Sorting, Selection, and Industry Shakeouts

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A number of plausible theories offer explanations for the propensity of many young industries to undergo a shakeout phase, during which the number of firms declines sharply in the face of continued rising output. However, none of the theories considers the role of labor market sorting. This paper presents a model in which individual abilities are complements in production, but frictions permit only gradual sorting among firms. The quality distribution of firms becomes wider over time, inducing exit of firms that have ended up with predominantly low-quality workers. The model does not ensure that a shakeout takes place, but when it does it will be characterized by rising output alongside a declining price, an increasing average wage, and a widening of the distributions across firms of employment, output, productivity and average wages.

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1. Introduction

Many industries undergo a shakeout phase during which there is a rapid decline in the number of producers despite continued expansion of aggregate output. Gort and Klepper (1982) document the prevalence of shakeouts: of 46 industries for which they had collected data, by the end of the sample period 36 had undergone or were undergoing a significant shakeout. Among the nineteen industries that appeared to have completed the shakeout phase by the end of the sample period, the average decline in the number of producers was forty percent.[1]

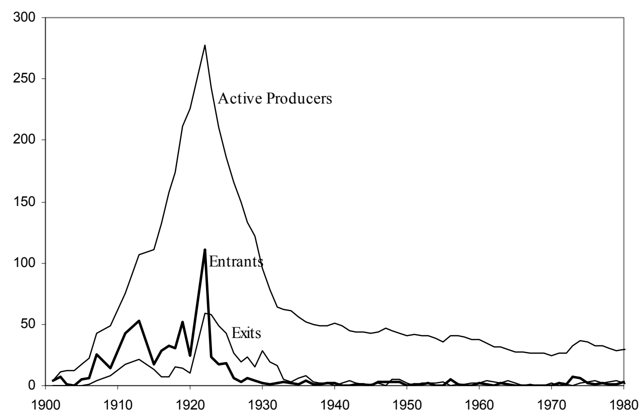

FIGURE 1. The shakeout in the U.S. tire industry, from Klepper and Simons (2000).

Figure 1 depicts the especially strong shakeout observed in the U.S. tire industry. The number of incumbents rose sharply in the early years as demand expanded, reaching a peak of 274 firms in 1922. After 1922, the entry rate fell while the exit rate rose sharply, leading to a rapid decline in the number of active producers. By 1936, there were only 49 producers, with a further, modest, decline over the subsequent fifty years [Klepper and Simons (2000, pp. 731-2)]. Despite the decline in the number of firms, output rose and

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1. See Klepper and Graddy (1990) and Agarwal (1998) for updates of the Gort-Klepper data. Simons (2005) offers some international comparisons.

prices declined dramatically during the first forty years of the industry. For example, between 1914 and 1935, the wholesale price of tires fell by 75 percent, despite technical improvements that greatly increased their longevity.

A number of explanations have been proposed for shakeouts. Utterback and Suárez (1993) and Hopenhayn (1993) attribute shakeouts to the emergence of a dominant design that precludes further entry while enhancing competition among incumbents. Jovanovic and MacDonald (1994) posit the introduction of a technological refinement that raises the minimum efficient scale of production. Klepper (1996) proposes that shakeouts are a natural consequence of advantages that accrue to early entrants because of increasing returns to scale, especially in R&D. Horvath, Schivardi, and Woywode (2003) suggest that shakeouts are simply a by-product of an earlier spike in entry by firms with heterogeneous quality [cf. Jovanovic (1982)], and where the entry was induced by news suggesting the industry is particularly profitable. Wang (2006) obtains a shakeout in a model where consumer adoption of the new product diffuses slowly and optimal firm size rises as a result of technical change.[2]

Jovanovic and Tse (2006) point out that all these explanations are plausible. They then develop another explanation where shakeouts result from a spike in the fraction of firms whose capital requires wholesale replacement. We continue this theme by proposing an additional explanation, this time based on sorting of workers with heterogeneous ability. The model is distinctive from much previous theorizing about shakeouts in that there is no technological change. A new industry consists of a number of firms, each of which employs exactly n workers. At the birth of the industry, workers are assigned to firms at random, but they soon discover that they vary in ability. The production function exhibits complementarity in worker abilities, so efficiency demands a reallocation of workers

2. A number of theories have also been offered for shakeouts that simultaneously affect multiple sectors. Atkeson and Kehoe (1993) attribute such events to national economic reforms; Caballero and Hammour (1994) show how temporary declines in aggregate demand can eliminate less efficient firms; general purpose technologies that raise minimum efficient scales may also induce widespread shakeouts [cf. Jovanovic and Rousseau (2006)]. However, Simons' (2005) observation that the timing of shakeouts within industries are highly correlated across countries suggests that they are more frequently driven by industry-specific events. See also Wang's (2006) analysis of shakeouts in television receivers in the US and the UK.

through positive sorting on ability [cf. Becker (1981), Kremer (1993)]. Frictions in the labor market make this reallocation process a slow one. High-ability workers eventually are reallocated to firms that already have a preponderance of high-ability workers, while other firms retain only low-ability workers. Thus, some firms endogenously become high-quality while others become low quality. The output of high-quality firms rises, while that of low-quality firms declines. Eventually, low-quality firms are forced out.

Complementarity of worker abilities and the incentives it creates for sorting among firms is familiar from Kremer's (1993) O-ring theory of production. The model in this paper essentially adds frictions to the O-ring theory. But frictions do more than simply draw out the reallocation process. Indeed, they are an essential part of the story, because in a frictionless, competitive, world it does not hurt to be a low-quality firm. To see why frictions are a necessary part of the shakeout story, consider the following version of Kremer's theory. All firms require n workers, and production is given by $\prod_{i=1}^{n}\theta_i$, where $\theta_i \in \left[\underline{\theta},\overline{\theta}\right]$ is worker i's ability. If $w(\theta)$ denotes the wage of workers with ability θ, profits are $\max_{\{\theta_i\}} \prod_{i=1}^{n}\theta_i - \sum_{i=1}^{n} w\left(\theta_i\right)$, with first-order condition $\prod_{j\neq i}\theta_j = w'\left(\theta_i\right)$, $i = 1, 2, \ldots, n$. Frictionless sorting implies that each firm only employs workers of identical ability, so $w'(\theta) = \theta^{n-1}$. The wage then satisfies $w(\theta) = \omega\left(\underline{\theta}\right) + \int_{\underline{\theta}}^{\theta}\omega'(s)ds = n^{-1}\theta^n$.[3] Given this equilibrium wage profile, the wage bill for a firm, $nw(\theta)$, is θ^n, and this is identical to output. Thus all firms earn zero profit; they are indifferent about the ability of the workers they employ, as long as they are identical, and sorting cannot induce firm exit. To create a situation where it is more profitable to have high-ability workers, we need a setting in which the wage for ability increases at a rate less than the marginal product. This is what labor market frictions do.

