Shaking All Over?
International Trade and Industrial Dynamics

Josh Ederington
University of Kentucky

Phillip McCalman
University of California-Santa Cruz*

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Abstract

This paper develops a model of international trade and industrial evolution. Evolution is driven by the endogenous technology choices of firms, which generates a rich industrial environment that includes the possibility of a dramatic shakeout. The likelihood, magnitude and timing of this shakeout is characterized and depends not only on the size of the innovation but also on the structure of production costs. In this setting, trade liberalization is shown to reduce the likelihood of a shakeout, resulting in a more stable industrial structure. However, when shakeouts arise in global markets, the distribution of firm exits can vary widely across countries. Furthermore, conditions exist where a shakeout occurs in a closed economy but not in an open economy. Empirical evidence is presented that is consistent with the prediction that more internationally integrated sectors are less likely to experience a shakeout.

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*Ederington: 335 Gatton Building, Department of Economics, University of Kentucky, Lexington, KY 40506 (email: ederington@uky.edu); McCalman: Department of Economics, University of California, 1156 High Street, Santa Cruz, CA 95064 (email: mccalman@ucsc.edu).

1 Introduction

The empirical literature on the industry life cycle has documented a variety of patterns in the evolution of market structure. While some industries exhibit a relatively stable structure in which the number of firms is constant or only gradually changing over time, other industries exhibit a decidedly non-monotonic pattern in which the number of firms falls, often dramatically, after achieving its peak. This change in the number of firms is common enough and dramatic enough to have its own title: a shakeout.[1] A prominent example of this phenomenon is the US automobile tire industry, where the number of firms declined from a peak of 275 in 1922 to just 132 firms in 1928. The number of firms continued to fall over time, eventually dropping to 30 firms by 1973. A second interesting example involves the evolution of market structure in the synthetic dye industry.[2] At its inception in the mid 1850s, three countries had significant firm entry into this industry: France, Britain and Germany. Over the initial growth phase, the number of French firms expanded most rapidly, with France having the largest number of synthetic dye producers. However, after this period of expansion, the number of French producers fell sharply, declining by over 60%. In contrast, the number of firms continued to expand in Germany, while the number of firms remained relatively constant in Britain.

The obvious questions that arise from such studies are why did such a dramatic event occur in the tire industry (and not, for example, in the gas turbine industry), and why did a shakeout occur in the French synthetic dye industry but not in Germany or Britain? These questions are directly connected since it seems quite possible that shakeout phenomena are related to forces of international competition. In addition, as the synthetic dye example makes clear, inferences based on single country studies of shakeouts are potentially incomplete: an industry that is stable in one country may well experience a shakeout in *some* other country. Thus, in this paper, we develop a model of endogenous shakeouts in order to both isolate the underlying determinants of shakeouts and analyze how shakeout phenomena may be related to global competition.[3]

Traditional explanations for these shakeout events have focused on technological change as the driving force (see Jovanovic and MacDonald (1994), Klepper (1996) and Utterback and Suarez (1993)), in which competitive pressure eventually drives technologically-lagging firms out of the market. The common thread in this literature is the assumption that shakeouts derive from some underlying heterogeneity in the ability of firms to adapt to technological innovation. Since the focus

[1] The pioneering papers in the empirical industry life cycle literature are Gort and Klepper (1982) and Klepper and Graddy (1990). Later contributions include Carroll and Hannan (2000). This literature has consistently documented the pervasive nature of shakeout events. Indeed, almost half of the 46 industries studied by Klepper and Graddy (1990) experienced a shakeout.

[2] The automobile tire industry is studied extensively by both Jovanovic and MacDonald (1994) and Klepper and Simons (2000). The synthetic dye industry is analyzed by Murmann and Homburg (2001).

[3] While shakeouts have not played a role in the international trade literature, models of firm heterogeneity have. For empirical evidence on the relationship between firm heterogeneity and international trade see Clerides, Lach, and Tybout (1998), Bernard and Jensen (1999) and Bernard, Eaton, Jensen, and Kortum (2003). For other models that incorporate international trade and firm-level heterogeneity see Bernard, Schott, and Redding (2004), Melitz (2003) and Yeaple (2005).

of these papers is on showing how the competitive pressures generated by technological progress can "fit" the particular dynamics of shakeout industries, the actual process by which firms adapt to technological innovation is taken as exogenously determined.[4] However, treating technological adoption as exogenous could potentially mask the underlying determinants of shakeouts and the relationship between shakeouts and global competition. Thus, in this paper we combine the traditional, technology-based explanation of shakeouts with the literature on the endogenous adoption of technological innovation (pioneered by Reinganum (1981a), Reinganum (1981b) and Fudenberg and Tirole (1985)) in order to derive a model of endogenous shakeouts.

The model we develop shares the feature that shakeouts are driven by technological progress which forces technologically-lagging firms from the market. However, in contrast to the previous literature, we derive firm heterogeneity as an equilibrium outcome of an endogenous technology adoption game, rather than imposing it exogenously. By endogenizing the process of technological diffusion, we can provide a more complete analysis of how underlying market conditions (i.e., demand conditions, the structure of production costs, and international competition) are related to shakeout events.

A key feature of our paper is that we are able to show how shakeouts can be derived naturally from game-theoretic models of *endogenous* technology adoption. Specifically, we envision a market in which *ex ante* identical firms, producing a differentiated product, endogenously choose when to adopt a cost-saving technological innovation. We show that the gradual diffusion of the cost-saving innovation through the industry may force a mass exit of the lagging firms from the market (i.e., a shakeout occurs). Thus, we find that one does not need to impose randomness or uncertainty into the adoption of technological innovations in order to derive shakeouts; rather, they can be a natural outcome of the diffusion process.[5] In this sense our paper is similar to Götz (2002) and Petrakis and Roy (1999) which also analyze industry evolution and the potential for shakeouts within fully deterministic models.[6] In such perfect information models, shakeouts arise from the existence of profitable opportunities early in the life of an industry, which encourages temporary entry and then exit by forward-looking firms. In Götz (2002), these profit opportunities are derived from exogenous limitations on the number of potential entrants. In Petrakis and Roy (1999), these profit opportunities are derived from limitations on investment (specifically, the idea that the optimal scale of production only gradually increases over time due to convex adjustment costs to investment

[4] In Jovanovic and MacDonald (1994) technologically-lagging firms are generated by assuming random failures at innovation, while Klepper (1996) assumes random differences in productivity and time of entry.

[5] A second interesting aspect of our model is to show how the adoption of new technologies (a process which is typically very gradual and often encompasses decades) can generate rapid, catastrophic exit of the type observed in the automobile tire industry. Specifically, our model shows that there is a feedback between firm exit and firm adoption (i.e., the decision to exit by a group of firms will increase the incentive for the remaining firms to adopt the new technology, which in turn induces more firms to exit, etc.) which results in technologically lagging firms exiting *en masse*.

[6] Also see Roy and Kamihigashi (2005).

activity).[7] In contrast, in this paper, the profit opportunities are derived from the well-documented gradualism in the adoption of new innovations.

This deterministic framework also makes clear the key role that the structure of production costs plays in the determination of whether an industry experiences a shakeout. Specifically, by producing differentiated products, firms earn positive profits which are used to defray the costs of entry along with the costs of technology adoption and any recurring fixed costs. What we show is that for a given innovation, the higher the size of the recurring fixed costs relative to the entry costs, the greater is the probability of a shakeout. This result has the intuitively appealing feature that shakeouts are most likely in industries that are not only undergoing technological change but are also relatively easy to enter. Moreover, it illustrates that dramatic technological change is not sufficient for a shakeout to occur. Indeed, a relatively small innovation can cause a shakeout in a market with relatively low entry costs, while a dramatic innovation will have little effect on market structure if entry costs are very large.

In thinking about open economy settings, it is important to note that the bulk of trade flows occur in differentiated products. [8] Given that product differentiation is the basis of our model, it is straightforward to incorporate this primary motivation for international trade. Following the synthetic dye example, we focus our attention on the case where the level of technological development varies across countries. In this setting we investigate how trade barriers affect the likelihood of a shakeout, as well as the forces that influence the location of any shakeouts that occur.[9] Specifically, we demonstrate how trade barriers can lead to a fragmentation of markets, thus encouraging the temporary entry of firms and raising the likelihood of a shakeout. In more fragmented markets, a given innovation has a more pronounced effect on the profits of firms that lag behind the frontier, raising the chances that these lagging firms will experience negative profits and exit. Therefore, from both a national and international perspective, freer trade generates a more stable market structure. With respect to the location of shakeouts, we show that technological asymmetries can be matched by an asymmetry in the pattern of exits across countries. Specifically, we show that the technologically backward country will always undergo a larger shakeout than the advanced country. In fact, for a large range of parameter values the advanced country has a relatively stable market structure, and may even experience an increase in the number of firms as exit in the less-advanced country induces entry in the advanced country.

These results provide a striking contrast to the closed economy model. The same conditions that generate a shakeout in the closed economy setting are associated with either a constant or growing

[7]There exists a nice connection between the models of Götz (2002) and, Petrakis and Roy (1999) and that of Klepper (1996) which assumes both exogenous limitations on entry and convex adjustment costs to investment.

[8]See, for example, Evenett and Keller (2002).

