Shaking All Over?
International Trade and Industrial Dynamics

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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. The model generates a rich industrial environment that includes the potential for a dramatic shakeout of firms. The likelihood, magnitude and timing of this shakeout are characterized. 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 across countries can vary widely. Thus, open economy models of industrial evolution offer very different conclusions from closed economy models.

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1 Introduction

As industries evolve, prices decline, output expands and the number of firms rises at first and then falls.[1] This change in the number of firms is common enough and dramatic enough to have its own title: a shakeout. In general, there is agreement that the explanation of these dramatic shakeouts, along with the other observed patterns, is technological change.[2] Indeed, this mechanism plays a central role in most theoretical models capable of generating a shakeout. However, one surprising aspect of work in this area has been the exclusive focus on US industries and their evolution. In particular, international trade has played no role in either the empirical work or the subsequent theoretical models. In this paper we seek to address this deficiency by developing a model that features industrial dynamics similar to those documented for US industries but that also incorporates international trade. Such an extension is important because the nature of US industrial evolution can depend critically on the degree of openness. For example, it will be shown that the conditions that generate a shakeout can concentrate all of the firm exit in only one country. If this country is not the US, then the empirical identification of conditions that generate a shakeout are severely compromised. In fact, a focus on just US data would mistakenly record no shakeout at all.

The model we develop shares the feature that technological change is the main force underlying a shakeout. However, unlike the price taking assumption of previous models, firms in our framework produce differentiated goods and therefore have market power. This market power generates profits that are used to defray the sunk costs of entry along with any recurring fixed costs. What we show is that in the presence of technological change, the relative size of these entry and recurring fixed costs is an important determinant of the likelihood that an industry will experience a shakeout. In particular, the higher the recurring fixed costs relative to 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. Furthermore, we establish that the likelihood, timing and the relative magnitude of a shakeout is increasing in the the elasticity of demand as well as the step size of innovations.

While a closed economy analysis is very useful, most manufacturing industries also face international competition. It is well established in the international trade literature that intra-industry in differentiated products accounts for the bulk of trade flows. Given that product differentiation is the basis of our model, it is straight forward to extend it to incorporate this primary motivation for international trade. However, an open economy version of the model can take at least as many forms as there are asymmetries between countries. We narrow our focus by restricting attention to the types of asymmetries that

[1] See for example Gort and Klepper (1982), Klepper and Graddy (1990), Carroll and Hannan (2000)

[2] See Jovanovic and MacDonald (1994) and Klepper (1996).

are most empirically relevant. The first type of asymmetry we consider is the asymmetry that trade can introduce between firms within an industry. As has been extensively documented, not all firms within an export industry become exporters.[3] The explanation for this exporter/non-exporter dichotomy has typically been the existence of sunk costs of entering foreign markets. We show in this setting that greater trade integration lowers the likelihood that an industry will experience a shakeout. The other type of asymmetry considered has a longer tradition in the international trade literature, differences in technology across countries. In this setting we are less interested in the likelihood of a shakeout, rather we focus on how the rate of firm exit is likely to differ across countries. What we show is that technological asymmetries can be matched by an asymmetry in the pattern of exits across countries. Specifically, the technologically backward country can undergo a shakeout, while the advanced country has a relatively stable market structure. In fact, the advanced country 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 number of firms for the advanced country in the open economy case. Given the growing role of international trade, an open economy perspective seems not only more natural, but also indispensable for a thorough understanding of the evolution of market structure.

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 in both symmetric and asymmetric country settings.

2 Shakeouts in a Closed Economy

In this section we present a closed economy model of technology adoption and industrial evolution. We consider an industry that is created at time $t = 0$ by the introduction of some rudimentary technology. A superior technology also exists, but its implementation at $t = 0$ is not commercially viable. Nevertheless, all firms are aware of the potential of these hi-tech methods when they make their entry decisions. It is the adoption of the new technology that drives the evolution of the industry. 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 (1981). In this section we follow Gotz (1999) and consider a closed economy model with an industry characterized by monopolistic competition. The main contribution

[3] Bernard and Jensen (1999), Clerides, Lach, and Tybout (1998), Hallward-Driemeier, Iarossi, and Sokoloff (2002), Baldwin and Gu (2003) and Bernard, Eaton, Jensen, and Kortum (2003). For a review of this literature see Tybout (2002).

of this section is to show how a straightforward modification of technology diffusion models can generate industry shakeout phenomena.