Although we use the generic term "worker", it is probably already apparent that what we have in mind are certain types of key workers – perhaps the founding managers or, in technical industries, senior engineers and scientists. There is ample evidence relating the quality of workers at all levels to firm performance. At the top of the hierarchy, the quality of the founding management team has been shown to matter for the performance of

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3. It is easy to verify the sorting result. Consider a firm that has $(n-1)$ workers with ability θ, and one with ability $\tilde{\theta}$. Profits are $\tilde{\pi} = \tilde{\theta}\theta^{n-1} - (n-1)n^{-1}\theta^n - n^{-1}\tilde{\theta}^n$, which attains a maximum when $\tilde{\theta} = \theta$.

young firms. For example, Eisenhardt and Schoonhoven (1990) report that semiconductor firms grew more rapidly the greater the industry experience of their founding teams, while Burton, Sørensen and Beckman (2002) find that Silicon Valley start-ups whose founders had been employed by prominent firms were more likely to obtain external financing than were start-ups with less prominent backgrounds. Similarly, Klepper (2002, 2007) provides detailed evidence that the fortunes of spinoffs in the U.S. automobile industry depended heavily upon the quality of the firm that had previously employed the spinoff's founder, so much so that concentration of the industry around Detroit can be fully explained by the inheritance of skills by founders of spinoffs. Outside of high-technology industries, Bates (1990) reports that the more educated is a male entering into self-employment, the more likely is his business to be in operation several years later. Yet others have shown that founder quality affects start-up size [e.g. Åstebro and Bernhardt (1999), Colombo, Delmastro, and Grili (2004)], and this is a known predictor of long-term survival [Geroski, Mata, and Portugal (2002), Thompson (2005)].

Moving down the firm hierarchy, Zucker, Darby, and Armstrong (1998, 2002) have shown that biotechnology firms employing scientists good enough either to be, or to work with, "star scientists" are likely to be larger and more innovative. Knowing, this, firms' location choices are often influenced by the prior location of star scientists in academia [Zucker, Darby and Brewer (1998)]. There is also evidence of a positive association between firm performance and the quality of its labor force as a whole. It is generally known that larger firms pay higher wages [cf. Oi and Idson (1999)], something that is on average true in our model, but this may in principle be due to payment of compensating differentials. However, in a study of one million French workers, Abowd, Kramarz, and Margolis (1999) conclude that three quarters of the relationship between firm size and wages is explained by individual worker effects, not firm effects.[4]

Section 2 presents the model and derives some basic properties. The behavior of the model becomes quite complex after the first round of labor reallocation, so Section 3 explores industry dynamics by computational means. The shakeout is characterized by suspension of entry followed by a more gradual decline, also eventually to zero, in the exit

4. Abowd, Kramarz and Moreau (1996) also find a positive correlation between worker quality and product quality in French manufacturing.

rate. The more rapidly labor is reallocated, the more quickly productivity rises, price falls, and the quicker the shakeout occurs. These correlations are consistent with the evidence in Jovanovic and Tse (2006, Figure 1). Reallocations also induce a widening of the distributions across firms of productivity and firm size, consistent with the findings of Cabral and Mata (2003).

However, the model does not always produce shakeouts. When ability varies only modestly between workers, worker reallocations are infrequent and few firms suffer losses of unusually valuable employees. In this case, industry dynamics are muted: there are only modest changes in the number of active firms, price and output, and little change in the distribution of firm size. When entry costs are high, market price is high and even low-quality firms can make positive profits. Thus, there is no wholesale exit. Nonetheless, in this case, one still observes the changes in output, wages and firm size that accompany shakeouts. Output is convex in firm quality, and so even without exit of low-quality firms we can observe rising output and productivity, and a declining price. At the other extreme, with very low entry costs, there is a dramatic decline in the number of active firms. However, neither entry nor exit decline to zero. Instead, there is sustained turnover of active firms. Somewhat surprisingly, the shakeout with low entry costs is not accompanied by increased output.

2. The Model

At the birth of a new industry, firms are created by bringing together n individuals, each of whom has ability indexed by $\theta_i \sim U(0,1)$. At the time of hiring, neither the firm nor the workers know their ability in this new industry, and all must be paid the reservation wage w in the first period. The creation of the firm requires the payment of a sunk cost, k. Firms are myopic, and maximize current-period profits. The production function for a firm is

$$y = n^{1+\beta} \prod_{i=1}^{n} \theta_i \, . \tag{1}$$

The price is $p(Y)$, where Y is industry output. Each firm takes the price as given. First-period profit, gross of the entry cost, is

$$\pi = p(Y) n^{1+\beta} \prod_{i=1}^{n} \theta_i - wn \ . \tag{2}$$

Let $\theta = \prod_{i=1}^{n} \theta_i$ index the "quality" of the firm, and let $E_n[\theta]$ denote its expected value when n workers are hired. Treating n as a continuous variable,[5] the first-order condition for risk-neutral firms is

$$(1+\beta) E_n[\theta] + n \frac{dE_n[\theta]}{dn} = \frac{w}{n^{\beta} p(Y)} \ . \tag{3}$$

With entry cost k, free entry implies

$$p(Y) \leq \frac{wn + k}{n^{1+\beta} E_n[\theta]} \ . \tag{4}$$

When entry is positive, (4) holds as an equality, in which case the industry price can be denoted by $\overline{p}$. Substituting (4) into (3) to eliminate price yields

$$\frac{d \ln E_n[\theta]}{d \ln n} = -\left(\beta + \frac{k}{wn + k} \right). \tag{5}$$

The optimality condition relates the elasticity of θ with respect to employment to the parameters of the model. Expected quality declines when employment is increased, but this is offset by an increase in output from having additional workers at a rate that depends on β. The optimal elasticity also depends on k because entry costs determine the scale of entry and, consequently, price.

The density of the product of n random variables drawn from a standard uniform distribution is [Springer and Thompson (1966)]

$$\phi_n(\theta) = \frac{\ln \left(\theta^{-1} \right)^{n-1}}{(n-1)!}, \qquad \theta \in [0,\, 1] , \tag{6}$$

and so the elasticity on the L.H.S. of (5) can be written as

5. The simulations in Section 3 do not use this sleight of hand, instead recognizing that n is an integer.

$$\varepsilon_\theta(n) = \frac{n\int_0^1 -\theta\left(-\ln(\theta)\right)^{n-1}\ln\left(-\ln(\theta)\right)d\theta}{\int_0^1 -\theta\left(-\ln(\theta)\right)^{n-1}d\theta} - n\psi(n)\,, \tag{7}$$

where $\psi(n)$ is the digamma function. The elasticity is strictly decreasing in n, with $\varepsilon_\theta(0) = 1$, and $\lim_{n\to\infty}\varepsilon_\theta(n) = -\infty$. The R.H.S. of (5) is strictly increasing in n, beginning at $-(1+\beta)$ when n=0, and rising to $-\beta$ as $n \to \infty$. Thus there exists a unique employment level, $\tilde{n}(\beta,k,w)$, that satisfies (5). It is easy to verify that $\tilde{n}$ is increasing in β and k, and decreasing in w, as one would expect. The method of transformations yields the p.d.f. for output,