[9]The Jovanovic (1982) model of entry with uncertainty about firm productivity has been applied to an open-economy setting by Clarida (1993). In that paper, firm entry induces informational gains as firms learn about their future profitability. Clarida (1993) shows that high demand can induce increased entry of firms, that in turn results in overseas dumping of production. Such dumping does not occur in our paper as firm technology decisions, and hence firm productivity, are treated as endogenous.

number of firms for the advanced country in the open economy case. Thus trade generates a more stable industrial evolution from an advanced country perspective. Note that a national focus would not accurately identify the mechanism behind this stability. Consequently, single-country studies are only likely to provide reliable evidence about the likelihood of a shakeout if there is very little trade. However, industries with this characteristic are increasingly rare, and the introduction of international trade adds an important dimension to the analysis that aides our understanding of the industrial dynamics of industries.

In order to establish these results, the paper is structured as follows. In Section 2, we set up the closed economy model and derive the equilibrium conditions. In Section 3, we characterize the comparative statics of the closed economy model. Section 4 extends the model to allow for international trade.

2 Shakeouts in a Closed Economy

In this section we present a closed economy model of industrial evolution that is driven by technology adoption. An industry is created at time $t = 0$ by the introduction of some rudimentary technology. A cost-saving innovation exists and its implementation gradually becomes commercially viable as the costs of adopting the innovation fall. It is the adoption of this new technology that drives the evolution of the industry. However, instead of treating technology adoption as an exogenous and random process, we endogenize technology adoption decisions using a standard game-theoretic treatment of technology diffusion that dates back to the work of Reinganum (1981a). In this section we follow Götz (1999) in considering a closed economy model with an industry characterized by monopolistic competition. The main contribution of this section is to show how a straightforward modification of technology diffusion models can generate industry shakeout phenomena.[10]

2.1 Market Demand Conditions

We assume that the economy has two sectors: one sector consists of a numeraire good, x_0, while the other sector is characterized by differentiated products. The following intertemporal utility function defines the preferences of a representative consumer:

$$U = \int_0^\infty (x_0(t) + logC(t))e^{-rt}dt \tag{1}$$

where $x_0(t)$ is consumption of the numeraire good in time t and $C(t)$ represents an index of consumption of the differentiated goods. We assume a CES specification which reflects a taste for variety in consumption and implies a constant (and equal) elasticity of substitution between every pair of

[10]By considering adoption in a setting of monopolistic competition we are following Götz (1999) and Ederington and McCalman (2004). However, neither of these papers address the issue of how technology adoption affects the evolution of market structure. Also see Bagwell and Staiger (1992) for a model of trade and technology that emphasizes strategic issues.

goods:

$$C(t) = \left[\int_0^{n(t)} y(z,t)^{\rho} dz \right]^{1/\rho} \tag{2}$$

where $y(z,t)$ represents consumption of brand z at time t and $n(t)$ represents the number of varieties available at time t. With these preferences, the elasticity of substitution between any two products is $\sigma = 1/(1-\rho) > 1$ and aggregate demand for good i at time t is:

$$y(i,t) = \frac{p(i,t)^{-\sigma} E}{\int_0^{n(t)} p(i,t)^{1-\sigma} dz} \tag{3}$$

where $p(i,t)$ is the price of good i in time t and E represents the total number of consumers in the economy.

2.2 Production Costs

All goods are produced in the economy using constant returns to scale technologies and a single factor of production, labor. Thus, production of any good (or brand) requires a certain amount of labor per unit of output. For simplicity, we assume that production of the numeraire good is defined by $l = x_0$ which ensures that the equilibrium wage is equal to unity.

Firms can enter the differentiated goods sector by paying a sunk entry fee of F_0. We assume that varieties of the differentiated good can be produced using either of two types of technology. A low-productivity technology is always available to any firm upon entering the industry. Production using the low-productivity technology is defined by $l(t) = F + y(t)$, where F is a fixed per-period cost of production.[11] A high-productivity technology is also available at time $t = 0$, but requires an additional fee of $X(t)$ where $X(0) = \infty$, $X(\infty) = 0$, $X' < 0$ and $X'' > 0$.[12] With this adoption cost function, earlier adoption is more expensive; however, the decreasing cost of technology adoption implies that eventually all firms that remain in the industry will adopt the high-tech process. Production using the high-productivity technology is defined by $l(t) = F + y(t)/\varphi$, where $\varphi > 1$.

2.3 Firm Behavior

In this model, firms have four choices to make: when to enter, what price to charge, when to adopt the new technology, and whether (and when) to exit. Since the pricing decision is central to all of the other decisions through its impact on profits, this is where we start our characterization of firm behavior.

[11] This production structure is common in the trade literature and is familair from Krugman (1980). It should be noted that F is not a quasi-fixed cost, but is a true fixed cost in that it is incurred even if the firm produces a quantity of zero.

[12] These are standard assumptions in the technology diffusion literature, see for example Reinganum (1981a) and Fudenberg and Tirole (1985).

Given Dixit-Stiglitz preferences, profit-maximizing firms use a simple mark-up pricing rule for given marginal costs.[13] Thus, the prices set by the low-tech firms and high-tech firms respectively are:

$$p_L = \frac{1}{\rho} = \frac{\sigma}{\sigma - 1} \quad , \quad p_H = \frac{1}{\rho\varphi} = \frac{\sigma}{\varphi(\sigma - 1)} \tag{4}$$

The operating profits of each firm can then be determined as a function of its own and rivals' behavior resulting in a profit differential of:

$$\pi_H(t) - \pi_L(t) = \frac{(\varphi^{\sigma-1} - 1)(\frac{\sigma}{\sigma-1})^{1-\sigma} E}{\sigma \int_0^{n(t)} p(i,t)^{1-\sigma} dz} \tag{5}$$

Let $q \in [0, 1]$ represent the fraction of firms that have already adopted the cost-saving innovation at a point in time. Then the price index is given by:

$$\int_0^{n(t)} p(i,t)^{1-\sigma} dz = (\frac{\sigma}{\sigma - 1})^{1-\sigma}((q\varphi^{\sigma-1} + (1 - q))n(t)) \tag{6}$$

Substituting (6) into (5) gives the profit differential as:

$$\pi_H - \pi_L = \frac{(\varphi^{\sigma-1} - 1)E}{(q(\varphi^{\sigma-1} - 1) + 1)n(t))\sigma} \tag{7}$$

Note that the profit differential $(\pi_H - \pi_L)$ is decreasing as the number of firms producing with the high-tech production process (q) increases. This is because adoption by rival firms reduces the market share of other firms and, thus, the gain to adopting a cost-saving innovation. It is this property of the model that leads diffusion of the new technology to be gradual rather than abrupt, as firms must trade off the increased operating profits from early adoption against the lower adoption costs of later adoption.

2.4 Technological Progress

The equilibrium distribution of technology at any point in time, $q(t)$, is determined by the firms' selection of their optimal adoption dates. A firm chooses the adoption date, T, to maximize the discounted value of total profits:

$$\Pi = \int_0^T e^{-rt}(\pi_L(q(t)) - F)dt + \int_T^\infty e^{-rt}(\pi_H(q(t)) - F)dt - X(T) - F_0$$

These profits depend on both the firm's own adoption date, T, and the adoption decisions of rival firms (which is summarized by the distribution function $q(t)$). Differentiating with respect to T yields the first-order condition:

$$\pi_H(q(T)) - \pi_L(q(T)) = -X'(T)e^{rT} \tag{8}$$

The above first-order condition demonstrates the trade-off faced by firms in the choice of when to adopt. The left-hand side is the lost profits from waiting one more period to adopt the high-productivity technology while the right-hand side is the gain from the decrease in adoption costs

[13] See Grossman and Helpman (1991).

from delaying adoption another period. Substituting the profit differential given by (7) into this first-order condition and solving for $q(t)$ then gives the equilibrium distribution function.[14]

As we discuss below, assuming the fixed costs of production are sufficiently low, operating profits will be positive in each time period and firms will choose to never exit the industry, with all entry occurring at $t = 0$.[15] Consequently, for sufficiently low F, $n(t) = n$ for all t. In this case the equilibrium distribution function is given by:

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \frac{-e^{-rt}E}{X'(t)n\sigma} - \frac{1}{\varphi^{\sigma-1}-1} & \text{for } t \in [T_L, T_H] \\ 1 & \text{for } t \in (T_H, \infty) \end{cases} \tag{9}$$

The above distribution function describes the process of technological progress in the closed economy case. Given initially high adoption costs, all firms are low-tech until T_L. At T_L the first firm adopts the high-productivity technology and, as adoption costs fall, more firms adopt the new technology, leading to a gradual diffusion of the new technology through the industry for periods $T_L \leq t \leq T_H$ (where the fraction of firms that have adopted at any point in time is given by $q^*(t)$). Finally, all firms will have adopted the new technology by period T_H.

