INTERNATIONAL ECONOMIC REVIEW
Vol. 50, No. 3, August 2009

INTERNATIONAL TRADE AND INDUSTRIAL DYNAMICS*

BY JOSH EDERINGTON AND PHILLIP MCCALMAN[1]

University of Kentucky, U.S.A.;
University of California, Santa Cruz, U.S.A.

In this article, industrial evolution is driven by endogenous technology choices of firms, generating a rich environment that includes the possibility of a dramatic shakeout. The likelihood, magnitude, and timing of this shakeout are characterized and depend not only on the size of an innovation but also on cost structure. In this setting, trade liberalization reduces the likelihood of a shakeout, resulting in more stable industrial structures. However, when shakeouts arise in global markets, the distribution of exits can vary widely across countries. Furthermore, conditions exist where a shakeout occurs in a closed economy but not in an open economy.

1. INTRODUCTION

The empirical literature on the industry life cycle has documented a variety of patterns in the evolution of market structure. Although some industries exhibit a relatively stable structure where the number of firms is constant or only gradually changing over time, other industries exhibit a pronounced nonmonotonic pattern in which the number of firms falls, often dramatically, after achieving a peak. This change in the number of firms is common enough and dramatic enough to have its own title: a shakeout. A leading example of this phenomenon is the U.S. tire industry, where the number of firms declined from a peak of 275 in 1922 to just 132 firms in 1928. A second intriguing example is 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

* Manuscript received March 2007; revised February 2008.

[1] This article previously circulated under the title "Shaking All Over? International Trade and Industrial Dynamics." Numerous individuals provided comments and suggestions that improved this article. We are particularly indebted to Goerg Götz, Jenny Minier, and three anonymous referees for useful suggestions and comments. We would also like to thank seminar participants at the University of British Columbia, University of California-Berkeley, University of California-Santa Cruz, University of California-San Diego, Deakin University, Georgetown University, Latrobe University, London School of Economics, University of Melbourne, Princeton University, Southern Methodist University, Sydney University, University of Virginia, the World Bank, CEPR-ERWIT, and NBER-UCR. Please address correspondence to: J. Ederington, Department of Economics, University of Kentucky, Lexington, KY 40506, U.S.A. Phone: 859-257-1588. E-mail: *ederington@uky.edu*.

[2] A key finding is that shakeouts do not appear to be explained by negative demand shocks and, consequently, are typically viewed as supply side phenomena. The pioneering paper in the empirical industry life cycle literature is Gort and Klepper (1982). The tire industry is studied by Jovanovic and MacDonald (1994) and Klepper and Simons (2000). The synthetic dye industry is analyzed by Murmann and Homburg (2001).

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, whereas the number of firms remained relatively constant in Britain.

The obvious questions that arise from these 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 possible that shakeout phenomena are related to forces of international competition. In addition, as the synthetic dye example illustrates, 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 article, we develop a model that is capable of generating a shakeout as an equilibrium outcome in order to both isolate the underlying determinants of shakeouts and analyze how shakeout phenomena may be related to global competition.

In order to understand these phenomena, we build a model in which entry and exit are endogenous and forward-looking firms make decisions regarding the state of their technology. In this setting ex ante identical firms, producing differentiated products, endogenously choose when to adopt a cost-saving technological innovation. Despite the initial symmetry of firms, in equilibrium they choose different adoption dates generating a gradual diffusion of the cost-saving innovation through the industry.[3] Somewhat remarkably we show that this gradual process of technology adoption can nevertheless generate the rapid, large-scale exit of the type documented in the industrial evolution literature. 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 (i.e., a shakeout occurs). Therefore, we are able to generate a shakeout in a model in which firms are forward looking and have complete information.[4]

Although our framework can generate a shakeout, it is important to understand that the model is also rich enough to capture the relative stability of many industries (i.e., not all industries experience a shakeout). Although it is tempting to portray these stable industries as also being technologically stable, this is typically not the case (e.g., the laser industry). What we show is that it is the interaction between technological change and the composition of costs that determines the likelihood of a shakeout. Specifically, for a given innovation, the higher the size

[3] Thus, our model generates endogenous heterogeneity across firms. Although 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 the survey by Tybout (2002). For work on diffusion in an international setting see McCalman (2005).

[4] In this sense our article is similar to Götz (2002) and Petrakis and Roy (1999), which also analyze industry evolution and the potential for exit within fully deterministic models. Also see Roy and Kamihigashi (2005).

of the recurring fixed costs relative to the entry costs, the closer the industry is to the set of parameters that trigger a shakeout. This result has the intuitively appealing feature that shakeouts occur 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, whereas a dramatic innovation will have little effect on market structure if entry costs are very large.

In order to gain insight into how shakeouts are related to global competition, we focus our attention on the case where the level of technological development varies across countries. This asymmetric environment is inspired by aspects of the synthetic dye example. 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. In particular, 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. Consistent with this prediction, we provide evidence that more stable industries also tend to be the most open to trade.