$$\phi_{\tilde{n}}(y) = \frac{\ln\left(\tilde{n}^{1+\beta}y^{-1}\right)^{\tilde{n}-1}}{\tilde{n}^{1+\beta}(n-1)!}, \qquad y \in \left[0,\ \tilde{n}^{1+\beta}\right], \tag{8}$$

and the p.d.f. for first-period profits, gross of the sunk cost,

$$\phi_{\tilde{n}}(\pi) = \frac{E_{\tilde{n}}[\theta]\cdot\ln\left(\frac{k+w\tilde{n}}{(\pi+w\tilde{n})E_{\tilde{n}}[\theta]}\right)^{\tilde{n}-1}}{(k+w\tilde{n})(n-1)!}, \qquad \pi \in \left[-w\tilde{n},\ \left(k+\left(1-E_{\tilde{n}}[\theta]\right)w\tilde{n}\right)/E_{\tilde{n}}[\theta]\right], \tag{9}$$

where $E_{\tilde{n}}[\theta]$ is readily obtained from (6).

Figure 2 plots a typical p.d.f. for first-period profit. Firms with the worst draws of θ earn negative profit and exit immediately. Firms with intermediate quality earn positive profit that is insufficient to cover the sunk entry cost, but these firms do not exit. Both profits and output are positively skewed, although at this point in time employment is the same in all firms.

2.1 Industry dynamics without worker reallocation

Industry dynamics are mundane without sorting. All firms that earned negative profits in the first period exit. Their exit induces an incipient price increase that is quashed by the entry of new firms. Because the survivors from period 1 produced more than the firms that exited, the number of new entrants in period 2 necessary to keep the price at the zero profit level indicated by (4) is less than the number of firms that exited. Each period

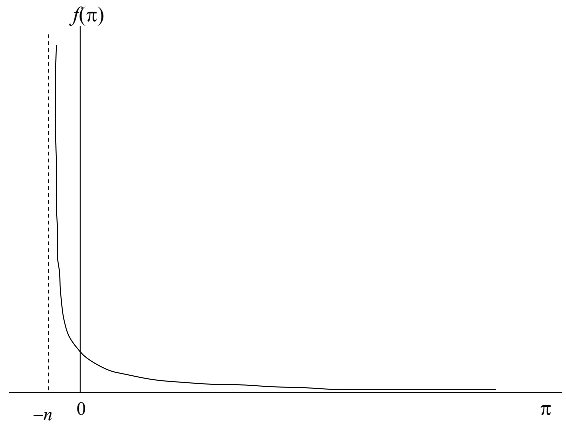

FIGURE 2. Density of profits in period 1 (gross of sunk entry cost).

the process repeats. A constant fraction of new entrants exit after one period of production, and they are replaced by a smaller number of entrants. Eventually, the number of firms making positive profits has risen sufficiently to preclude further entry.

The net effect is to create an industry in which price remains constant. Firms that survive their first period of production survive for ever. They do not grow, but selection raises the average output of firms. Finally, the number of active firms, entry rates, and exit rates decline monotonically over time. These are not the dynamics we typically observe.

2.2 Voluntary departures with downward wage rigidity

We describe a simple model of worker reallocation. At the end of the first period, abilities are known to all. A firm would then prefer to lower the wages of workers that have turned out to be low ability. Because the initial wage was set at the reservation level, any worker whose wage is reduced would immediately leave the new industry, so such wage reductions are equivalent to dismissal. However, we assume that a firm cannot lower wages.[6]

At the end of the first period, firms are randomly assigned to one of two groups of equal

6. Research on high-quality datasets finds strong evidence for pervasive downward wage rigidity [Altonji and Devereux (1999), Wilson (1999), Lebow, Saks, and Wilson (2003)].

size. One group consists of firms that will make an offer to an employee of another firm, the other consists of firms with employees receiving offers. Firms are matched in pairs, again at random, and the **offering firm** makes an offer of employment to a random member of the **receiving firm** with which it is paired. The wage offered depends upon the quality of the offering firm, the quality of the receiving firm, and the worker's ability. The offering firm makes a wage offer that is the lowest necessary to induce the worker to move, as long as this does not exceed the marginal product of the worker at the offering firm. The receiving firm may make a counteroffer, if doing so is profitable. If the counteroffer is not successful or the receiving firm chooses not to make a counteroffer, the worker moves to the offering firm. The receiving firm may, if it is profitable to do so, immediately replace the worker with a new hire. The new hire is drawn from outside the industry, has unknown ability drawn from $\theta_i \sim U(0,1)$, and is paid the reservation wage, w.

Let the individual receiving an offer be worker i, let $\mathrm{MP}_i^{\mathrm{R}}$ denote his marginal product with the receiving firm, and let $\mathrm{MP}_i^{\mathrm{O}}$ his prospective marginal product with the offering firm. We consider first wage offers and counteroffers that may be made in the first round of reallocations. These are $\mathrm{MP}_i^{\mathrm{R}}$ if $\mathrm{MP}_i^{\mathrm{O}} > \mathrm{MP}_i^{\mathrm{R}} \geq w$, and w if $\mathrm{MP}_i^{\mathrm{O}} > w \geq \mathrm{MP}_i^{\mathrm{R}}$. In contrast, the receiving firm makes a successful counteroffer of $\mathrm{MP}_i^{\mathrm{O}}$ if $\mathrm{MP}_i^{\mathrm{R}} \geq \mathrm{MP}_i^{\mathrm{N}} > w$. Finally, if $w > \mathrm{MP}_i^{\mathrm{O}}$ i remains with his current employer at the wage w. The value of output lost if i leaves the receiving firm is

$$\mathrm{MP}_i^{\mathrm{R}} = p(Y)\left[\theta_i \tilde{n}^{1+\beta} - (\tilde{n}-1)^{1+\beta}\right]\prod_{j\neq i}\theta_j \ , \tag{10}$$

where $\prod_{j\neq i}\theta_j$ is the ability index of i*'s* colleagues. If i relocates his marginal product will be

$$\mathrm{MP}_i^{\mathrm{O}} = p(Y)\theta_{\mathrm{O}}\left[\theta_i(\tilde{n}+1)^{1+\beta} - \tilde{n}^{1+\beta}\right], \tag{11}$$

where θ_{O} is the quality of the offering firm.