2.5 Present Value of Profits

As noted above, if F is sufficiently low, then the number of firms is constant through time (i.e., $n(t) = n$ for all t). To close the model we now solve for the equilibrium number of firms, n. We assume that firms can enter the differentiated goods sector by paying a sunk entry fee of F_o. The decision to enter the industry is endogenous, and entry will occur until the present value of lifetime profits of the firm are equal to zero. The present value of profits is derived by substituting in the respective profit and distribution functions. Thus, the zero-profit condition requires that:

$$\Pi^* = \frac{(1 - e^{-rT_L} + e^{-rT_H})E}{n\sigma r} + \frac{X(T_L) - \varphi^{\sigma-1}X(T_H)}{\varphi^{\sigma-1} - 1} - \frac{F}{r} - F_0 = 0 \tag{10}$$

A straightforward application of the envelope theorem verifies that equilibrium profits are declining in n. This ensures a unique equilibrium for the constant n case. Given that entry occurs until the present value of profits is equal to zero, this zero-profit condition along with $q(t)^*$ (defined by 9) characterizes the closed economy equilibrium.

2.6 Characteristics of the No-Exit Equilibrium

To this point, we have claimed that an equilibrium with a constant number of firms requires that F is sufficiently small. We will now be more precise about this requirement and its implications.

[14] The second order condition is also assumed to hold: $r(\varphi^{\sigma-1} - 1)\pi_L(q(T))e^{-rT} - X''(T) < 0$

[15] Ederington and McCalman (2004) provides a proof that all entry will occur at $t = 0$ in the absence of fixed costs of production. The proof when fixed costs of production are sufficiently small is analogous. However, as we show in a later section, if F is sufficiently large, then late entry is possible.

Since per-period profits are strictly positive for sufficiently small F, the exposition of the no-exit equilibrium is most transparent when $F = 0$. In this case the zero-profit condition can be expressed as:

$$F_0 = \frac{(1 - e^{-rT_L})E}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{n\sigma r} - X(T_H) \tag{11}$$

The no-exit equilibrium also requires that a low-technology firm cannot profitability stay in the market permanently (i.e., eventually $X(T)$ decreases to the point where all firms adopt the new technology):

$$F_0 \geq \frac{E(1 - e^{-rT_L})}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{\varphi^{\sigma-1} n\sigma r} \tag{12}$$

Note that (11) and (12) imply that $\frac{Ee^{-rT_H}}{n\sigma r} > X(T_H)$. This says that the present value of post-adoption profits are greater than adoption costs. Consequently, the zero-profit condition can only hold if sunk entry costs, F_o, are not paid off until after all firms have adopted the new technology (i.e., after T_H). That is, some of the post-adoption profits are used to cover the entry cost. This provides insight into why the number of firms is constant through time. High entry costs ensure that firms must remain in the industry for a long time in order to cover these costs. This provides the industry with a strong stabilizing force.

For small F the above analysis is essentially unchanged except (11) and (12) are now given by:

$$F_0 + \frac{F}{r} = \frac{(1 - e^{-rT_L} + e^{-rT_H})E}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} - X(T_H) \tag{13}$$

$$F_0 + \frac{F}{r} \geq \frac{E(1 - e^{-rT_L})}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{\varphi^{\sigma-1} n\sigma r} \tag{14}$$

From (13) and (14) there exists a date when F_o is paid off, $\widetilde{T} \geq T_H$, such that:

$$\frac{F}{r} + F_0 = \frac{E(1 - e^{-rT_L})}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{n\sigma r} - \left(\frac{E}{n\sigma r} - \frac{F}{r}\right) e^{-r\widetilde{T}} \tag{15}$$

This equation implicitly defines the date, $\widetilde{T}$, at which F_o is paid off. Equation (15) has a number of interesting properties, not the least of which is that the composition of fixed costs can be changed (holding the value of total fixed costs constant) in such a way that F_o is paid off earlier. To see this, start from $F = 0$, and imagine decreasing entry costs, F_o, and increasing fixed per-period costs, F, such that the present value of profits over the lifetime of the firm remains constant (i.e., $F_o + \frac{F}{r}$ is a constant). Note that such a trade-off (i.e., $dF_o = -d\frac{F}{r} < 0$) will hold n, T_L and T_H constant over some range of F and F_o. Figure 1 depicts the changes implied by this trade-off. However, as F_o is decreased, the date at which F_o is paid off, $\widetilde{T}$, will occur earlier in equilibrium (i.e., for (15) to hold, it must be the case that $dF_o < 0$ implies $d\widetilde{T} < 0$). Thus, as F_o is lowered, $\widetilde{T}$ approaches T_H. Meanwhile, as F is increased, net per-period profits for each firm will be reduced. However, as long as F is sufficiently small so that $\pi_L(T_H) > F$ (i.e., profits remain positive for low-tech firms) and F_o is sufficiently large so that $\widetilde{T} > T_H$ (i.e., sunk entry costs are not paid off until all firms have adopted), then no firm will have an incentive to exit the industry.

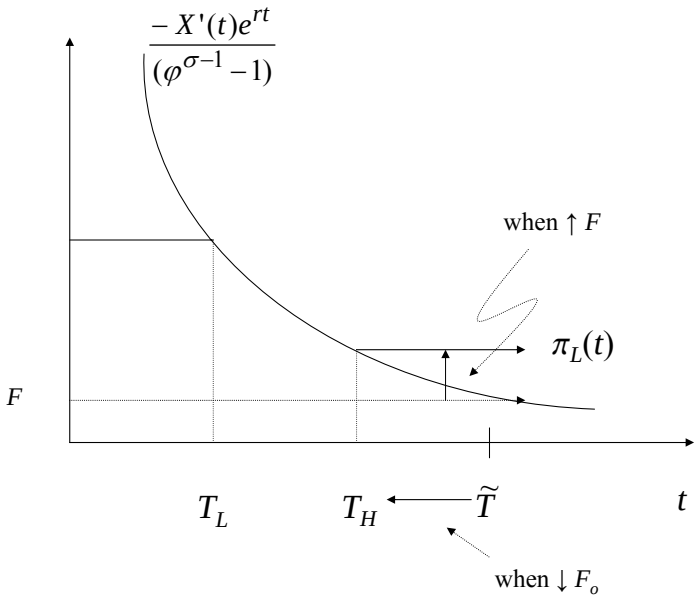


Figure 1: The Effects of Decreasing F_o and Increasing F

2.7 Shakeouts

As discussed in the previous section, if one were to lower F_o and increase F, then $\widetilde{T}$ would approach T_H and F would approach $\pi_L(T_H)$. A natural question is which gap is closed first? While logically there are a number of possibilities, only two are consistent with the no-exit equilibrium: either $\pi_L(T_H) = F$ and $\widetilde{T} = T_H$, or $\pi_L(T_H) = F$, while $\widetilde{T} > T_H$. In this second case, continuing to trade off F_o and F will eventually lead to a point where $\pi_L(T_S) = F$ and F_o is paid off at $\widetilde{T} = T_S < T_H$. Thus, T_S denotes the point where both per-period profits are zero for non-adopters and entry costs have just been paid off. A characteristic of these $\tilde{T} = T_S \leq T_H$ situations is that a non-adopter is indifferent between staying in the market and adopting, or not adopting and exiting at T_S since both options result in discounted profits of zero.

Once $\tilde{T} = T_S \leq T_H$, what happens if we keep trading off $dF_o = -d\frac{F}{r} < 0$? An obvious result of this trade-off is that low-tech firms will be making negative per-period profits at some point during the diffusion process. As we show in the following proposition, such negative profits will necessarily result in the exit from the industry of a group of low-tech firms, provided that these firms have paid off the entry cost.

PROPOSITION 1 *Assuming that F is sufficiently high ($F > \overline{F}$) and F_o is sufficiently small ($F_o < \overline{F_o}$), a group of low-tech firms will choose to exit the industry once per-period profits become zero.*

Proof: Assume $\overline{F}$ and $\overline{F_o}$ are such that $\widetilde{T} = T_S \leq T_H$. Refer to this $\widetilde{T}$ as $\overline{T}$. In this case, the following conditions hold in equilibrium:

$$\begin{aligned} \overline{F} &= \pi_L(q(\overline{T})) && (16) \\ \overline{F}_0 &= (\frac{E}{n\sigma} - \overline{F})\frac{(1-e^{-rT_L})}{r} + \int_{T_L}^{\overline{T}} e^{-rt}(\pi_L(q(t)) - F)dt && (17) \\ X(T_H) &= (\frac{E}{n\sigma} - \overline{F})\frac{e^{-rT_H}}{r} + \int_{\overline{T}}^{T_H} e^{-rt}(\pi_L(q(t)) - F)dt && (18) \end{aligned}$$

Now, continue to decrease F_o such that $dF_o = -d\frac{F}{r} < 0$. Assume that no firms exit the market (i.e., n remains constant). In this case, for (13) to continue to hold, given our definition of $\tilde{T}$, requires that:

$$X(T_H) = \int_{\tilde{T}}^{\overline{T}} e^{-rt}(\pi_L(q(t)) - F)dt + \int_{\overline{T}}^{T_H} e^{-rt}(\pi_L(q(t)) - F)dt + (\frac{E}{n\sigma} - F)\frac{e^{-rT_H}}{r} \qquad (19)$$

However, given that we increased F from the point defined by (18) implies that for (13) to hold, it must be that $\int_{\tilde{T}}^{\overline{T}} e^{-rt}(\pi_L(q(t)) - F)dt > 0$. However, this is inconsistent with the no-exit equilibrium, since it implies that low-tech firms can make positive lifetime profits by remaining in the market until per-period profits become zero and then exiting (i.e., since they have already paid off their sunk entry costs at $\tilde{T}$). Thus, the no-exit equilibrium is no longer sustainable. Q.E.D.