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. 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 a constant 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, and neglected, dimension to the analysis that aides the understanding of the industrial dynamics of industries.

In order to establish these results, the article 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 an equilibrium framework that dates back to Reinganum (1981). In this section, we follow Götz (1999) in considering a closed economy model with an industry characterized by monopolistic competition that allows us to abstract from the question of whether or not firms irrevocably commit to an adoption date since, in equilibrium, all firms earn the same profit.[5] The main contribution of this section is to show how a straightforward modification of technology diffusion models can generate industry shakeout phenomena.

2.1. *Market Demand Conditions.* We assume that the economy has two sectors: One sector consists of a numeraire good, x_0, whereas the other sector is characterized by differentiated products. The following intertemporal utility function defines the preferences of a representative consumer:

$$U = \int_0^{\infty} (c_0(t) + \log C(t)) e^{-rt}\, dt, \tag{1}$$

where $c_0(t)$ 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 that reflects a taste for variety in consumption and implies a constant (and equal) elasticity of substitution between every pair of 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. Given the quasi-linear structure of preferences it is straightforward to solve for the demand functions of a differentiated good, $y(i, t)$, with the elasticity of substitution between any two products given by $\sigma = 1/(1 - \rho) > 1$

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

[5] Reinganum (1981) assumes that firms commit to an adoption date at time $t = 0$. However, in this precommitment equilibrium, the firms earn different profits. In contrast, Fudenberg and Tirole (1985) assume that firms do not commit to their adoption data and, thus, profits are equalized in equilibrium. By considering adoption in a setting of monopolistic competition we are following Götz (1999) and Ederington and McCalman (2008). However, neither of these papers addresses the issue of how technology adoption affects the evolution of market structure. Also see Bagwell and Staiger (1992), Miyagiwa and Ohno (1995), and Crowley (2006) for models of trade and technology that emphasize strategic issues.

where $p(i, t)$ is the price of good i in time t and E represents the total number of consumers in the economy. This stable demand function captures the working assumption in the literature that it is supply-side factors that underlie the shakeout phenomena, and not fluctuations in demand.

2.2. *Production Costs.* All goods are produced in the economy using a single factor of production, labor. For simplicity, we assume that production of the numeraire good is defined by $l = c_0$, which ensures that the equilibrium wage is equal to unity. Hence, the nonnumeraire sector perceives a perfectly elastic labor supply at this wage rate.

Firms can enter the differentiated goods sector by paying a sunk entry fee of F_o. 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.[6] A high-productivity technology is also available at time $t = 0$, but requires an additional fee of $x(t)$ where $x(0) = \infty$, $x(\infty) = \underline{x}$, $x' < 0$ and $x'' > 0$.[7] 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 $\varphi > 1$.[8]

It should be noted that we implicitly assume that the cost of adopting the advanced (high-productivity) technology is declining over time whereas the cost of adopting the rudimentary (low-productivity) technology is constant. The consequence of this asymmetry is that adoption of the advanced technology will be gradual whereas entry into the market (adoption of the rudimentary technology) will be sudden (i.e., all entry will occur at time period 0).[9] Allowing the sunk-cost of entry, F_o, to decline over time would have the desirable feature of matching the more gradual process of entry observed in the data; however, it increases the notational burden without adding insight. For the sake of transparency, we develop the more stylized version of the model with a constant entry cost to focus on the shakeout episode.

[6] This production structure is common in the trade literature and is similar to 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 (i.e., a firm cannot avoid paying F by being idle).

[7] These are standard assumptions in the technology diffusion literature; see for example Reinganum (1981), Fudenberg and Tirole (1985), and Götz (1999). Also see Saggi and Lin (1999), which motivates similar assumptions in an FDI setting. The only difference is that we assume $x(t)$ is bounded from below to rule out the possibility of entry occurring after all the initial entrants have adopted (see the Appendix for details).

[8] Note that adoption results in a decline in the marginal cost of producing the good. The results of this article do not extend to a reduction in fixed costs of production, F, since in the Dixit–Stiglitz framework a reduction in fixed costs has no impact on the pricing/output decisions of firms.

[9] Ederington and McCalman (2008) provide 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 and is provided in the Appendix. Intuitively, the combination of positive per-period profits and rational, forward-looking firms implies that firms have little incentive to delay entry and thus all firms enter at $t = 0$.

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.