Figure 3 illustrates the effect of a worker's ability on his marginal product with his current employer and with the offering firm. The lines **O** and **R** plot the marginal productivity with the offering firm and receiving firm respectively, which are negative for low-ability workers. Note that, because the offering firm is contemplating increasing its size above $\tilde{n}$ and the receiving firm is contemplating losing a worker, the ability level at

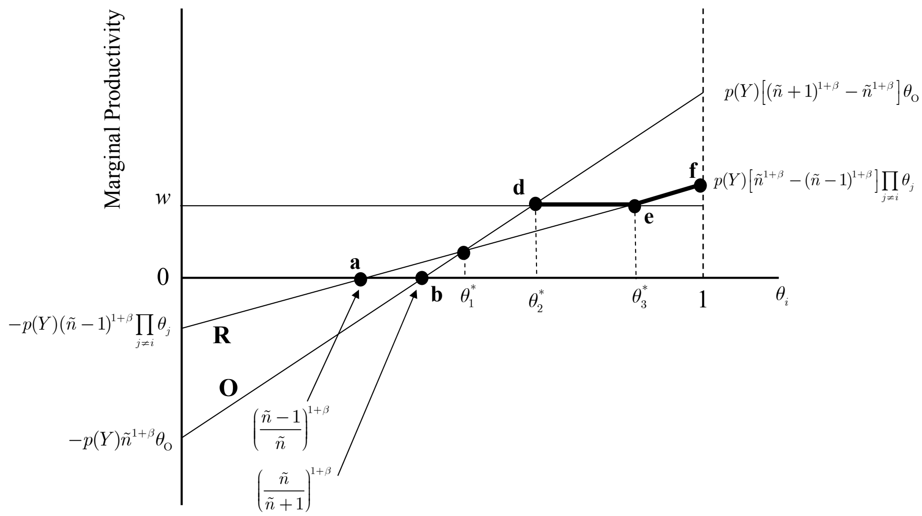

FIGURE 3. Marginal productivities, firm quality and worker ability (no successful counteroffers). First round of reallocations.

which the marginal product becomes positive is greater for the offering firm, regardless of firm qualities. A worker is more valuable to the offering firm if his ability exceeds θ_1^*. However, his value at this point does not exceed the reservation wage, w, so the offering firm does not succeed in recruiting him. In contrast, any worker with ability exceeding θ_2^* is offered a wage that induces him to change employers. For workers with ability in the range $\theta_i \in \left[\theta_2^*, \theta_3^*\right]$ the offered wage is w. For workers with $\theta_i \in \left[\theta_3^*, 1\right]$, the offered wage is given by the line **R**. Thus, the bold line **def** depicts the offered wages as a function of worker ability.

Figure 3 illustrates a case in which the receiving firm can never make a successful counteroffer. Figure 4 provides an example in which it can. An increase in the quality of the receiving firm rotates **R** counterclockwise around point **a**. Thus, Figure 4 shows a receiving firm that is higher quality than in Figure 3. In this case, it can fend off outside bids for any worker with ability $\theta_i \in \left[\theta_2^*, \theta_3^*\right]$, but it continues to lose workers with ability $\theta_i \in \left[\theta_3^*, 1\right]$. Wages earned by a worker that receives an offer are indicated by the bold segment **def**. Of course, if the quality of the receiving firm relative to the offering firm is sufficiently great, then there is no worker that the offering firm can successfully recruit.

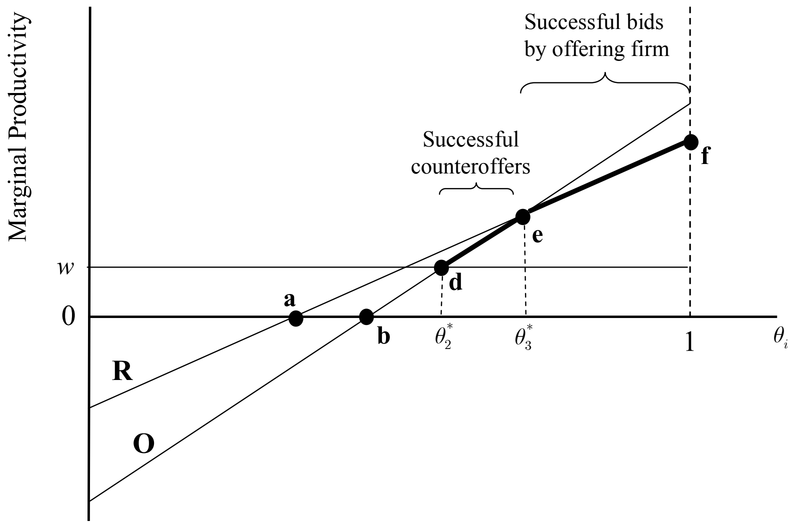

FIGURE 4. Marginal productivities, firm quality and worker ability (with successful counteroffers for some employees). First round of reallocations.

Before this point is reached, however, the ability level above which the offering firm must offer a wage in excess of w declines as the quality of the current employer rises. If a worker exceeds this critical ability, the wage that must be paid by the offering firm increases with ability at a greater rate.

Industry dynamics with worker reallocation are quite rich. They are also complicated, and so we defer to Section 3 a computational analysis of the dynamics. In the remainder of this section, we summarize some implications of the model that clearly may lead to shakeouts.

P1. (a) *The probability that the offering firm is successful in recruitment is increasing in the quality of the offering firm.* **(b)** *The probability that the receiving firm loses a targeted worker is decreasing in the ability of the worker's colleagues.*

Part (a) of P1 is evident from Figures 3 and 4. An increase in the quality of the offering firm rotates **O** counterclockwise around point **b.** Hence, for any given quality of receiving firm, θ_2^* in Figure 3 moves left, as does θ_3^* in Figure 4. This expands the range of worker abilities over which the offering firm outbids both the reservation wage and any counteroffer, thereby raising the probability that a worker contacted at random is recruited.

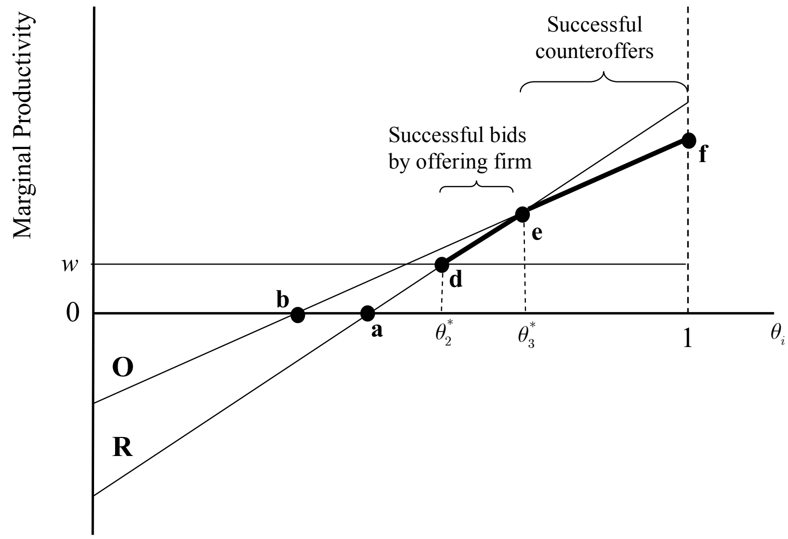

FIGURE 5. Recruitment and counteroffers when the offering firm is smaller than the receiving firm.