An implication of Proposition 1 is that the number of firms is no longer constant through time, with at least some low-tech firms having an incentive to exit. The intuition behind this result is direct. The gradual diffusion of the high-tech methods through the industry results in lower industry prices and profits. Eventually, per-period profits are diminished to the point where at least some of the low-tech firms would prefer to exit from the industry. While the basic story is a familiar one in the industry life-cycle literature (i.e., exit occurring because technological progress creates competitive pressure which forces technologically lagging firms out of the market), the means by which shakeouts are created in our model requires more explanation. Specifically, an obvious characteristic of a shakeout event is over-entry in the early stages of the industry (i.e., more firms initially enter the industry than will remain permanently). In the industry evolution literature, such over-entry is typically generated through either uncertainty about the process of technological innovation (as in Jovanovic and MacDonald (1994)), myopic decision-making by firms with randomized access to the market (as in Klepper (1996)) or coordination failures (as in Klepper and Miller (1995)). In contrast, our model, similar to other deterministic models of shakeouts (i.e., Götz (2002) and Petrakis and Roy (1999), derives over-entry from profit oppurtunities at beginning of the life of the industry. We have a perfect information framework in which both the decision to innovate and the decision to enter/exit are fully endogenous. What causes over-entry in our framework is the realization by forward-looking firms that, given gradual technology diffusion and suitable industry conditions, they can make profits by entering the market at its inception and then exiting before competitive forces require them to adopt new technological innovations. Thus, in pursuit of those profits, a mass of

firms will temporarily enter the market, leaving when technological progress pushes their per-period profits to zero. Thus, we show that shakeouts are a natural outcome of a standard technological diffusion framework, and one does not need to assume any degree of randomness or exogeneity in the technology adoption process to generate periods of exit.[16]

It should be noted that the presence of this period of exit is a common feature in industrial evolution. For example, of the 46 industries studied by Gort and Klepper (1982) and Klepper and Graddy (1990), 22 experienced a shakeout. These episodes of firm exit were non-trivial with an average of 52% of the firms leaving the industry.[17] A noteworthy feature of this period of exit is how sudden and dramatic it can be, with a prime example being the tire industry where the number of firms halved in a period of 5 years. Thus, a focus in the literature lies not only in explaining why firms exit an industry, but also why such periods of exit can be so dramatic and abrupt. While our framework provides an incentive for low-tech firms to exit, the natural question is what the pattern of exit looks like. While the gradual diffusion of technology through the industry suggests that a gradual exit of firms is a likely pattern, we show in the following proposition that a more dramatic transformation occurs.

PROPOSITION 2 *All firms that exit, do so at the same date (i.e., a shakeout occurs)*

Proof: Let T_S define the date that the shakeout occurs. For a low-tech firm to leave the industry, it must be the case that their profits are non-positive:

$$\pi_L(q(T_S)) = F \tag{20}$$

and the entry costs are paid off:

$$F_0 = \frac{E(1-e^{-rT_L})}{n\sigma r} + \frac{X(T_L)-X(T_S)}{\varphi^{\sigma-1}-1} - \frac{(1-e^{-rT_S})F}{r} \tag{21}$$

Using the first order condition of an adopting firm implies:

$$(\varphi^{\sigma-1}-1)F = -X'(T_S)e^{rT_S} \tag{22}$$

Since the T_S that solves this equation is unique, all firms that exit must do so at T_S. Note that by construction $T_S \in [T_L, T_H]$.[18] Q.E.D.

This dramatic exit of firms is driven by *feedback* between the exit decisions and technology adoption decisions of low-tech firms. Specifically, the reduction in the number of firms brought on by exit increases the incentive for the remaining firms to adopt the high-productivity technology; however, this increase in adoption induces more low-tech firms to exit. It is this positive feedback that results in exit being sudden rather than gradual. Thus, by endogenizing the process of technology

[16]This is not to say that uncertainty or randomness cannot contribute to over-entry by firms. Rather, the point of the paper is to provide a completely deterministic model of shakeouts in order to clarify their underlying determinants.

[17]This result is not driven by small numbers, with the average industry having 55 producers before the shakeout.

[18]Note that if $T_S < T_H$, then (20) implies that firms that stay in, but have yet to adopt, will make negative profits until they adopt.

adoption, our model also provides some insight into how technological diffusion (which the available empirical evidence suggests is a very lengthy and gradual process) is capable of explaining even very abrupt shakeout-events.[19]

A final characteristic of the shakeout equilibrium in our framework is that it may induce late entry by high-tech firms. Specifically, the same variation in F and F_o that provided the conditions for firms to exit also raises the possibility that firms might enter, especially at some date after the shakeout. This logic is confirmed in the following proposition:

PROPOSITION 3 *If there is a shakeout and $X(t)$ has the assumed properties, then there is an incentive for high-tech firms to enter at or after T_H.*

Proof: See Appendix

A feature of Proposition 3 is that, following the shakeout, new firms will only enter the industry as high-tech firms.[20] Thus, entry costs at any point in time are implicitly $F_o + X(T)$. However, note that this implies that, with exogenous technological progress, the costs of entering the industry are declining over time. Thus, Proposition 3 implies that eventually these technological costs will be reduced to the point where entry occurs.[21]

Given that late entry occurs, it should happen at an optimal date. The optimal late entry date T^e must maximize:

$$\int_{T^e}^{\infty} \pi_H(t) e^{-rt} dt - X(T^e) - F_o e^{-rT^e} - \frac{F e^{-rT^e}}{r}$$

Solving the first order condition gives the time path of $n(t)$ after T^e as:

$$n(t) = \frac{E}{(-X'(t)e^{rt} + F + rF_o)\sigma} \tag{23}$$

Given a pool of potential late entrants, the profits of these firms must be driven to zero:

$$\frac{F e^{-rT^e}}{r} + F_o e^{-rT^e} + X(T^e) = \frac{E}{\sigma} \int_{T^e}^{\infty} \frac{e^{-rt}}{n(t)} dt \tag{24}$$

Entry also ensures that the present value of profits for firms that are in the market permanently is also zero. Let n_p denote the number of firms that remain in the market permanently and let n_d denote the number of firms that enter at $t = 0$ but only remain in the market until T_S:

$$\frac{F}{r} + F_0 + X(T_H) = \frac{E(1 - e^{-rT_L})}{(n_p + n_d)\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{E(e^{-rT_H} - e^{-rT^e})}{n_p \sigma r} + \frac{E}{\sigma} \int_{T^e}^{\infty} \frac{e^{-rt}}{n(t)} dt \tag{25}$$

[19] See Jovanovic and Lach (1997) and Karshenas and Stoneman (1995) for empirical evidence on the length of the diffusion process.

[20] While the phenomenon of late entry into mature industries does not typically appear on the list of stylized facts explained by models of shakeouts, Jovanovic (2001) suggests that these lists should be amended to include late entry.

[21] These results are derived under the assumption that $X(\infty) = 0$. However, if $X(t)$ is bounded away from zero then late entry may not occur.

Finally, the zero profit condition for low-tech firms that exit the market requires that:

$$\frac{F}{r} + F_0 = \frac{E(1 - e^{-rT_L})}{(n_p + n_d)\sigma r} + \frac{X(T_L) - X(T_S)}{\varphi^{\sigma-1} - 1} + \frac{Fe^{-rT_S}}{r} \tag{26}$$

Using (26) and (24), (25) can be simplified to:

$$\frac{X(T_S) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{(e^{-rT_H} - e^{-rT^e})E}{n_p \sigma r} - \frac{(e^{-rT_S} - e^{-rT^e})F}{r} = X(T_H) - X(T^e) - F_o e^{-rT^e} \tag{27}$$

Note in particular that this is only a function of n_p. Therefore, to solve for n_d, (27) can be combined with (26).

To complete the description of the equilibrium, we must derive the distribution function. Since firms that adopt the high-tech methods stay in the market forever, and late entry of additional high-tech firms occurs after T_H, the first order conditions for firms that enter at $t = 0$ and adopt are exactly the same as in the no-shakeout case. However, since there is a shakeout during the adoption process, the equilibrium distribution function now has a discontinuity at T_S, reflecting the change in the number of firms in the market:

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \frac{-e^{-rt}E}{X'(t)n_p\sigma} - \frac{n_d + n_p}{n_p(\varphi^{\sigma-1}-1)} & \text{for } t \in [T_L, T_S) \\ \frac{-e^{-rt}E}{X'(t)n_p\sigma} - \frac{1}{\varphi^{\sigma-1}-1} & \text{for } t \in [T_S, T_H] \\ 1 & \text{for } t \in (T_H, \infty) \end{cases} \tag{28}$$

Intuitively, the positive feedback between firm exit and adoption results in a jump in the number of firms adopting the high-tech methods at the time of the shakeout. Therefore the shakeout equilibrium is described by n_p, n_d, $n(t)$, $q^*(t)$, T_S and T^e.

