presence of left-censored data) produces a stable survivor function that is very close to the first estimate of the survivor function determined by deleting the left-censored data (see Table 1)(Chi-squared statistic 0.08 of with 3 d.f.).

The Klein and Moeschberger (1997) technique is based on increasing the number of other firms extant up to the time of the exit of each left-censored firm proportionately to the change in the survivor function. This assumes that the data prior to the start of the study (the left-censored firms) are similar in form to that of the data post the start. For mines, this assumption is not valid. Prior to 1950, mines were very small and hand-worked, with little mechanisation. Of the 46 left-censored mines, we have been able to find actual start dates for 17. Their average age at 1960 was 46 years, and using the mines' actual start dates for the analysis would have resulted in a number of mines over 100 years old.

Moffitt and Rendall (1995) and Iceland (1977) analyzed their data twice: including the left-censored data and excluding them. As there are a large number of left-censored mines, deleting them reduces the amount of information available and could introduce selection bias. Assuming that the left-censored mines are born at the start of the study has some justification because of the

[20] Dunne et al. (1988), Merrell (2000) and Disney et al. (2003) handle left-censored data by including establishments that entered in the period under study only and ignoring establishments already in existence.

low prior production. The survivor functions produced by the two methods are not greatly different, and we use the average of a survivor function produced by deleting the left-censored data and one produced by including the left-censored data, using the Kaplan-Meier product limit estimator.

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Table 1. Firm data

Age	Total number	Left Censor	Right censored[1]	Number of exiting firms	Observed survivor function[2]	Survivor function 3d iteration	Integrated hazard[3]
0	0	0	0		1	1	0
2	4	0	2	2	0.969	0.966	0.034
3	5	0	3	2	0.936	0.931	0.071
4	8	0	3	5	0.851	0.838	0.176
5	4	0	2	2	0.815	0.799	0.225
6	4	0	1	3	0.758	0.736	0.306
7	5	0	0	5	0.661	0.629	0.463
8	6	0	0	6	0.544	0.501	0.691
9	3	0	0	3	0.486	0.437	0.829
10	1	0	0	1	0.467	0.415	0.879
11	4	1	0	4	0.408	0.351	1.047
12	7	1	3	4	0.350	0.291	1.235
13	6	2	0	6	0.257	0.198	1.619
14	4	1	0	4	0.187	0.137	1.990
15	5	2	0	5	0.117	0.079	2.539
16	2	1	0	2	0.093	0.062	2.785
18	1	0	0	1	0.070	0.045	3.096
19	1	1	0	1	0.093	0.042	3.170
20	2	1	0	2	0.062	0.027	3.621
21	2	1	0	2	0.031	0.014	4.288
24	1	1	0	1	0.031	0.013	4.343
35	1	0	0	1	0	0	
40	1	1	0	1			
42	1	1	1	0			
Totals	78	14	15	63			

F06

[1] there is one double-censored firm

[2] excluding left-censored data

[3] –ln(suvivor function from 3d iteration)

Table 2. Descriptive statistics for firm data.

	Size	Queensland share		Number
			Total firms	78
Mean	0.032	0.276	Right Censored	15
Standard Deviation	0.042	0.180	Left censored	14
Range	0.172	0.458	Foreign firms	20
Minimum	0.0002	0.000	In period 1	26
Maximum	0.173	0.458	In period 2	52