Figures 3 and 4 illustrate possibilities that arise when the offering firm has at least as many employees as the receiving firm. But in later rounds of reallocations, it is possible that the offering firm has fewer employees. From (11) it is clear that sensitivity of marginal productivity to worker quality increases with firm size. Consequently, a reduction in the size of the offering firm flattens the marginal productivity schedule, as well as shifting its intersection with the reservation wage to the left. Figure 5 shows that if the offering firm is sufficiently small relative to the receiving firm, it may successfully recruit workers of intermediate ability while being unable to recruit the highest-ability workers. However, an increase in the quality of the offering firm moves θ_2^* to the left and θ_3^* to the right, thereby expanding the ranges of abilities that are successfully recruited. Thus, part (a) of P1 holds regardless of the sizes of the offering and receiving firms.

Part (b) of P1 is evident in Figures 4 and 5: A counterclockwise rotation of **R** around point **a** expands the range of abilities for which counteroffers are successful.

P2. *Every worker transfer yields an increase in industry output.*

P2 follows because every transfer involves an increase in the offering firm's output that exceeds the loss in output of the receiving firm.[7] In Figures 2 and 3, any time a worker is made a wage offer, his marginal product at the receiving firm is positive. Thus, in the first period of reallocations, every firm that loses a worker suffers a decline in output. But this is not always the case in subsequent periods, when the offering firm may have fewer employees than the receiving firm. In such a case it is possible for a worker's marginal product to exceed his reservation wage at the offering firm but be negative at the receiving firm.

P3. (a) *Every successful recruitment raises the profit of the offering firm.* **(b)** *Every counteroffer, whether or not successful, lowers the profit of the receiving firm.*

There is almost no case in which a successful bid by the offering firm requires it to pay the marginal product of the worker it recruits. Thus, successful recruitment raises profit. The effect of losing a worker on the receiving firm's profit is more complicated, even in the first period of reallocations. Consider first Figure 3. If the lost employee has ability $\theta_i \in \left[\theta_3^*, 1\right]$, then the receiving firm loses output that exceeds the wage it was paying. In contrast, if the worker has ability $\theta_i \in \left[\theta_2^*, \theta_3^*\right]$ the reduction in the wage bill exceeds the lost output, and profit rises. In Figure 4, however, profit always declines when the receiving firm loses a worker. Moreover, it also sees profit decline if it defends against an outside bid with a successful counteroffer (in this case it preserves output but suffers an increase in its wage bill). The connecting theme in the two figures is that the receiving firm loses profit whenever it responds to a bid for one of its workers with a counteroffer, whether or not the counteroffer is successful. In contrast, it gains profit whenever it loses a worker to whom it did not extend a counteroffer. This dependency on the counteroffer decision of the response of profits to losing a worker applies also after the first round of reallocations.

Taken together, these propositions establish the basic conditions for a shakeout. When workers switch employers, they will tend to do so by abandoning low-quality firms for high-quality firms. Expanding firms experience rising profits relative to stagnant firms (that are forced to pay counteroffers), or contracting firms (that lose high-ability workers). All reallocations raise industry output, so that price is non-increasing, and is likely

7. Unless, of course, the loss of a worker induces the receiving firm to exit.

eventually to be strictly decreasing.

2.3 Wages and labor mobility

The model also has some distinctive predictions for wage dynamics and labor mobility. These are incidental to the primary focus of the paper, and so we simply summarize and relate them to empirical evidence. First, average wages are increasing in firm age; firms that ultimately survive the shakeout will see their average wage rising over time as they collect together workers of higher ability, while firms destined to exit may exhibit a declining wage bill. Dunne and Roberts (1990a, 1990b) Korobow (2002), Troske (1998), and Brixy, Kohaut and Schnable (2007) report that older plants pay higher wages, and these results survive controlling for, *inter alia*, employer size and industry. However, wages rise in our model because high-quality firms succeed in recruiting high-ability workers. Thus, much of the effect of age on wages should be explained by worker characteristics, and this is what Brown and Medoff (2003) and Heyman (2007) find.

Second, an individual's career is characterized by a sequence of jumps in wages, resulting from changes of employer or from counteroffers to outside bids. The average age-wage profile is positively sloped and concave, consistent with evidence [Murphy and Welch (1992)], and it is steeper the younger the industry.[8] The wage trajectory for any individual depends in large part on luck (in receiving outside offers), but there are also patterns. A worker's marginal product at any firm is increasing in his ability, so offers and counteroffers above the reservation wage, w, are more rapidly forthcoming. Thus, although workers with greater ability do not begin with a higher wage, they enjoy a steeper age-earnings profile. The best workers are also the ones most likely to switch employers.

Third, labor turnover is greater for younger firms (controlling for size), while labor mobility is greater for younger workers with relatively little experience in the industry and less tenure in the firm. These predictions are consistent with evidence. For example, it is well known that job turnover is greater among young firms [cf. Dunne, Robert and Samuelson (1989), Storey (1994), Davis, Haltiwanger and Schuh (1996); Brixy, Kohaut, and Schnabel (2005) follow individual firms to show that this finding is not due to selection]. Hall

8. Thompson (2003) has documented that in the merchant marine experience earnings profiles are steeper when technology is newer.

(1982), and Topel and Ward (1992) both report that two-thirds of job changes made during an average career are made during the first ten years.[9]

2.4 Complications

The implications of the model rapidly become more complicated after the first round. The first complication arises when offering firms have fewer employers than receiving firms. In these cases, offering firms do not successfully recruit the best employees, but they can recruit workers with intermediate ability levels. Second, the assumption that abilities are random draws from the standard uniform distribution yields a tractable distribution for firm quality upon entry, but this tractability quickly breaks down. Worker reallocations change both the distribution of employment numbers and the distribution of abilities across firms in a non-random fashion. In addition, exit of contracting firms removes from the pool firms whose workers are concentrated at the left of the ability distribution. Thus the distribution of ability in the industry population of abilities soon departs from the standard uniform.[10] Third, exit of low-quality firms creates additional uncertainties, because whether their exit induces an additional wave of entry must remain for the moment a matter of speculation. On the one hand, reallocation may proceed sufficiently slowly that exits due to worker losses only happen after entry has dried up. In this case, by the time these exits begin to occur the increase in average firm output may have already driven price well below the level defined by the zero-profit condition. Because the loss in output caused by exits may easily exceed the gain in output from expanding firms, industry output need not rise monotonically and price need not decline monotonically. On the other hand, a quicker process of reallocation-induced exit may lead to exits before price

9. There is little direct evidence that variations in turnover rates by worker quality is a major determinant of performance. One would imagine the effect of turnover to be self-evident, but there is a particularly difficult issue of causality. For example, Lengermann and Vilhuber (2002) document that high-quality workers are more likely to depart a firm in the years immediately before that firm exits. But it seems likely that firm difficulties are more obvious to high-quality workers, who anyway have better outside options. The evidence in Lettermann and Vilhuber is consistent with our model, but it is equally consistent with a model in which emerging firm difficulties drive the best, most forward-looking, workers away.