3 The Determinants of Shakeouts in a Closed Economy

In the previous section, we characterized both the shakeout and no-shakeout equilibria. In this section, we investigate the comparative statics of this model. It should now be apparent that the basic parameter that determines whether a shakeout is likely to occur is the size of the sunk costs of entering the market relative to the recurring fixed costs of production, given the existence of an innovation. It proves informative to focus on the case where $\widetilde{T} = T_H$, since this allows the parameter space to be divided between combinations of F_o and F where shakeouts occur and combinations that do not involve exit. The interaction between F_o and F in determining the occurrence of a shakeout is clarified in figure 2.

To interpret figure 2, consider starting from a point on the horizontal axis where per-period fixed costs are zero and thus no shakeout occurs. As in the previous section, imagine trading off F_o and F along the line with slope $-r$. Consider the case where $\tilde{T} = T_H$ and the last low-tech firm is indifferent between adopting and remaining in the market, or not adopting and exiting. This point

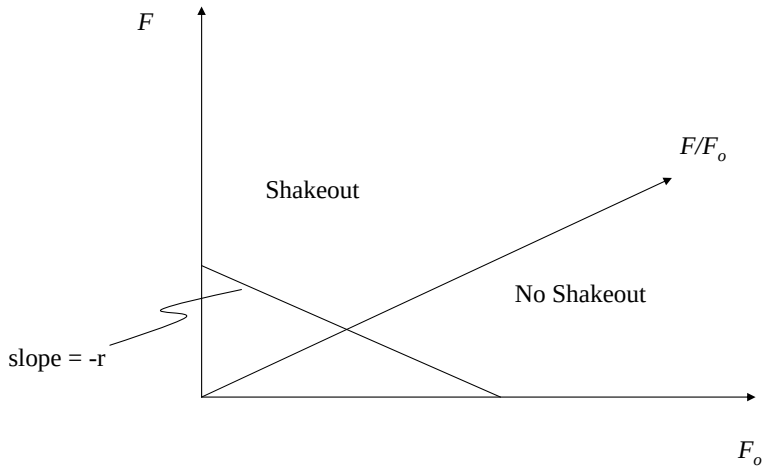


Figure 2: Division of Parameter Space into Shakeout and No-Shakeout Equilibria

is characterized by (17) and (18), which are associated with a unique F/F_o ratio (denoted by the ray from the origin). Finally, as discussed in the previous section, any additional trade-off between F and F_o will result in a shakeout. Thus, figure 2 illustrates the division of the parameter space between shakeout and no-shakeout equilibria where higher ratios of F/F_o increase the probability that an industry will undergo a shakeout, holding the size of the innovation constant. The intuition behind this division of the parameter space is direct: the easier it is to enter (low F_o) and the more sensitive firms are to technological change (high F), the more likely a shakeout is. Moreover, this result illustrates that dramatic technological change is not sufficient for a shakeout to occur. Indeed, a relatively small innovation can cause a shakeout in a market with relatively low sunk entry costs, while a dramatic innovation will have little effect on market structure if sunk entry costs are very large.

3.1 Comparative Statics

While the interaction of technological change and fixed costs are the main determinants of industry shakeout, it of interest to explore how the likelihood of a shakeout is influenced by other parameters in the model. In the context of figure 2, this can be determined by calculating how changes in parameter values affect the F/F_o cutoff between the shakeout and no-shakeout equilibria. The results are summarized in the following proposition:

PROPOSITION 4 *A shakeout is more likely (i.e. the critical F/F_o that divides the shakeout*

equilibria from the no-shakeout equilibria is lower) the higher is:

i) F_o *(holding* F *constant) ,*

ii) the elasticity of demand, σ*,*

iii) the innovative step, φ*.*

However, the likelihood of a shakeout is independent of market size, E*.*

Proof: In Appendix

Note that an increase in either the step size of the innovation or the elasticity of demand increases the likelihood of a shakeout. Intuitively this is due to the fact that more important technological innovations or higher elasticity of demand place low-tech firms at a greater disadvantage during the diffusion process. Thus, low-tech firms are more likely to experience negative per-period profits, and subsequently more likely to exit the industry.

Similar intuition implies that increases in the step size of the innovation or the elasticity of demand should also affect the timing and magnitude of the shakeout. This intuition is borne out by the following two propositions:

PROPOSITION 5 *Given that a shakeout occurs,* T_S *will be earlier the larger is:*

i) F*,*

ii) the elasticity of demand, σ*,*

iii) the innovative step, φ*.*

However, the timing of a shakeout is independent of market size, E*.*

Proof: In Appendix

PROPOSITION 6 *Given that* $F_o = 0$ *(a shakeout must occur), the relative magnitude of the shakeout is larger, the larger is:*

i) the elasticity of demand, σ*,*

ii) the innovative step, φ*.*

However, the magnitude of a shakeout is independent of market size, E*.*

Proof: In Appendix

The fact that increases in the size of the high-tech innovation and the elasticity of demand cause shakeouts to be larger and to occur earlier in equilibrium requires little explanation since, as previously explained, such changes have a disproportionately negative impact on low-tech firms in the diffusion process. The fact that market size has no impact on the likelihood, timing or magnitude of shakeouts requires more discussion since, as we discuss later, it has strong implications for the structure of shakeouts in a global economy. The neutrality of market size is due largely to the endogeneity of entry decisions in our model (as well as the assumption of a constant elasticity of demand). That is, larger market size simply results in a proportionately larger number of firms, and thus does not affect average firm size or the decisions of individual firms.[22]

[22]Syverson (2004a) and Syverson (2004b) presents alternative models that can be used to assess the robustness of these market size results. Both models essentially have a linear demand structure, and this raises the issue of what is

3.2 Empirical Evidence

An obvious implication of the preceding analysis is that the ratio of sunk costs to recurring fixed costs is a key predictor of whether an industry is likely to experience a dramatic shakeout event. This prediction is relatively intuitive; shakeouts are most likely to occur in industries that are relatively easy to enter (i.e. relatively low entry cost). Indeed, a recent paper by Ghosal (2003) shows that industries with higher sunk costs have significantly lower variability of firm numbers. However, as an additional check on the consistency of this prediction with the empirical evidence, we took the 46 industries studied by Gort and Klepper (1982) and Klepper and Graddy (1990), and divided them into those that had experienced a dramatic shakeout event and those that had not (i.e., they had either not experienced a period of exit or such a period was characterized by only gradual exit). This demarcation was based on the figures reported by Klepper and Graddy (1990) in which the 11 industries with the most rapid exit (i.e., greater than 4 net firm exits per year after the peak) were considered to have experienced a dramatic shakeout while the 18 industries that had experienced no exit or slow exit (i.e., less than one net firm exit per year after the peak) were considered to have not experienced a shakeout.[23] Both sets of industries are similar in terms of longevity, with the average birth date of 1930 for industries with a dramatic adjustment and 1934 for the more stable industries.

These industry lines were then assigned into their respective 4-digit 1972 SIC industries, for which we calculated average plant intensity (plant stock divided by value of shipments) and capital intensity figures (capital stock divided by value of shipments).[24] We use plant and capital intensities as proxies for the ratio of sunk costs to fixed costs within an industry under the assumption that a substantial portion of the investment in physical capital stock (especially plant stock) is a one-time sunk investment.[25] In contrast, the fixed costs of more labor-intensive industries (e.g., management, bureaucracy, contract workers, etc.) are not sunk investments but rather recurring fixed costs. Thus, our hypothesis is that the more stable industries will have greater levels of physical capital intensity (and thus relatively greater sunk costs), while those industries that experience a rapid shakeout will have lower levels (and thus relatively greater recurring fixed costs). Table 1 reports 10-year averages

meant by an increase in market size. If an increase in market size is modeled by an outward shift of the demand curve, then the results presented above go through. However, if an increase in market size is modeled as an upward rotation around the price axis, then different results emerge. Naturally, such an increase in demand is associated with a more elastic demand function. Consequently, by increasing market size in this way, the results are the same as an increase in the elasticity of demand (σ) described above.

[23]Given that our theory does not provide a precise definition of what could be considered a "dramatic shakeout" we simply concentrate on the extremes: those industries with the most rapid exit and those industries with the least rapid exit.

[24]The data are from Bartelsman and Gray (1996) which provides industry level data at the 4-digit SIC level for the years 1958-1996.

[25]Of course, the existence of used and rental markets would imply that physical capital investment is not sunk; however, rental and used capital are a small portion of total capital stock (less than fifteen percent). Likewise, capital depreciation rates (which would turn a one-time sunk investment into a recurring fixed cost) are also small and roughly constant across industries.

Table 1: Sunk Costs and Stability of Market Structure

	No/Slow Decline	Fast Decline
1958-67		
Plant Stock	0.67 (1.16)	0.21 (0.11)
Capital Stock	1.26 (2.21)	0.39 (0.20)
1968-77		
Plant Stock	0.47 (0.75)	0.20 (0.07)
Capital Stock	0.84 (1.21)	0.38 (0.16)
Number of industries	18	11

Notes to Table: Plant Stock and Capital Stock are weighted by industry shipments.
"No/Slow Decline" includes industries with less than one net exit per annum; "Fast Decline" includes those with more than 4 net exits per annum. Standard deviations in parentheses.

of these measures for our two sets of industries for both the period 1958-67 and 1968-77 (the mean date at which the peak number of firms occurred was 1953 for the dramatic adjustment industries and 1971 for the stable industries). As can be seen, the data are consistent with our hypothesis. For example, for the 1958-67 period, the 18 industries that did not experience a rapid shakeout event had an average physical plant ratio of 0.67 in comparison to just 0.21 for the 11 industries that did experience rapid exit.