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

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

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

$$\pi_H(t) - \pi_L(t) = \frac{(\varphi^{\sigma-1} - 1)\left(\dfrac{\sigma}{\sigma - 1}\right)^{1-\sigma} E}{\sigma \displaystyle\int_0^{n(t)} p(z,t)^{1-\sigma}\,dz}. \tag{5}$$

In order to characterize the denominator of this expression, 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

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

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

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

where $X(T) = e^{-rT}\,x(T)$. 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 whereas the right-hand side is the gain from the decrease in adoption costs from delaying adoption another period. Note that this condition holds for all firms that have yet to adopt. However, if all such firms adopted at once this first-order condition would not hold, with most firms instead preferring to adopt at other dates in the future (since adoption en masse would drive the LHS below the RHS). This implies that the first-order condition does not just hold at one point in time but over an interval, with a firm indifferent over which date in this interval it adopts (i.e., an early adoption date confers a greater increase in profits but is associated with a higher opportunity cost, whereas a later date involves a lower profit differential but also a lower opportunity cost of waiting). Given this, substituting the profit differential given by (7) into this first-order condition and solving for $q(t)$ then yields the equilibrium distribution function.[10]

As we discuss below, assuming that 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 (e.g., for $F = 0$, $n(t) = n$ for all t). In this case, the equilibrium distribution function is given by

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

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 $T_L \le t \le T_H$ (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.

[10] As in Götz (1999), it is assumed that the second-order condition holds in order to get a concave profit-maximization problem: $re^{-rT}((\varphi^{\sigma-1} - 1)\frac{E}{\sigma n}) - X''(T) < 0$.

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). In order to close the model, we now solve for the equilibrium number of firms, n. 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 are derived by substituting in the respective profit and distribution functions and subtracting off the costs (both the per-period fixed cost, F, and the entry cost, F_o). Thus, the zero-profit condition requires that

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

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 equal zero, this zero-profit condition along with $q^*(t)$ (defined by 9) characterizes the closed economy equilibrium.

2.6. *Characteristics of the Stable (No-Exit) Equilibrium.* Up 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. Note that, by producing differentiated products, firms earn positive profits that are used to defray the costs of entry along with the costs of technology adoption. When F is sufficiently small, these per-period profits are strictly positive and the zero-profit condition, (10), can be expressed as

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

The no-exit equilibrium also requires

$$\frac{e^{-rT_H}(\pi_H(q=1) - \pi_L(q=1))}{r} > X(T_H).$$

Consequently

$$\frac{e^{-rT_H}(\pi_H(q=1) - F)}{r} > X(T_H).$$

Thus, the zero-profit condition for the stable (no-exit) equilibrium holds if sunk entry costs, F_o, are not paid off until after all firms have adopted the new technology (i.e., after T_H). This condition has two implications. First, stability in the number of firms follows directly from a relatively large F_o. When F_o is relatively large, even dramatic changes in technology do not disrupt the market sufficiently to induce firms to exit since firms will have to adopt the new technology prior to paying off their entry costs. Second, we can find the date $\tilde{T} > T_H$ when F_o is paid off. This date is implicitly defined by

$$X(T_H) = \frac{e^{-r\tilde{T}}}{r}(\pi_H(q = 1) - F).$$

Using this condition, the zero-profit condition can be rewritten as

(12)

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

Equation (12) 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. In order 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 fixed costs over the lifetime of the firm remains constant (i.e., $F_o + \frac{F}{r}$ is a constant). Note for a relatively large range of F and F_o such that $F_o + \frac{F}{r} = K$, the equilibrium values of n, T_L, and T_H will not be affected by this trade-off. Consequently, as F_o is decreased and F is increased, Equation (12) tell us that the date at which F_o is paid off, $\tilde{T}$, will occur earlier in equilibrium.

Figure 1 depicts the changes implied by this trade-off. As F_o is decreased $\tilde{T}$ occurs earlier (i.e., for (12) to hold, it must be the case that $dF_o < 0$ implies $d\tilde{T} < 0$). Thus, as F_o is lowered, $\tilde{T}$ approaches T_H. Meanwhile, as F is increased, net per-period profits for each firm will be reduced. However, as long

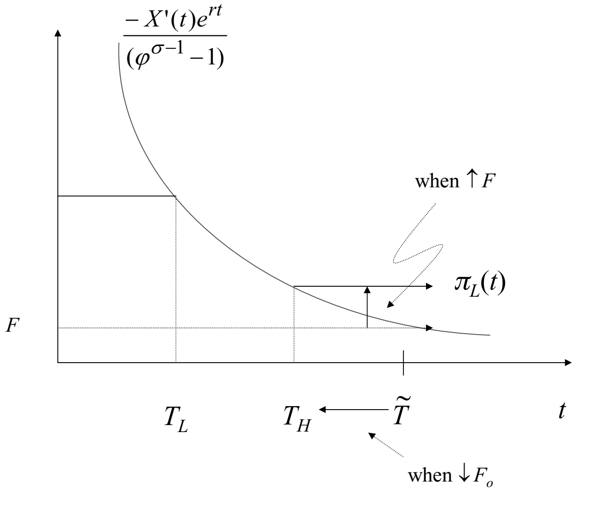

FIGURE 1

THE EFFECTS OF INCREASING, F_O AND INCREASING F

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 $\tilde{T} > T_H$ (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 and the equilibrium involves a constant number of firms.