10. In fact, tractability breaks down even in the first round for uniform distributions with a range different from the unit interval.

has fallen, which in turn creates an incipient price increase that induces additional entry. Examining which of these effects is likely to dominate also requires a simulation approach.

3. Industry Dynamics

Simulation of the model was carried out in MATLAB.[11] The production technology is as described in the previous section, with individual abilities drawn from the uniform distribution on $\left[\underline{\theta},\overline{\theta}\right]$. Demand takes the constant elasticity form, $Y = Ap^{-\varepsilon}$. For some parameter values, the model generates dynamics consistent with a strong shakeout. However, as will become readily apparent, the shakeout typically begins immediately. We begin in subsection 3.1 with a review of simulations for parameter values that generate a shakeout. Subsection 3.2 describes the changes in parameters that preclude shakeouts.

3.1 Shakeout dynamics

We report the results of a simulation using the following parameters. $\underline{\theta} = 0.4$, $\overline{\theta} = 0.8$, $\beta = 2$, $w = 1$, $k = 3.73$, $A = 31,822$, and $\varepsilon = 4$. These parameter values induce an initial entry of 5,000 firms, each employing five workers, and an equilibrium initial price of $p = 0.9$. Although each run of the model is stochastic, the large number of initial entrants leads to extremely stable behavior across runs.

Figures 6 presents the entry and exit rates as well as the number of incumbents in each of 300 periods simulated. At the end of the first period, over 16 percent of the initial entrants choose to exit after suffering negative profits. After reallocation of workers and the resulting increase in output of surviving firms, a little less than half of the exiting firms are replaced by new entrants. Entry of new firms dries up almost immediately, the last entrants being in the second period. In contrast, the exit rate remains positive for some considerable time. It does not decline monotonically, but there is clearly a declining trend toward zero. Figure 7 shows the net effect on the number of active firms in the industry, which does decline monotonically. Reallocation of workers induces firms to exit, both because price is declining and because some firms fall below the optimum size as a result of

11. The program is available at http://www.fiu.edu/~thompsop.

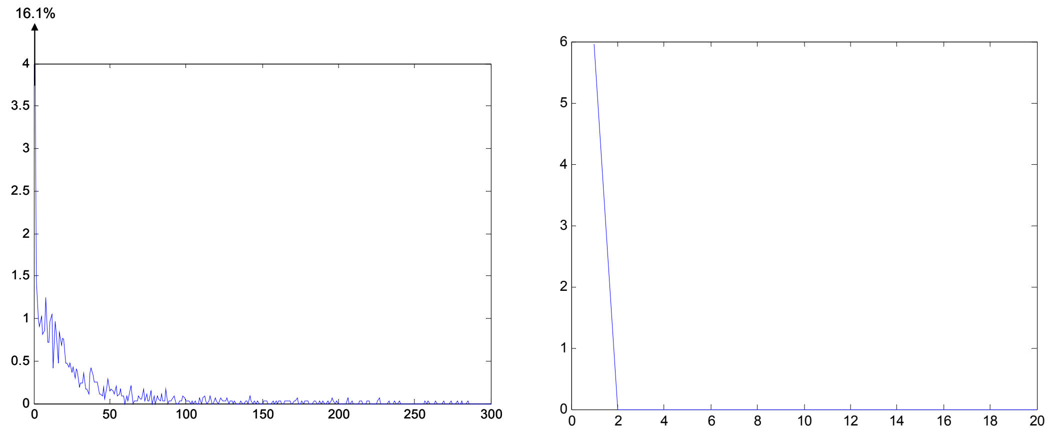

FIGURE 6. Exit rate (left panel) and entry rate (right panel), percentages. Note the changes in scales.

losing workers to poaching firms. Eventually, however, reallocation becomes increasingly rare, and the number of incumbents approaches a steady-state, in this case with about 65 percent of the number of firms that initially entered.

Figure 8 shows the effects of reallocation and exit on price and industry output. The former declines while the latter rises, both at more or less a declining rate. In neither case is the change monotonic: in some periods the lost output from exiting firms exceeds the expansion in output from growing firms, but this is the exception rather than the rule. Figure 9 shows that the average wage initially grows rapidly before approaching an upper bound, in this case about twice the starting wage. A worker's wage only increases if he changes employers or receives a counteroffer to an outside bid, and many workers are never the target of a recruitment bid. Thus, the considerable rise in average wage is driven by a large increase in wage dispersion. This is documented in Figure 10, which shows the density of wages at three points in time. Note in each case the persistence of a mass point at w=1; these are the wages of workers that never received an offer from an outside firm.

Just as the dispersion of wages increases, so does the dispersion of firm size, whether measured by employment (Figure 11, left panel), or output (Figure 11, right panel). The left panel reveals an initially sharp mode in the density of employment at n=5, which decays only slowly with the passage of time. Note that about fifteen percent of incumbent

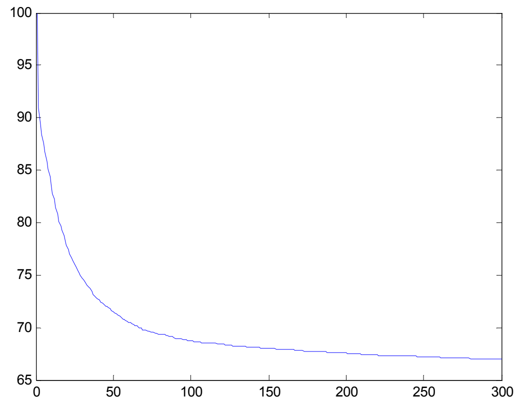

FIGURE 7. Number of incumbents (index = 100 at t=0).

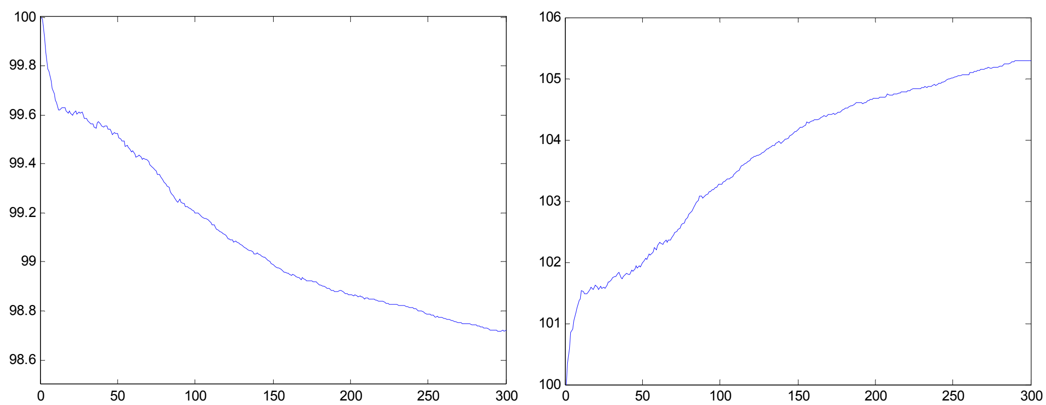

FIGURE 8. Price (left panel) and industry output (right panel), indices.