While Table 1 is suggestive, there are a number of caveats to be kept in mind. First, as can be seen, there is a large degree of variance in the data and our sample size is quite small.[26] In addition, we are mapping the specific disaggregated industry lines analyzed by Gort and Klepper (1982) and Klepper and Graddy (1990) into the more aggregate categories of the 1972 four digit SIC. Thus, we can only make the claim that industry lines that experienced a dramatic shakeout are contained in industries that tend to be more physically capital-intensive. Finally, other dimensions of industry heterogeneity that influence the probability of a shakeout (e.g,. the size of the innovation or the elasticity of demand) are not taken into account. Nevertheless, Table 1 does show that our theory is, at the least, not inconsistent with the available empirical evidence.

4 Shakeouts and International Trade

The preceding section characterized a shakeout in a closed economy. This focus on a closed economy mirrors the emphasis in the existing empirical and theoretical literature that has sought to understand shakeouts in a domestic US context. However, such a focus neglects the role that international factors can play in determining the evolution of an industry's market structure. In particular, international trade decouples the link between consumption and production. The implication of this for

[26]Indeed, a large reason for the sizable difference in the means across the industry groups (as well as the large standard deviations) is due to the very high capital-intensity ratios of the computer industry. In the absence of the computer industry, the plant and capital intensity ratios for the stable industries in the period 1958-67 are .42 and .78 respectively.

the evolution of market structure is evident in the media with seemingly constant reference to the threat posed by import competition to domestic firms. In this case, international trade represents an increase in productive capacity that can reduce the number of domestic firms, in much the same way that an innovation can. However, this is only one side of the story. Access to international markets also allows firms to export their surplus production to other countries. This offers a potentially important way to accommodate the extra capacity created by the adoption of a better technology by domestic firms, mitigating the possibility of a domestic shakeout. Moreover, if there is intra-industry trade, then both mechanisms can potentially operate. This suggests that the extent of openness of an industry is likely to be an important factor determining the evolution of market structure.

However, extending the model to allow for international trade also introduces a number of new questions. In particular, how does the degree of openness affect the probability of a shakeout? Moreover, countries need not share a common evolution of market structure. This naturally raises the question of whether countries experience shakeouts of the same magnitude or whether shakeouts occur at the same time across different countries. The answers to these questions will rely to some extent on whether or not there are differences across countries and whether these differences influence the evolution of the industry. It is instructive, in this case, to consider the results of the previous section. Specifically, a fundamental difference across countries is market size (e.g., countries are much more likely to exhibit vast differences in market size than in the the elasticity of demand for a product or the stepsize of a given innovation). Thus, the neutrality of market size on industry evolution suggests that the shakeout phenomena should be quite similar across countries (i.e., shakeouts should occur at roughly equal times and be of equal magnitude). In this sense it is reassuring to find documented cases where the timing and relative magnitude of shakeouts are, in fact, similar across countries.[27]

However, there are also documented examples of asymmetry such as the synthetic dye industry. In this industry, France, Germany and Britain all had non-trivial firm entry. As reported in the introduction, only France experienced a shakeout in the period from the start of the industry (1857) to the First World War (1914). Specifically, in the mid 1860s the number of French synthetic dye producers dropped from 21 to 7 (from 40 to 15 if the suppliers of intermediates are included). In contrast, the number of German firms increased, reflecting a dominance of the synthetic dye industry before 1914, with this superiority attributed to a number of factors that allowed German firms to gain an advantage in the adoption of new technology (both methods of manufacturing dye as well as the introduction of new colors). These advantages include trained chemical engineers, patent laws that only allowed for process patents, and other institutional factors.[28] Thus, guided by the synthetic dye example, in this section we introduce a model of shakeouts in an open economy in which countries are differentiated by their technological capabilities.

[27] For example, see Carroll and Hannan (1995) for evidence relating to the symmetry of shakeouts in the automobile industry across European countries and the US.

[28] See Murmann and Homburg (2001) for an in-depth analysis of the synthetic dye industry.

4.1 Asymmetric Adoption Costs

While countries can differ in a number of dimensions, the synthetic dye example suggests that differences in adoption costs are an important factor determining the longevity of firms. Guided by this example, we assume that the cost of the high-tech methods in the foreign country are prohibitive (i.e. $X(t) = \infty$ for all t). Since this makes countries asymmetric, we denote foreign variables by a star (*). To explore the implications of varying the degree of openness, we assume that exporting firms face transport costs of the traditional iceberg form where $b \geq 1$ units of a good need to be shipped for one unit to arrive. While each firm's pricing rule in its domestic market is the same as before (and given by (4)), firms that export will set higher prices in the foreign markets to reflect the higher marginal cost of serving those markets:

$$p_L^F = \frac{\sigma b}{\sigma - 1} \quad , \quad p_H^F = \frac{\sigma b}{\varphi(\sigma - 1)}$$

From these prices, we can then solve for the operating profits of each firm.

4.2 Free Trade

As a benchmark case, consider free trade (i.e. $b = 1$) and the equilibrium international distribution of production. Once again it is possible to imagine a situation where entry costs are sufficiently high and per-period operating costs are sufficiently low (e.g., $F = 0$) that no firm with an incentive to enter the industry would ever consider leaving. Consequently, if the parameters imply that there is no shakeout in equilibrium, then these conditions also imply that there are no foreign firms in the market and all production is concentrated in the home economy.

However, the location of production can be more varied if a shakeout occurs in equilibrium. To generate a shakeout the now familiar exercise of trading off F_o and F can be employed, with a critical F_o and F that separates the shakeout from the no-shakeout equilibria. As this trade-off continues, the size of the shakeout increases. While a particular combination of F_o and F generates a shakeout of a given size as it did in a closed economy, in contrast to the closed economy case, the location of the firms that exit is no longer uniquely determined. Under free trade, if it is feasible for a home firm to enter and subsequently exit the market before adopting the high-technology, then it is also possible for a foreign firm to do the same. Since the location of production has no impact on the degree of competition faced by firms in either country, the location of firms that exit during the shakeout is arbitrary in equilibrium.

4.3 Trade and the Location of Shakeouts

In contrast, if an arbitrarily small trade barrier is introduced, then the international distribution of firm exit is uniquely determined. Intuitively, reciprocal trade barriers provide relatively greater protection to firms located in the country where the differentiated product industry is smallest (since the major source of competition is from abroad). In a setting of asymmetric adoption costs, more

firms will locate in the technologically advanced (home) country, since they are better able to adapt new technologies. However, a small number of firms will choose to locate in the foreign country to take advantage of the lower levels of competition generated by the presence of trade barriers (which help to mitigate competition from abroad). Note that firms located in the foreign country will have relatively high profits early in the industry life cycle (due to the presence of trade barriers), and relatively lower profits late in the industry life cycle (since high adoption costs preclude them from adopting new technologies as readily as home firms). Since shakeouts are generated in our model by the ability of firms to recoup their sunk entry costs before having to adopt new technologies, the foreign country seems a likely candidate to be the location for a shakeout to occur. This intuition is borne out in the following proposition:

PROPOSITION 7 *If a shakeout occurs and the parameters are such that the number of permanent firms is greater than the number of firms that exit, then all of the exit occurs in the foreign country ($n_d^* > 0$ and $n_d = 0$) and all of the permanent firms are located in the home country ($n_p > 0$).*

Proof: In Appendix

This proposition says that for relatively small shakeouts, all of the exit will occur in the foreign country. Proposition 7 is a reflection of the fact that, in the presence of trade barriers, firms that intend to exit the industry may locate away from the heart of the industry in order to take advantage of reduced competition early in the industry life cycle. This behavior, in turn, can result in shakeouts being located overseas. It is important to note that Proposition 7 characterizes the equilibrium distribution of firms when the shakeout is relatively small (i.e., less than 50% of firms exit the market). This assumption ensures that the number of foreign (i.e., exiting) firms is relatively small, and thus firms locating in the foreign country benefit from the presence of trade barriers.

However, under certain conditions, it is also possible for shakeouts to involve more than 50% of firms exiting. From the previous section we know that the relative size of a shakeout can be approximated by $\frac{n_d}{n_p} \approx \varphi^{\sigma-1} - 1$, with this approximation being more accurate the closer F_o is to zero. Consequently, when $\varphi^{\sigma-1} > 2$ (the innovation is sufficiently large) we can always find a sufficiently small F_o such that more than 50% of the firms exit. However, if all of these exiting firms were located in the foreign country (as is implied by Proposition 7), then the foreign industry would actually be larger than the home industry and thus home firms would be the beneficiaries of any trade barriers. This, in turn, would imply that home firms enjoy relatively higher profits early in the industry life cycle, increasing the speed with which they can recoup their sunk entry costs and thus making the home country more susceptible to a shakeout. As the following proposition shows, under these conditions both countries experience a shakeout, but these shakeouts occur at different times and are of different intensities.