2.7. *Characteristics of the Shakeout (Exit) Equilibrium.* One can derive, from the properties of the no-exit equilibrium, that continuing to trade off F_o and F (such that $dF_o = -d\frac{F}{r} < 0$) will eventually lead to a point where $\pi_L(T_S) = F$ and F_o is paid off at $\tilde{T} = T_S \leq T_H$. We refer to the combination of F and F_o that achieves this situation as $\bar{F}$ and $\overline{F_o}$, and to this $\tilde{T}$ as $\bar{T}$. Thus, T_S denotes the point where both per-period profits are zero for nonadopters and entry costs have just been paid off. A characteristic of these $\tilde{T} = T_S \leq T_H$ situations is that a nonadopter 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.

However, once we reach the point where $\tilde{T} = T_S \leq T_H$, 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 ($F > \bar{F}$) and F_o is sufficiently small ($F_o < \overline{F_o}$), technology adoption within the industry will reduce the net per-period profits of low-tech firms to zero. Furthermore, a subset of the low-tech firms will choose to exit since they will have paid off their entry costs.*

PROOF. See the Appendix.

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 leave the industry. Although this part of the story is a familiar one in the industry life-cycle literature (i.e., exit occurring because technological progress creates competitive pressure that forces technologically lagging firms out of the market), the means by which exits occur requires more explanation since, in our model, firms can always choose to become high-tech and thus earn higher profits. The traditional literature typically assumes that periods of exit derive from some underlying heterogeneity in the ability of firms to adapt to technological innovation in a setting of imperfect information. In the industry evolution literature, overentry and subsequent exit 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, we assume a perfect information environment in which ex ante identical firms make endogenous decisions about whether to adopt new technologies or exit (thus, in our framework, technologically lagging firms could choose to respond to competitive pressures by innovating rather than exiting). Moreover, no firm subsequently regrets their decision.[11] As noted earlier, our article is more similar to Götz (2002) and Petrakis and Roy (1999), which also analyze industry evolution and the potential for exit within fully deterministic models. In Götz (2002), exogenous limitations on the number of potential entrants results in the existence of profit opportunities early in the life of an industry, which encourages temporary entry and then exit by forward-looking firms. In Petrakis and Roy (1999), limitations on investment (specifically, the idea that the optimal scale of production only gradually increases over time due to convex adjustment costs to investment activity) results in a gradual increase in the minimum efficiency scale due to accumulated investment spending, and thus a reduction in the number of firms that the (perfectly competitive) market can sustain. In contrast, the reason firms exit in our framework follows from the realization by forward-looking firms that, given gradual technology diffusion and suitable industry conditions (i.e., low costs of entry relative to recurring fixed costs), they can make profits by entering the market at its inception and then exiting before competitive forces require them to adopt any technological innovations. Thus, we show that exit can be a natural outcome of technological diffusion, even in the absence of uncertainty or constraints on entry/investment decisions.

The evidence that some industries experience a period of net exit during their life cycle is quite compelling. 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 nontrivial with an average of 52% of the firms leaving the industry.[12] A prominent 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 five years. Thus, a model of industry evolution must not only explain why firms exit an industry, but also why such periods of exit are so dramatic and abrupt. Proposition 1 demonstrates that our framework can generate exit endogenously; the next question is whether it can generate a shakeout. Although the gradual diffusion of technology through the industry suggests that the 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. See the Appendix.

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

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

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

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, and represents a key distinction between the mechanism in this article and those at work in the rest of the literature. Note that such a feedback effect results in a discrete increase in adoption (i.e., a jump in q) at the time of the shakeout. Intuitively, the reduction in n is compensated for by an increase in q so that the first-order condition remains satisfied. Thus, by endogenizing the process of technology adoption, our model also provides 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.[13]

So far we have shown that the constant n equilibrium does not hold for all parameter values and that if firms exit, they do so en mass. In order to complete the description of the equilibrium we need to confirm that given this series of events, firms would actually be willing to enter the industry and play the various roles. That is we need to characterize the entry conditions. Start by noting that all firms that exit must do so having earned present value profits of zero. In equilibrium it must be the case 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; then the zero-profit condition for permanent firms is

$$\frac{F}{r} + F_o + X(T_H) = \frac{E(1 - e^{-rT_L})}{(n_p + n_d)\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{n_p \sigma r}, \tag{13}$$

Whereas the zero-profit condition for firms that exit the market requires that

$$\frac{F}{r} + F_o = \frac{E(1 - e^{-rT_L})}{(n_p + n_d)\sigma r} + \frac{X(T_L) - X(T_S)}{\varphi^{\sigma-1} - 1} + \frac{Fe^{-rT_S}}{r}. \tag{14}$$

Combining (13) and (14) implies

$$X(T_H) = \frac{X(T_S) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{n_p \sigma r} - \frac{Fe^{-rT_S}}{r}. \tag{15}$$

Note in particular that this is only a function of n_p. Therefore, to solve for n_d, (15) can be combined with (14). Furthermore, the pair n_p and n_d are the unique solution to this system.