F07x SPSS3

Table 3. Mine data

Age (years)	Total number	Number left-censored	Number exiting	Number right-censored[1]	Survivor function (incl. left-censored)	Survivor function (excl.left-censored))	Estimated hazard[2]	Integrated hazard[2]
0	0	0	0	0	1	1	0	0
3	11	0	7	4	0.959	0.944	0.048	0.050
4	6	0	5	1	0.929	0.903	0.038	0.088
5	6	0	4	2	0.905	0.869	0.032	0.120
6	4	0	3	1	0.887	0.844	0.025	0.145
7	4	0	3	1	0.868	0.818	0.026	0.171
8	6	0	4	2	0.843	0.783	0.036	0.207
9	7	0	3	4	0.824	0.756	0.028	0.235
10	3	0	3	0	0.805	0.728	0.030	0.266
11	10	1	7	3	0.760	0.672	0.067	0.334
13	4	0	3	1	0.740	0.643	0.035	0.369
15	5	1	3	2	0.719	0.623	0.029	0.399
16	2	0	2	0	0.706	0.603	0.026	0.424
17	2	0	2	0	0.692	0.582	0.027	0.451
18	4	0	3	1	0.671	0.552	0.041	0.492
19	4	0	2	2	0.658	0.531	0.029	0.520
20	9	0	2	7	0.643	0.509	0.031	0.551
21	3	0	1	2	0.636	0.497	0.018	0.569
22	5	1	3	2	0.612	0.470	0.046	0.614
23	3	2	2	1	0.596	0.470	0.013	0.629
24	2	2	2	0	0.580	0.470	0.014	0.645
25	7	2	6	1	0.531	0.411	0.105	0.753
26	1	1	1	0	0.523	0.411	0.008	0.762
27	2	1	2	0	0.506	0.396	0.034	0.797
28	1	0	1	0	0.498	0.381	0.027	0.823
29	3	0	2	1	0.481	0.350	0.057	0.878
30	6	3	4	2	0.447	0.334	0.058	0.940
31	2	1	2	0	0.430	0.317	0.046	0.986
32	4	1	3	1	0.403	0.281	0.086	1.072
33	5	4	4	1	0.368	0.281	0.044	1.126
34	3	1	2	1	0.349	0.261	0.061	1.187
35	1	0	0	1	0.349	0.261	0.000	1.187
37	2	2	2	0	0.330	0.261	0.028	1.219
38	6	2	4	2	0.291	0.214	0.150	1.377
39	4	3	3	1	0.260	0.214	0.054	1.441
40	1	1	1	0	0.249	0.214	0.021	1.464
41	1	0	1	0	0.238	0.178	0.105	1.569
42	1	1	1	0	0.227	0.178	0.023	1.596
43	2	2	2	0	0.206	0.178	0.048	1.651
44	3	2	2	1	0.184	0.178	0.053	1.709
45	1	0	0	1	0.184	0.178	0.000	1.709
46	1	1	1	0	0.172	0.178	0.033	1.743
47	1	1	1	0	0.159	0.178	0.036	1.779
49	6	4	5	1	0.098	0.119	0.359	2.221
51	5	4	2	3	0.070		0.143	3.351
52	2	2	0	2	0.070		0.000	
Totals	171	46	116	55				

F10c

[1] There are four double censored mines

[2] Calculated from the average of the two survivor functions

Table 4. Descriptive statistics for mine data.

	Size underground mines	Size surface mines	Age underground mines	Age surface mines
Mean	0.009	0.015	25.11	14.40
Standard Error	0.001	0.002	1.30	1.56
Median	0.009	0.009	24	11
Standard Deviation	0.006	0.016	14.70	10.23
Range	0.027	0.055	49	31
Minimum	0.000	0.001	3	3
Maximum	0.027	0.056	52	34
Count	128	43	128	43

F10dx

Table 5. Results of Cox regression for firms

	Coefficient	SE	df	Significance
Size	3.098	3.60	1	0.389
Period[1]	1.756	1.74	1	0.314
Foreign	-0.129	0.34	1	0.699
Queensland share[2]	-4.431	4.766	1	0.352

F07 spss3

[1]testing of differences between periods 1970-1985 and 1985-2001

[2]Queensland proportion of total of NSW and Queensland production

Table 6. Results of Cox regression for mines

Including left-censored data	Coefficient	SE	df	Significance
Size	-89.77	16.62	1	0.000
Type of mine (surface or underground)	0.83	0.25	1	0.001

Excluding left-censored data	Coefficient	SE	df	Significance
Size	-129.11	22.27	1	0.000
Type of mine (surface or underground)	0.42	0.27	1	0.117

Figure 1
General form of firm duration data

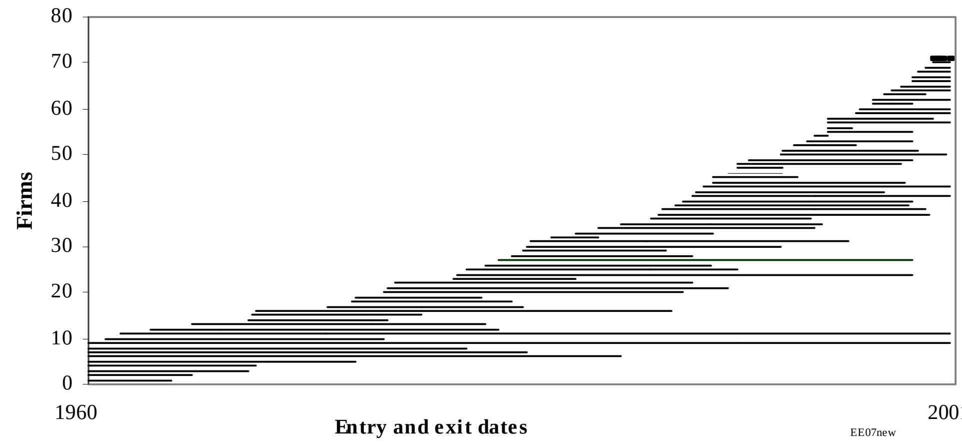

Figure 2
Integrated hazard of firms and mines