PROPOSITION 8 *If $\varphi^{\sigma-1} > 2$ and F_o is sufficiently low, then both countries have a shakeout. The shakeouts occur at different times across countries: the shakeout in the home country occurs first ($T_S^* > T_S$), but the magnitude of the shakeout is greater in the foreign country ($n_d^* > n_d$).*

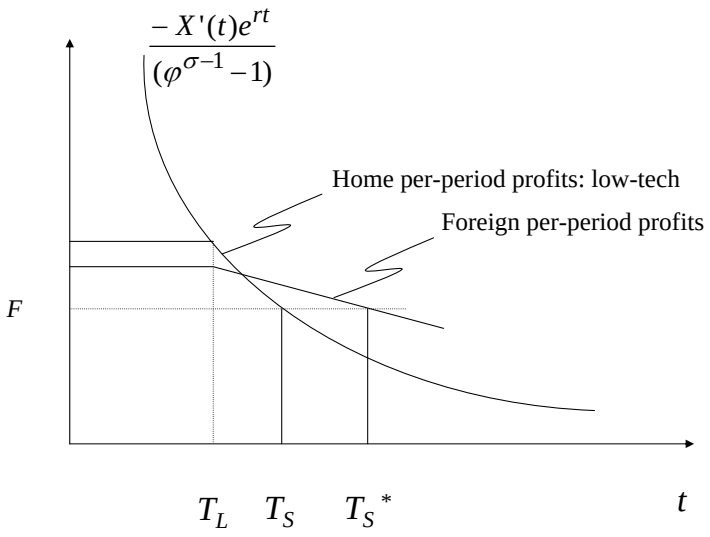


Figure 3: Multiple Country Shakeout

Proof: In Appendix

This proposition can be understood with the aid of figure 3. At the beginning of the industry life cycle, when firms in both countries have symmetric rudimentary technology (i.e., before T_L), the greater number of foreign firms results in lower per-period profits for foreign firms relative to home firms. As before, the adoption of the new cost-saving innovation reduces the per-period profits of all low-tech firms in the industry. However, since trade barriers partially isolate the foreign firms from the more competitive high-tech home firms, the process of technology adoption reduces foreign profits relatively less than for a low-tech home firm. At some point the increase in the competitive pressure at home pushes the operating profits of low-tech home firms below their foreign counterparts. After this change in the ranking of profits occurs, low-tech home firms find that their operating profits are eventually driven to zero at T_S. At this point these firms have also paid off their entry costs, F_o, which is the area between the per-period profit curve and the per-period fixed cost line, F, and thus a shakeout occurs in the home country. At T_S, a foreign firm has not yet paid off F_o, and therefore is still earning positive operating profits, but the process of continued adoption in the home country will eventually drive the operating profits of foreign firms to zero as well. In equilibrium this coincides with the date at which the entry costs are paid off, T_S^*, resulting in a shakeout in the foreign country.

Propositions 7 and 8 have important implications for empirical studies that attempt to identify the factors that generate a shakeout. As noted previously, the current literature has focused solely

on the number of domestic firms and changes in the domestic market structure. Since these studies examine US industries in the 20th century, it is natural to assume not only that technological change is underlying the dynamics of market structure, but that the US industries are also the technology leaders. Given these assumptions, the implications of propositions 7 and 8 become apparent. In particular, these propositions imply that two industries can have exactly the same characteristics (market size, rate of technological change, elasticity of demand, IRS and barriers to entry), but the domestic evolution of market structure can be completely different depending on the extent of their international integration. Suppose that one of the industries is closed to trade and experiences a shakeout where half of the firms exit during the shakeout. If the only difference between the two industries is that one is open to trade, then the open industry will not experience any shakeout at all. Even if the shakeout in the closed industry is greater than 50%, the open industry is likely to only experience a very small decline in the number of firms. Indeed, when a shakeout occurs, regardless of its location, the conditions for proposition 3 are satisfied and there will be late entry in the home country by high-tech firms. Clearly, openness to trade can have a profound effect on the evolution of domestic market structure, yet to date this has played no role in the current literature.

4.4 Trade and the Probability of Shakeouts

In the preceding discussion, trade barriers were kept relatively low in order to facilitate comparisons between the open and closed economy cases. With low trade barriers, the conditions that generate a shakeout in a closed economy also generate a shakeout in the open economy, so the only question is from what countries do firms exit. However, as trade barriers are increased and the international market becomes more fragmented, it is natural to ask what happens to the likelihood of a shakeout. This question is answered in the following proposition:

PROPOSITION 9 *There exists a set of parameter values such that a shakeout will not occur under free trade but will occur with positive trade barriers ($b > 1$).*

Proof: In Appendix

The direct implication of Proposition 9 is that more open industries are less susceptible to shakeout events. The intuition behind this Proposition is direct. Recall from the discussion of the closed economy model that shakeouts endogenously arise from over-entry into the industry. Intuitively, entry into the industry is encouraged by the existence of profit opportunities arising from gradual technology adoption which allow firms to recoup their sunk costs of entry before technological progress drives industry profits negative. The introduction of trade barriers creates a more fragmented international market and thus creates profit opportunities, especially from the perspective of foreign firms. The protection provided by trade barriers creates a window of opportunity for foreign firms to enter the market, since they now have higher profitability than under free trade, and pay off their entry costs before the competitive pressures associated with the adoption of better technology

by home firms drives them from the market. In contrast, free trade is associated with a more stable market structure.[29]

4.5 Empirical Evidence

A consistent result of the preceding propositions is that, in more technologically advanced countries, the more open an industry is to international trade, the more stable the resulting market structure. Specifically, the more open an economy is, the less likely a shakeout is to occur, and if a shakeout does occur it will be less severe in a more open setting. As a consistency check, we repeat the empirical analysis of Section 3.2 in which we take the 46 industries studied by Gort and Klepper (1982) and Klepper and Graddy (1990) and separate those industries experiencing the most rapid shakeout events and those industries experiencing no (or only gradual) exits. We then assign these industry lines into their respective 4-digit 1972 SIC industries, for which we have calculated measures of openness to trade. Two measures of openness are employed: the fraction of domestic output exported (i.e., exports divided by the value of shipments) and the fraction of domestic output traded (i.e. the sum of imports and exports divided by the value of shipments within the industry).[30] These data are reported for two time periods, 1958-67 and 1968-77. As is apparent from Table 2, the more stable industries have higher average export and trade shares across both periods, consistent with the prediction that more open industries are also more stable. The results of this table are subject to the same caveats as those discussed in Section 3.2; however, as in that case, the empirical evidence is at least not inconsistent with our theory.

5 Conclusion

Single country studies of industrial evolution have documented pronounced patterns in prices, output and firm numbers. The variation in firm numbers has been particularly intriguing since many industries have experienced dramatic shakeouts. These shakeouts have generally been attributed to technological change, with formal models developed to incorporate this mechanism. However, by only considering closed economy models, the literature has neglected the important role that international trade can play in industrial evolution. In particular, models with international trade can feature very different patterns of firm exit both within and across countries.

[29]The result that greater openness leads to a more stable market structure can also be derived in a symmetric country setting. In particular, assume that countries are symmetric but that firms within countries can be asymmetric in terms of whether or not they export. This decision can be endogenized by including a sunk cost of exporting as in Ederington and McCalman (2004). As a direct implication of Proposition 4 in Ederington and McCalman (2004) it follows that as trade barriers are lowered the per-period profits of the last adopter (a non-exporter) must increase. This increase in profitability is associated with a higher proportion of profits being earned after the adoption process is complete, a situation that discourages firm exit, lowering the likelihood of a shakeout.

[30]The data are taken from Feenstra (1997) which provides trade volume data at the 4-digit SIC level for the years 1958-1994.

Table 2: Openness and Stability of Market Structure

	No/Slow Decline	Fast Decline
1958-67		
Exports	0.13 (0.12)	0.03 (0.02)
Trade	0.17 (0.16)	0.04 (0.03)
1968-77		
Exports	0.19 (0.15)	0.04 (0.03)
Trade	0.28 (0.20)	0.11 (0.13)
Number of industries	18	11

Notes to Table: Exports and trade are weighted by industry shipments.
"No/Slow Decline" includes industries with less than one net exit per annum; "Fast Decline" includes those with more than 4 net exits per annum.

To develop a model capable of matching the evidence from national studies of industrial evolution that is also consistent with the patterns of international trade, we utilize a model of product differentiation. This model refines the factors that contribute to a shakeout. In particular, we show that it is the interaction of technological change, entry costs and recurring fixed costs that create the conditions for a shakeout. Specifically, for a given pattern of technological change, the higher are the recurring fixed costs relative to the entry costs, the higher is the likelihood of a shakeout. We also show that markets which have a more elastic demand or are more innovative are also more likely experience a shakeout, and that when they do, these shakeouts occur earlier and are more dramatic.

The extension of the model to incorporate international trade illustrates the shortcoming of a solely national view of industrial evolution. In particular, we show that industries that are more integrated by international trade are also likely to have a lower probability of a shakeout. Thus trade generates a more stable industrial evolution, both from a national and international perspective. However, a national focus would not accurately identify the mechanism behind this stability.