Finally, we must derive the distribution function. Since firms that adopt the high-tech methods stay in the market forever, the first-order conditions for firms that enter at $t = 0$ and adopt are exactly the same as in the no-shakeout case.

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

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 and the increased incentive to adoption

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \dfrac{-e^{-rt}E}{X'(t)n_p\sigma} - \dfrac{n_d + n_p}{n_p(\varphi^{\sigma-1} - 1)} & \text{for } t \in [T_L, T_S) \\ \dfrac{-e^{-rt}E}{X'(t)n_p\sigma} - \dfrac{1}{\varphi^{\sigma-1} - 1} & \text{for } t \in [T_S, T_H] \\ 1 & \text{for } t \in (T_H, \infty), \end{cases} \tag{16}$$

where $q(t)$ is the fraction of *permanent* firms that have adopted at any point in time. Therefore 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. Consequently, the shakeout equilibrium is described by n_p, n_d, $q^*(t)$, and T_S.

A feature of this equilibrium is that low-tech firms that remain in the market after T_S will make negative per-period profits until they adopt. Thus, the shakeout does not eliminate all low-tech firms, with the process of adoption continuing until T_H. Note that the fraction of firms making negative profits at any point in the interval $[T_S, T_H]$ is given by $1 - q^* = \frac{2-\varphi^{\sigma-1}}{\varphi^{\sigma-1}-1} + \frac{e^{-rt}E}{X'(t)n_p\sigma}$.

3. THE DETERMINANTS OF SHAKEOUTS IN A CLOSED ECONOMY

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 occurs 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 ($\varphi < 1$). The interaction between F_o and F in determining the occurrence of a shakeout is illustrated in Figure 2.

In order to interpret Figure 2, start from a point on the horizontal axis where per-period fixed costs are zero (i.e., $F = 0$ and $F_o > 0$). At this point it should be apparent that no exit will occur since net per-period profits are bounded to be strictly positive (thus, we are in the no-exit equilibrium). As in the previous section, imagine trading off F_o and F along the line with slope $-r$ from this intercept. Eventually, you will reach a situation in which the last low-tech firm is indifferent between adopting and remaining in the market, or not adopting and exiting. This is the point characterized in Proposition 1 and is associated with a unique $\frac{\bar{F}}{\bar{F}_o}$. As discussed in the previous section, any additional trade-off between F and F_o will result in a shakeout. The characterization of a shakeout is most transparent when $F_o = 0$ and $F > 0$. With no entry costs, the number of firms in the market before T_S is given by a per-period zero profit condition $\pi_L = \frac{E}{\sigma(n_p+n_d)} = F$. This cost configuration also implies that $T_L = T_S = T_H$ since no low-tech firm can

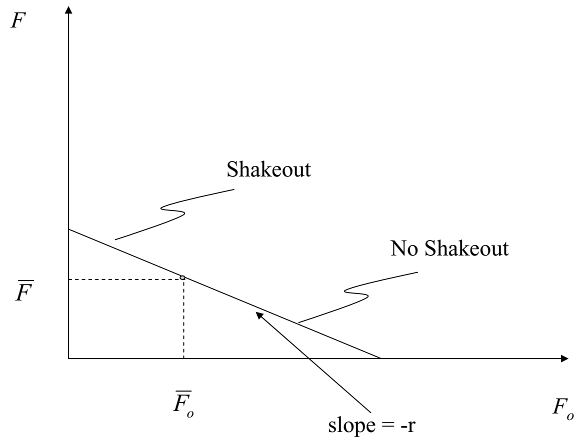

FIGURE 2

DIVISION BETWEEN SHAKEOUT AND NO-SHAKEOUT EQUILIBRIA

cover its recurring fixed cost once the adoption process begins. Thus all firms that adopt do so at the same time. Although there is general indifference about being in the market before T_L, this is not so after adoption. Once firms adopt, they must make positive per-period profits in order to cover their adoption costs, $X(T_L)$.[14] Furthermore, the size of the shakeout is easily calculated to be $\frac{n_d}{n_p} = (\varphi^{\sigma-1} - 1)$.[15]

Thus, Figure 2 illustrates, for a given total fixed cost $(F_o + \frac{F}{r})$, how variation in the composition of these costs can change an industry from one with a relatively stable structure (high F_o, low F) to one that experiences a dramatic shakeout (low F_o, high F). The intuition 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, whereas a dramatic innovation will have little effect on market structure if sunk entry costs are very large.

3.1. *Comparative Statics.* Although the interaction of technological change with the composition of fixed costs is the main determinant of a shakeout, it is 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 $\frac{\bar{F}}{\bar{F}_o}$ threshold between the

[14] For these firms the zero-profit condition is $X(T_L) = (\frac{E}{\sigma n_p} - F)\frac{e^{-rT_L}}{r}$.