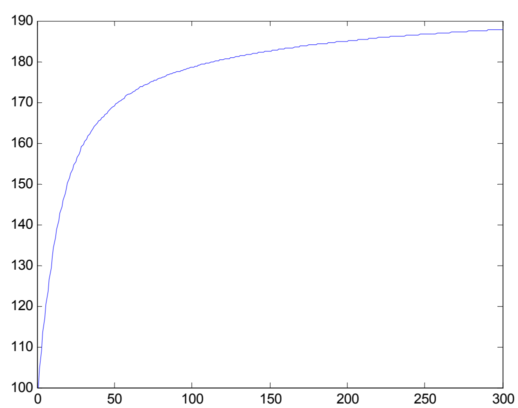

FIGURE 9. Average wage (index).

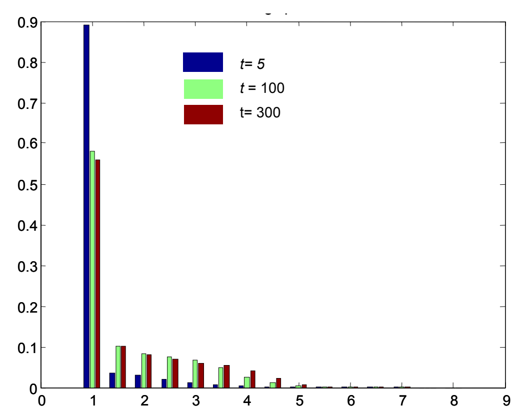

FIGURE 10. Density of wages at t=5, t =100, and t =300.

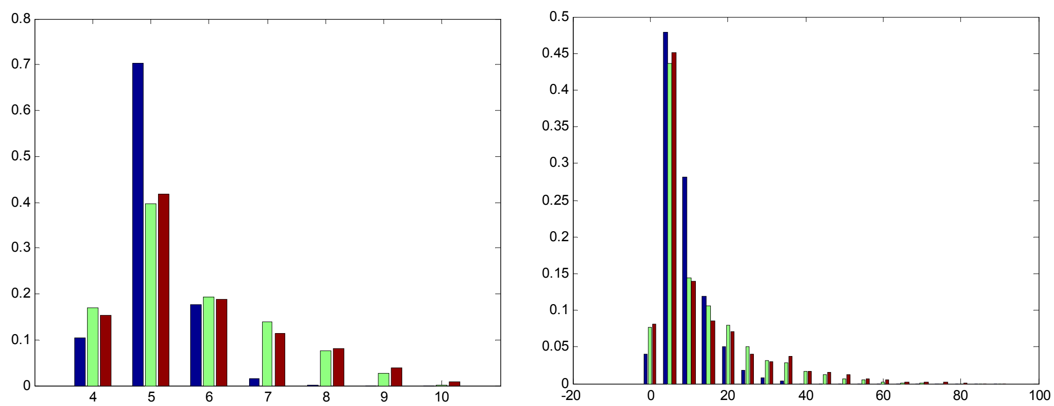

FIGURE 11. Density of employment (left panel) and output (right panel) at t=5, t =100, and t =300.

firms have reduced their workforce to four employees. These are low-quality firms that cannot justify hiring from outside the industry. Presumably, because there are no incumbents with only three employees, a firm that is sufficiently low quality that it chooses not to replace two workers lost to other firms is never profitable. The right panel does not reveal quite as strong a mode (note the change in scale) because firm output is a continuous random variable even upon entry with n=5. The evolution of the size distribution of firms – characterized by increasing mean and dispersion – is consistent with the empirical evidence reported in Cabral and Mata (2003).

3.2 Industries without shakeouts

For many parameter values, the model does not generate shakeouts with rising output and falling price. To conserve space, we consider in this subsection just two parameter variations, the entry cost, k, and the range, $\left[\underline{\theta}, \overline{\theta}\right]$, of abilities in the population.

Figure 12 reports the simulated patterns of entry and exit when the cost of entry is greatly reduced to k=0.2. In contrast to the simulation in the previous section, when k was about 3.7, entry and exit persist at significant levels throughout the entire simulation period. At first, exit rates exceed entry rates, so there is a marked decline in the number of active firms, characteristic of a shakeout. However, by t=150 or so, entry and exit rates are almost equal. As a group of firms exits, a group of almost the same size enters to replace them. In contrast to the previous section, then, there is sustained turnover in the members of the industry. However, for k=0.2, there is no increase in output and no reduction in price. In fact, the simulations yield price and output levels at t=300 almost identical to those observed at t=0 (not shown). In view of the sustained entry seen in Figure 12, this should not be surprising. If there is positive entry, price cannot have fallen below the level determined in equilibrium at the birth of the industry, and of course if

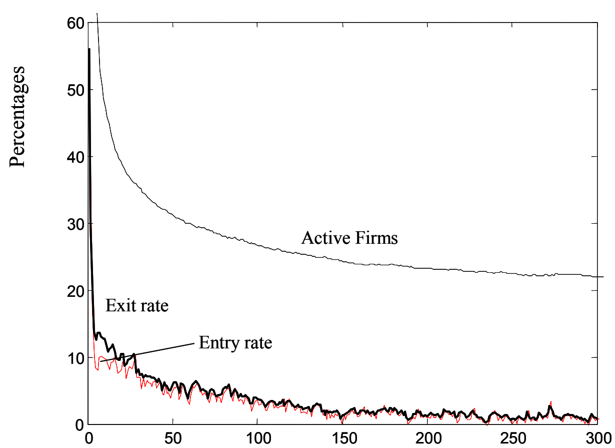

FIGURE 12. Entry and exit rates, and active firms for k=0.2. Entry and exit rates are percentages of incumbents. Number of active firms is a percentage of the initial entry cohort size).

price does not fall then output does not rise. Clearly, with output constant and the number of firms declining by over 75 percent, there is a marked rise in average output. It is also the case that the dispersion of output greatly increases, as illustrated in Figure 13.

Consider now the other extreme, when k is very large. For values of k in excess of twenty, there is no exit and consequently no entry. The reasoning is straightforward. When entry costs are high, the equilibrium number of entrants at the birth of the industry is small and price is high. Reallocation of workers without exits unambiguously raises output and reduces price, precluding any subsequent entry. Firms may then lose a number of key workers but nonetheless make positive profits as all incumbents are protected behind the entry barrier. For large entry costs, then, there is no shakeout, but price falls and output rises.