2.1 Demand

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 preferences of a representative consumer are defined by the following intertemporal utility function:

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

where $x_0(t)$ is consumption of the numeraire good in time t and $C(t)$ represents an index of consumption of the differentiated product good. For $C(t)$ we adopt the CES specification which reflects tastes for variety in consumption and also imposes 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. It is straightforward to show that, with these preferences, the elasticity of substitution between any two products is $\sigma = 1/(1-\rho) > 1$ and aggregate demand for good i at any point in time is given by:

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

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

2.2 Production

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. A high-productivity technology is also available at time $t = 0$, but requires an additional fee of $X(t)$ where

$X' < 0,\ X'' > 0,\ X(0) = \infty,\ X(\infty) = 0$.[4] With this adoption cost function, earlier adoption is more expensive, however, the decreasing costs 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 $\varphi > 1$.

The Dixit-Stiglitz preferences result in profit-maximizing firms using a simple mark-up pricing rule for given marginal costs.[5] 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 with the profit differential being given by:

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

To characterize the price index for the differentiated goods sector, let $[0, qn(t)]$ be the range of firms that have adopted the high-productivity technology, where q is between 0 and 1 and represents the fraction of firms that have already adopted 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 to the gradual diffusion of the new technology through the industry as firms must trade off the increased operating profits from early adoption against the lower adoption costs of later adoption.

2.3 Adoption Decision

The equilibrium distribution of technologies, $q(t)$, 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:

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

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

[5]See Grossman and Helpman (1991).

As can be seen, 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 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.[6]

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 $t = 0$.[7] Consequently, for sufficiently low F, $n(t) = n$ for all t. In this case the equilibrium distribution function is given by:

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \frac{-e^{-rt}E}{X'(t)n\sigma} - \frac{1}{\varphi^{\sigma-1}-1} & \text{for } t \in [T_L, T_H] \\ 1 & \text{for } t \in (T_H, \infty) \end{cases} \tag{10}$$

The above distribution function describes industry evolution 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-tech 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.

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

[7] To see that all entry occurs at $t = 0$, suppose that the contrary were true and a mass of firms entered at a later date. Since both types of entrants must make zero profits over the life of their operation, this implies that $\pi_L(0) - F = rF_o$ (i.e. net period profits must equal interest savings). In addition, the late entrants must pick when to enter. The first order condition implies

$$-(\pi_H(0) - F)e^{-rT_e} - X'(T_e) + rF_o e^{-rT_e} = 0 \tag{9}$$

Using the condition $\pi_L(0) - F = rF_o$, we see the entry decision for the latecomers is very similar to the decision of the first adopter, with the exception that if the first adopter is an incumbent, then they face n competitors, while a later entrant will face $n + n_e$ competitors. Consequently, the profit differential will be greater for an incumbent, so the potential entrants won't enter as the first adopters. Repetition of this argument for each subsequent adopter generates the result that an incumbent will adopt before the potential entrants. Finally, the potential entrants can't be the last adopter since this would imply $\pi_H(1) - F < \pi_L(0) - F = rF_o$ (i.e. other investment opportunities offer a higher return). Therefore, there will not be entry at any time other that $t = 0$ for sufficiently small F.

2.4 Present Value of Profits

The model can be closed by solving for the equilibrium number of firms, n. The present value of profits is derived by substituting in the respective profit and distribution functions. Given perfect foresight, firms will enter the industry until the present value of profits are equal to zero:

$$\Pi^* = \frac{(1 - e^{-rT_L} + e^{-rT_H})E}{n\sigma r} + \frac{X(T_L) - \varphi^{\sigma-1}X(T_H)}{\varphi^{\sigma-1} - 1} - \frac{F}{r} - F_0 = 0 \tag{11}$$

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 entry occurs until the present value of profits is equal to zero, this zero-profit condition along with $q(t)^*$ (defined by 10) characterizes the closed economy equilibrium.