[15] See proof of Proposition 5 for more details.

shakeout and no-shakeout equilibria. The results are summarized in the following proposition:

PROPOSITION 3. *The critical $\frac{\bar{F}}{F_o}$ that divides the shakeout equilibria from the no-shakeout equilibria is lower*

(i) the smaller is F_o (holding F constant),
(ii) the larger is the elasticity of demand, σ,
(iii) the larger is the innovative step, φ.

However, the critical $\frac{\bar{F}}{F_o}$ is independent of market size, E.

PROOF. See the 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 4. *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. See the Appendix.

PROPOSITION 5. *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. See the 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.[16]

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 U.S. 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 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 elasticity of demand for a product or the step-size of a given innovation). Thus, the neutrality of market size on industry evolution suggests that the shakeout phenomena should be quite

[16] Syverson (2004) presents an alternative demand specification that can be used to assess the robustness of these market size results. The model has a linear demand structure, and this raises the issue of what is 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.

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.[17]

However, there are also documented examples of asymmetry such as the synthetic dye industry. In this industry, France, Germany, and Britain all had nontrivial 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.[18] Thus, guided by the synthetic dye example, we introduce a model of shakeouts in an open economy in which countries are differentiated by their technological capabilities.

4.1. *Asymmetric Adoption Costs.* Although 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. In line with this example, we assume that the cost of the high-tech methods in the foreign country is prohibitive (i.e., $x(t) = \infty$ for all t).[19] Since this makes countries asymmetric, we denote foreign variables by a star (*). In order 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. Although 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

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

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

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

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

[19] Although this assumption may seem extreme, the same results emerge provided the two countries have different adoption costs that decline at different rates. Under free trade this implies that the first-order conditions for adoption cannot hold simultaneously in both countries (i.e., the marginal profit from adopting is the same across countries but the marginal adoption cost differs). Thus, the process of adoption must be completed in the low-cost country before the process of adoption can start in the high-cost country. In order to avoid unnecessary clutter we make the convenient assumption that $x(t) = \infty$ for all t in the foreign country.

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 in which 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. In order 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. Although 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, symmetric 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 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 two propositions.

For each of the following propositions, we assume that parameter values are such that a shakeout occurs (i.e., our interest is solely in the location of the shakeout). Proposition 6 considers the case in which the shakeout is small (less than 50% of firms in the market exit) whereas Proposition 7 considers the case in which the shakeout is large (more than 50% of firms exit). Given the structure of the model 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 small) we can always find a sufficiently small F_o such that less than 50% of the firms exit, and when $\varphi^{\sigma-1} > 2$ we can find a sufficiently small F_o such that more than 50% of the firms exit.

PROPOSITION 6. *If $\varphi^{\sigma-1} < 2$ and F_o is sufficiently low, 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. See the Appendix.

This proposition says that for relatively small shakeouts, all of the exit will occur in the foreign country. Proposition 6 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. As mentioned previously, Proposition 6 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, if all of these exiting firms were located in the foreign country (as is implied by Proposition 6), 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 7. *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 ($n_d^* > n_d$).*

PROOF. See the 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

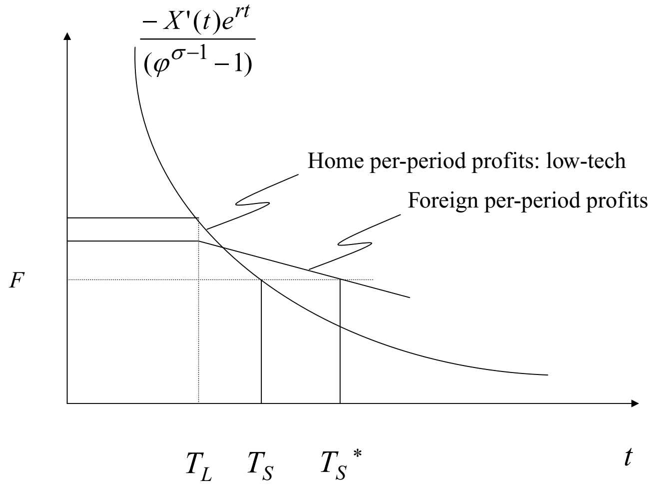

FIGURE 3

MULTIPLE COUNTRY SHAKEOUT

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 6 and 7 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 the U.S. 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 U.S. industries are also the technology leaders. Given these assumptions, the implications of Propositions 6 and 7 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 whereas the other industry will have up to 50% of its firms exit. 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. Thus, greater openness can result in greater stability for industries located in more technologically advanced countries. 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 literature.

4.4. *International Trade and the Frequency 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 which country 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 frequency of shakeouts. This question is answered in the following proposition.

PROPOSITION 8. *Assume conditions are such that a shakeout does not occur in either country under free trade. In this situation the imposition of a positive trade barrier* ($b > 1$) *can generate a shakeout*.

PROOF. See the Appendix.