When countries have different technological capacities, the limitations of a national focus become even more evident. Now it is possible to identify conditions that would generate a shakeout in the closed country setting in the home country, but in an open economy setting the shakeout is concentrated entirely in the foreign country. Even more confounding is the fact that the home country would experience gradual growth in firm numbers. Such a possibility can undermine the empirical identification of the conditions that contribute to a shakeout. Consequently, national studies are only likely to provide reliable evidence if there is very little trade. However, industries with this characteristic are increasingly rare, and the introduction of international trade adds an important dimension to the analysis that aides our understanding of industrial dynamics.

6 Appendix

6.1 Proof of Proposition 3

Let n_p denote the number of firms that enter at time $t = 0$ and remain in the market permanently. Similarly, define n_d as the number of firms that enter at $t = 0$ but only remain in the market temporarily. For a firm to be indifferent between entering at $t = 0$ or some date up to T_L requires:

$$rF_o = \frac{E}{(n_p + n_d)\sigma} - F$$

Note that this implies from T_H to ∞ the following is true:

$$\left(\frac{E}{n_p\sigma} - F\right)\frac{e^{-rT_H}}{r} > \left(\frac{E}{(n_p + n_d)\sigma} - F\right)\frac{e^{-rT_H}}{r} = F_o e^{-rT_H}$$

Note also that for $T_S < T_H$ it must be the case that:

$$\left(\frac{E}{n_p\sigma} - F\right)\frac{e^{-rT_H}}{r} > X(T_H)$$

In addition if $F_o > 0$ then:

$$X(T_H) + F_o e^{-rT_H} > \left(\frac{E}{n_p\sigma} - F\right)\frac{e^{-rT_H}}{r}$$

Nevertheless, since $X' < 0$ and $X(\infty) = 0$, there exists a $\widehat{T}$ such that late entry will occur (i.e. $\exists$ a $\widehat{T}$ s.t. $X(\widehat{T}) + F_o e^{-r\widehat{T}} = \left(\frac{E}{n_p\sigma} - F\right)\frac{e^{-r\widehat{T}}}{r}$). Q.E.D.

6.2 Proof of Proposition 4

A shakeout becomes possible when the following two conditions hold:

$$\overline{F} = \frac{E}{\varphi^{\sigma-1} n_p \sigma} \tag{29}$$

$$\overline{F}_o = [(1 - e^{-rT_L})\varphi^{\sigma-1} - (1 - e^{-rT_H})]\overline{F} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} \tag{30}$$

From these equations, it is clear that if $\overline{F}_o$ is increased, $\overline{F}$ must increase more than proportionally for these conditions to be met. Consequently, starting from a higher F_o when $F = 0$ lowers the probability of a shakeout.

The effect of changes in φ, σ and E on the $\overline{F}/\overline{F}_o$ can be confirmed by totally differentiating (29). Q.E.D.

6.3 Proof of Proposition 5

If a shakeout occurs it must be the case that $T_S \in [T_L, T_H]$. Combining the first-order conditions with the zero per-period profit condition implicitly defines the timing of the shakeout, T_S:

$$F(\varphi^{\sigma-1} - 1) = -X'(T_S)e^{rT_S}$$

The proposition follows directly from the differentiation of this condition. Q.E.D.

6.4 Proof of Proposition 6

Consider the jump in the distribution at T_S. If we define the maximum value of the distribution function before the jump as $\underline{q}$ and the minimum value of the distribution function after the jump as $\overline{q}$, then from (28) the size of this difference must satisfy:

$$(\varphi^{\sigma-1} - 1)(\overline{q} - \underline{q}) = \frac{n_d}{n_p}$$

In this special case $\overline{q} - \underline{q} = 1$, which implies:

$$(\varphi^{\sigma-1} - 1) = \frac{n_d}{n_p}$$

Consequently, increases in the step size of an innovation or the elasticity of demand increase the magnitude of shakeout. However, the magnitude of the shakeout is independent of market size, E. Q.E.D.

6.5 Proof of Proposition 7

Since a shakeout is assumed to occur, it must be the case that at the time of the shakeout low-tech firms in both countries are making either zero or negative net per-period profits. Per-period profits for low-tech home firms are:

$$\pi_L + b^{1-\sigma}\pi_L^*$$

Per-period profits for foreign low-tech firms are:

$$\pi_L^* + b^{1-\sigma}\pi_L = \pi_L + b^{1-\sigma}\pi_L^* + (1 - b^{1-\sigma})(\pi_L^* - \pi_L)$$

While b is close to unity, it is strictly greater than 1. Therefore the ranking of profits in these two locations depends on $\pi_L^* - \pi_L$. The sign of this difference is given by the sign of $n_p(q(\varphi^{\sigma-1} - 1) + 1) + n_d - n_d^*$, which is negative since $n_p > n_d + n_d^*$. Therefore, at the time of the shakeout:

$$\pi_L^* + b^{1-\sigma}\pi_L = F > \pi_L + b^{1-\sigma}\pi_L^*$$

Since foreign low-tech firms always have higher per-period profits than home low-tech, they will have paid off the entry cost, F_o before the home low-tech firms. Hence, foreign low-tech firms will exit when their net per-period profits become zero having just paid off the entry costs. In contrast, low-tech home firms begin making negative net per-period profits before they have paid off F_o; consequently they have an incentive to remain in the market to adopt the superior technology. Therefore the equilibrium involves $n_p > 0$, $n_d^* > 0$ and $n_d = 0$. Q.E.D.

6.6 Proof of Proposition 8

Assuming that both countries experience a shakeout, low-tech firms must be able to pay off the entry cost:

$$F_o + \frac{(1-e^{-rT_S})F}{r} = \int_0^{T_L} (\pi_L + b^{1-\sigma}\pi_L^*)e^{-rt}dt + \frac{X(T_L)-X(T_S)}{\varphi^{\sigma-1}-1}$$

$$F_o + \frac{(1-e^{-rT_S^*})F}{r} = \int_0^{T_L} (\pi_L^* + b^{1-\sigma}\pi_L)e^{-rt}dt + \frac{X(T_L)-X(T_S^*)}{\varphi^{\sigma-1}-1} + (1-b^{1-\sigma})\int_0^{T_S^*} (\pi_L^* - \pi_L)e^{-rt}dt$$

In addition, firms in both locations must have an incentive to exit with operating profits for low-tech firms equaling zero at some point:

$$\begin{aligned} F &= \pi_L(T_S) + b^{1-\sigma}\pi_L^*(T_S) \\ F &= \pi_L^*(T_S^*) + b^{1-\sigma}\pi_L(T_S^*) \end{aligned}$$

Let's deal first with the timing of the shakeouts. Assume that $T_S > T_S^*$. This implies:

$$\pi_L^*(T_S^*) + b^{1-\sigma}\pi_L(T_S^*) = F < \pi_L(T_S^*) + b^{1-\sigma}\pi_L^*(T_S^*)$$

However, this means:

$$\int_0^{T_S^*} (\pi_L^* + b^{1-\sigma}\pi_L)e^{-rt}dt = F_o < \int_0^{T_S^*} (\pi_L + b^{1-\sigma}\pi_L^*)e^{-rt}dt$$

which cannot be part of an equilibrium that features $T_S > T_S^*$. Note also, that $T_S = T_S^*$ cannnot be part of an equilibrium, since firms are paying off F_o at different rates through time. Consequently, it is not possible for both the present value and the zero operating profits conditions to hold simultaneously in both countries. Therefore, $T_S^* > T_S$ is the only possible configuration consistent with equilibrium.

The relative intensity of the shakeouts follows directly from the requirement that profits of firms in the foreign country must be lower than the profits of firms at home before the process of adoption has begun (i.e. when all firms are low-tech). This requires $\pi_L - \pi_L^* > 0$ before T_L. However, this implies that $n_d^* > n_p + n_d$. Therefore, $n_d^* > n_d$ and the foreign country experiences a more intense shakeout. Q.E.D.

6.7 Proof of Proposition 9

Under free trade it is assumed that:

$$\begin{aligned} F_o + \frac{F(1-e^{-rT_S})}{r} &> \left[\frac{2(1-e^{-rT_L})E}{n_p\sigma r} + \frac{X(T_L)-X(T_S)}{(\varphi^{\sigma-1}-1)}\right] \\ F &= 2\pi_L(T_S) \end{aligned}$$

Note that these conditions are exactly the same for both home and foreign firms under free trade. However, if trade barriers exist ($b > 1$) then the profit conditions for a foreign and home firm diverge.

If there is no shakeout, the conditions remain the same for home firms, while the conditions for a foreign firm become:

$$\begin{aligned} F_o + \frac{F(1-e^{-rT_S})}{r} &< (b^{\sigma-1} + b^{1-\sigma}) \left[\frac{(1-e^{-rT_L})E}{n_p \sigma r} + \frac{X(T_L) - X(T_S)}{2(\varphi^{\sigma-1} - 1)} \right] \\ F &> (b^{\sigma-1} + b^{1-\sigma}) \pi_L(T_S) \end{aligned}$$

While the foreign firm has not paid off F_o, its operating profits are still positive. Hence, if b is made sufficiently large, a foreign firm will be able to pay off F_o. If this occurs before T_H, then any foreign firm that enters will also have an incentive to exit the industry (i.e. shakeout). Q.E.D.

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