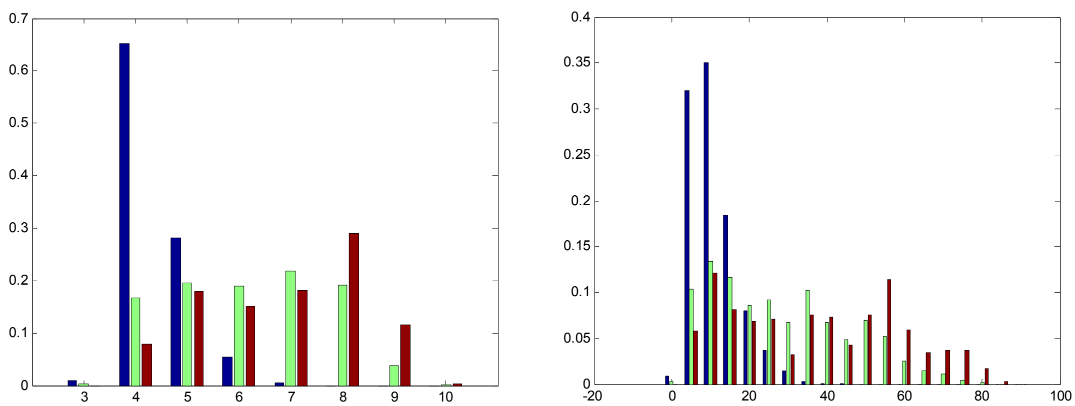

FIGURE 13. Density of employment (left panel) and output (right panel) at t=5, t =100, and t =300, for k=0.2.

Figure 14 summarizes the effects of changes in entry cost on the "terminal" industry size and output (calculated when t=300, after which there is very little change). For very low entry costs, there is a dramatic drop in the number of active firms, but very little increase in aggregate output. At the other extreme, there is no decline in the number of active firms, but a considerable increase in output. What we have in mind as a typical shakeout, with rising output and a declining number of active firms, occurs with interme-

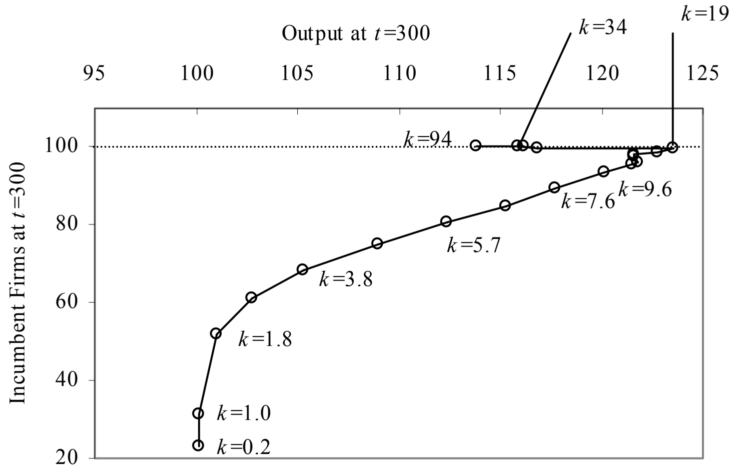

Figure 14. Effect of changes in entry cost on terminal output and firm numbers. Indices, based on initial entry cohort of 3,000 firms.

diate values of the entry cost.[12]

We turn next to a change in the distribution of worker abilities. A reduction in the range of abilities has a moderating effect on industry dynamics.[13] First, labor reallocations are less frequent, because it is less likely that an additional worker will be more productive at an expanding firm than at a contracting firm. When reallocations do occur, they lead to smaller variations in wages and smaller increases in aggregate output. Losing a worker is also less likely to force a firm out of business. To the contrary, the firm is usually able to hire a replacement with similar abilities from outside the industry, and as a result it is only modestly affected by the loss of an employee. In the limit, as all workers become identical, all industry dynamics vanish.

4. Conclusions

There are a number of plausible models generating industry shakeouts. These theories are

12. A curious feature in Figure 14 is the decline in terminal industry output as k is increased beyond twenty. This decline in terminal output appears to be driven by the absence of selection: exits remove unproductive firms from the market, leaving room for more productive firms to expand.

13. These effects are sufficiently intuitive that we shall not reproduce graphs of simulations here.

not mutually exclusive, and in this paper we have presented an additional mechanism. We combine the strong skill complementarity in Kremer's (1993) O-ring theory of production with a frictional sorting process. As high-skill and low-skill workers are gradually collected together within firms, firms endogenously sort themselves along a continuum of quality. Firms that find themselves only with low-skill workers, are eventually forced out of the industry. Surviving firms expand output and aggregate output rises alongside a decline in the number of active firms.

Some caveats are in order. First, we made some modeling decisions that proved necessary for tractability. Perhaps the most important of these decisions was to assume that firms are myopic. This assumption is unlikely to be innocuous. For example, far-sighted firms may choose not to hire someone today even though they raise the firm's current profit, because doing so may preclude them from hiring someone better in the future; similarly, firms will not exit as soon as they earn negative profits, because the option value of remaining in the industry is always positive. It is difficult to know the extent to which our simulations would differ with far-sighted firms without actually carrying out the simulations. Unfortunately, the high-dimensionality of such a problem is beyond our capabilities. Another assumption we have made is that firms cannot fire low-ability workers or, equivalently, reduce their wages to force a "voluntary" departure. The assumption is a convenient way to impose losses on firms whose only workers are low-ability, and we are less concerned that this assumption is critical: obviously, some mechanism must exist to create losses for firms, but reasonable alternatives such as the presence of a fixed operating cost would do the job equally well.

Second, the simulations generate shakeouts in which the growth in industry output and the decline in price is modest in comparison with those observed in much industry data. In part, this is due to the stylized nature of the model (there is no capital, for example, the presence of which would amplify the output effects of labor reallocation). But, more important, we do not claim that the labor reallocation process we model is the only, nor even the most important, driving force for shakeouts. Without doubt, firms increase productivity even without acquiring high-quality workers, either through passive learning or active research.

Finally, the shakeouts generated by the model begin immediately. Figure 1, however, depicts a process in which the number of active firms first rose and then fell in the tire industry, and this is typical of most industries that experience shakeouts. We do not see this in our model because we have not modeled an extended process of industry birth. The number of active firms may experience a period of protracted growth prior to the shakeout either because demand for the industry's output grows over the early years of the industry, or because there is a limit at any point in time to the number of entrepreneurs that have the relevant skills to enter. Certainly, in the case of the tire industry, demand could only grow over a period of many years in lock step with the expansion of the automobile industry. Incorporating this protracted birth into the simulations would of course be straightforward, but doing so would provide little additional insight.

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