The direct implication of Proposition 8 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 arise from overentry into the industry. Intuitively, entry into the industry is encouraged by the existence of profit opportunities generated by the 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 drive them from the market. In contrast, free trade is associated with a more stable market structure.[20]

4.5. *Evidence.* A consistent result of Propositions 6 through 8 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 took the 46 industries studied by Gort and Klepper (1982) and Klepper and Graddy (1990),

[20] 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 (2008). As a direct implication of Proposition 4 in Ederington and McCalman (2008) it follows that as trade barriers are lowered the per-period profits of the last adopter (a nonexporter) 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.

TABLE 1

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: 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 four net exits per annum.

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 four net firm exits per year after the peak) were considered to have experienced a dramatic shakeout whereas 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.[21] 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. We then assign these industry lines into their respective four-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).[22] These data are reported for two time periods, 1958–67 and 1968–77. As is apparent from Table 1, 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. Although the results in the table are only suggestive and should not be interpreted as a "test" of our model, they are consistent with the notion that more open industries are less likely to experience a dramatic shakeout.

[21] 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.

[22] The data are taken from Feenstra (1997), which provide trade volume data at the four-digit SIC level for the years 1958–1994.

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.

In order 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 that have a more elastic demand or are more innovative are also more likely to 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, from both 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 economy setting in the home country, but in an open economy setting the shakeout is concentrated entirely in the foreign country. 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 on the probability 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 the understanding of industrial dynamics.

APPENDIX

PROOF. All entry occurs at $t = 0$.

First, note that, in this model, both $\pi_L(t)$ and $\pi_H(t)$ are nonincreasing (and are monotonically decreasing during the diffusion phase). Second, note that $\pi_L(t = 0) > F + rF_o$ (otherwise, the present discounted value of profits for firms that enter at time $t = 0$ and adopt at T_H will be negative) and $\pi_L(t = \infty) < F + rF_o$ (otherwise, the present discounted value of profits for firms that enter at time

$t = 0$ and never adopt will be positive). Thus, no firm will enter after $t = 0$ as a low-tech firm, since if they enter when $\pi_L > F + rF_o$, they would have made greater discounted profits by entering as a low-tech firm earlier, and if they enter when $\pi_L < r + rF_o$, they would have made greater discounted profits by entering as a high-tech firm later. Therefore, we can restrict attention to late entry by high-tech firms. High-tech firms that enter after $t = 0$ will choose their entry date to maximize

$$\text{(A.1)} \qquad \Pi_e = \int_{T_e}^{\infty} e^{-rt}(\pi_H(t) - F)\,dt - e^{-rT_e}x(T_e) - e^{-rT_e}F_o.$$

Differentiating with respect to T_e yields the first-order condition

$$\pi_H(t = T_e) - F - rF_o = rx(T_e) - x'(T_e).$$

The above first-order condition demonstrates the trade-off faced by firms in the choice of when to enter. The left-hand side is the lost profits from waiting one more period to enter the industry whereas the right-hand side is the gain from the decrease in adoption costs from delaying entry another period. Note that, by the first-order condition for optimal adoption, between T_L and T_H the profit differential is given by (8). Thus, there are three points in time when the entry first-order condition is satisfied: first, before T_L when $\pi_L > F + rF_o$; second, between T_L and T_H when $\pi_L = F + rF_o$, and finally, after T_H when $\pi_L < F + rF_o$. However, note that the first two potential entry dates are when $\pi_L \geq F + rF_o$ and, since π_L is nonincreasing over time, this implies that these firms would have made greater discounted profits from entering earlier as a low-tech firm. Thus, the only possible entry date is the one after T_H. Although such late entry does not have an appreciable impact on results of this article (since it occurs after technological diffusion is complete and any shakeout episodes have occurred), it complicates the expressions for the present discounted profits. Thus, to abstract away from late entry, we assume that the lower bound for adoption costs, $\underline{x}$, is sufficiently high such that the present value of profits for potential late entrants will be negative. Specifically, this requires that the present value of profits for late-entrants, given by (A.1), is bounded to be negative when the present value of profits for $t = 0$ entrants is zero. A sufficient condition for this to be true is when

$$\underline{x} > \frac{1}{r}\left(\frac{E}{n\sigma} - F - rF_o\right).$$

PROOF OF PROPOSITION 1. Assume $\bar{F}$ and $\overline{F_o}$ are such that $\tilde{T} = T_S \leq T_H$. Refer to this $\tilde{T}$ as $\bar{T}$. In this case, the following conditions hold in equilibrium. First, the per-period profits of low-tech firms are equal to zero

$$\text{(A.2)} \qquad \bar{F} = \pi_L(q(\bar{T})).$$

Second, low-tech firms have just paid off the sunk costs of entry

$$\text{(A.3)} \qquad \bar{F}_0 = \left(\frac{E}{n\sigma} - \bar{F}\right)\frac{(1 - e^{-rT_L})}{r} + \int_{T_L}^{\bar{T}} e^{-rt}(\pi_L(q(t)) - F)\,dt.$$

Finally, the cost of adoption is just equal to the present discounted value of future profits

$$\text{(A.4)} \qquad X(T_H) = \left(\frac{E}{n\sigma} - \bar{F}\right)\frac{e^{-rT_H}}{r} + \int_{\bar{T}}^{T_H} e^{-rt}(\pi_L(q(t)) - F)\,dt.$$

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 (11) to continue to hold, given our definition of $\tilde{T}$, requires that

$$\text{(A.5)} \qquad X(T_H) = \int_{\tilde{T}}^{\bar{T}} e^{-rt}(\pi_L(q(t)) - F)\,dt + \int_{\bar{T}}^{T_H} e^{-rt}(\pi_L(q(t)) - F)\,dt + \left(\frac{E}{n\sigma} - F\right)\frac{e^{-rT_H}}{r}.$$

However, given that we increased F from the point defined by (A.4) implies that for (11) to hold, it must be that $\int_{\tilde{T}}^{\bar{T}} e^{-rt}(\pi_L(q(t)) - F)\,dt > 0$. 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. ■

PROOF OF PROPOSITION 2. 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 its profits are nonpositive

$$\text{(A.6)} \qquad \pi_L(q(T_S)) = F$$

and the entry costs are paid off

$$\text{(A.7)} \qquad F_o = \frac{E(1 - e^{-rT_L})}{n\sigma r} + \frac{X(T_L) - X(T_S)}{\varphi^{\sigma-1} - 1} - \frac{(1 - e^{-rT_S})F}{r}.$$

Using the first-order condition of an adopting firm implies

$$\text{(A.8)} \qquad (\varphi^{\sigma-1} - 1)F = -X'(T_S)e^{rT_S}.$$

Since the T_S that solves this equation is unique, all firms that exit must do so at T_S. Note that by construction $T_S \in [T_L, T_H]$.[23] ■

PROOF OF PROPOSITION 3. A shakeout becomes possible when the following two conditions hold:

$$\bar{F} = \frac{E}{\varphi^{\sigma-1} n_p \sigma}, \tag{A.9}$$

$$\bar{F}_o = [(1 - e^{-rT_L})\varphi^{\sigma-1} - (1 - e^{-rT_H})]\bar{F} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1}. \tag{A.10}$$

From these equations, it is clear that if $\bar{F}_o$ is increased, $\bar{F}$ 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 $\bar{F}/\bar{F}_o$ can be confirmed by totally differentiating (A.9). ■

PROOF OF PROPOSITION 4. 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. ■

PROOF OF PROPOSITION 5. 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 (16) 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. ■

PROOF OF PROPOSITION 6. Since a shakeout is assumed to occur, we will show that it must be the case that at the time of the shakeout low-tech firms in both

[23] Note that if $T_S < T_H$, then (A.5) implies that firms that stay in but have yet to adopt will make negative profits until they adopt.

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

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

Although 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 positive 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 $n_d = 0$. ■

PROOF OF PROPOSITION 7. Assuming that both countries experience a shakeout, low-tech firms must be able to pay off the entry cost

$$\begin{aligned} F_o + \frac{(1 - e^{-rT_S})F}{r} &= \int_0^{T_L} \left(\pi_L + b^{1-\sigma}\pi_L^*\right)e^{-rt}\,dt + \frac{X(T_L) - X(T_S)}{\varphi^{\sigma-1} - 1} \\ F_o + \frac{(1 - e^{-rT_S^*})F}{r} &= \int_0^{T_L} \left(\pi_L^* + b^{1-\sigma}\pi_L\right)e^{-rt}\,dt + \frac{X(T_L) - X\left(T_S^*\right)}{\varphi^{\sigma-1} - 1} \\ &\quad + (1 - b^{1-\sigma})\int_0^{T_S^*} \left(\pi_L^* - \pi_L\right)e^{-rt}\,dt. \end{aligned}$$

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 us deal first with the timing of the shakeouts. Assume that $T_S > T_S^*$. This implies

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

However, this means

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

which cannot be part of an equilibrium that features $T_S > T_S^*$. Note also, that $T_S = T_S^*$ cannot 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. ■

PROOF OF PROPOSITION 8. Under free trade it is assumed that

$$F_o + \frac{F(1-e^{-rT_S})}{r} > \left[\frac{2(1-e^{-rT_L})E}{n_p\sigma r} + \frac{X(T_L)-X(T_S)}{(\varphi^{\sigma-1}-1)}\right] \tag{A.11}$$

$$F = 2\pi_L(T_S). \tag{A.12}$$

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, whereas the conditions for a foreign firm become

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

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

Although 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). Note finally that if the conditions in (A.11) and (A.12) both hold with equality (i.e., F_o has just been paid off at T_s), than even an infinitesimal trade barrier will generate a shakeout. ■

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