2.5 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. 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:

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

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):

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

Note that (12) and (13) 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 (12) and (13) are now given by:

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

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

From (14) and (15) there exists a date when F_o is paid-off, $\widetilde{T} \geq T_H$, such that:

$$\frac{F}{r} + F_0 = \frac{E(1 - e^{-rT_L})}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} + \frac{Ee^{-rT_H}}{n\sigma r} - \left(\frac{E}{n\sigma r} - \frac{F}{r}\right) e^{-r\widetilde{T}} \tag{16}$$

This equation implicitly defines the date that F_o is paid-off. This equation has a number of interesting properties, in particular, 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., $dF_o = -d\frac{F}{r} < 0$), while reducing per-period profits, will hold n, T_L and T_H constant over some range of F and F_o. However, as F_o is decreased, the date at which F_o is paid-off will occur earlier in equilibrium (i.e., for (16) to hold, it must be the case that $dF_o < 0$ implies $d\widetilde{T} < 0$). However, provided that $\widetilde{T} \geq T_H$, per-period profits for all firms are strictly positive and no-firm will have an incentive to exit.

From (15) and (16):

$$\frac{Ee^{-rT_H}}{n\sigma r} - \left(\frac{E}{n\sigma r} - \frac{F}{r}\right) e^{-r\widetilde{T}} \geq \frac{Ee^{-rT_H}}{\varphi^{\sigma-1} n\sigma r} \tag{17}$$

Note that when $dF_o = -d\frac{F}{r}$ the term in parenthesis is constant and eventually $\tilde{T}$ will decrease until $\tilde{T} = T_H$. At this point F_o is paid off at the end of the diffusion process (since $\tilde{T} = T_H$) while per-period profits for the last adopter when they are low-tech are equal to zero at T_H (i.e., $\frac{E}{\varphi^{\sigma-1} n\sigma} = F$).

A further characteristic of the $\tilde{T} = T_H$ situation is that the last adopter is indifferent between staying in the market to payoff $X(T_H)$ or not adopting and exiting at T_H. Both options result in discounted profits of zero. Thus, at $\tilde{T} = T_H$ the following conditions hold in equilibrium:

$$\overline{F} = \frac{E}{\varphi^{\sigma-1} n\sigma} \tag{18}$$

$$\overline{F}_0 = \frac{E(1 - e^{-rT_L})}{n\sigma r} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} - \frac{(1 - e^{-rT_H})\overline{F}}{r} \tag{19}$$

$$X(T_H) = \left(\frac{E}{n\sigma} - \overline{F}\right)\frac{e^{-rT_H}}{r} \tag{20}$$

These equations define a situation where a low-tech firm is just indifferent between adopting the new technology at T_H or exiting the industry. Thus, these conditions endogenize the exit decision as a function of the relative sizes of F_o and F. Furthermore, note that $\overline{F}$ defines the largest per-period fixed cost that is consistent with a no shakeout equilibrium.

2.6 Shakeouts

Once $\tilde{T} = T_H$, 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 begin 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.

PROPOSITION 1 *Assuming 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: From the point where $\tilde{T} = T_H$ 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 (14) to continue to hold, given our definition of $\tilde{T}$, requires that:

$$\int_{\tilde{T}}^{T_H} e^{-rt}(\pi_L(q(t)) - F)dt + (\frac{E}{n\sigma} - F)\frac{e^{-rT_H}}{r} - X(T_H) = 0 \tag{21}$$

However, given that we increased F from the point defined by (20) implies that for (14) to hold requires that $\int_{\tilde{T}}^{T_H} e^{-rt}(\pi_L(q(t)) - F)dt > 0$. 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 a 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 a decrease in 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.[8]

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.[9] A noteworthy feature of this period of

[8]This story of technological change inducing exit is a familiar one in the industrial organization literature and is featured in Jovanovic and MacDonald (1994) and Klepper (1996).

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

exit is how sudden and dramatic it can be. Thus, the focus in the industrial organization literature lies not only in explaining why firms exit an industry, but also why such periods of exit can be so dramatic (i.e., why do "shakeouts" exist). 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:

$$\pi_L(q(T_S)) = F \tag{22}$$

Using the first order condition of an adopting firm implies:

$$(\varphi^{\sigma-1} - 1)F = -X'(T_S)e^{rT_S} \tag{23}$$

Since the T_S that solves this equation is unique, all firms that exit must do so at T_S. Note that by construction $T_S \in [T_L, T_H]$.[10] Q.E.D.

While our model of industry exit is similar to the existing industrial organization literature (i.e., technological change reducing industry prices and thus forcing out low-tech firms), the mechanism that generates a "shakeout" is novel. In our framework, shakeouts are derived from the *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. Thus, this positive feedback results in exit being sudden rather than gradual. What is novel about our framework is that traditional models of industry shakeout assume some degree of randomness or uncertainty in the technology process. In contrast, in our model firm heterogeneity is derived endogenously as an equilibrium outcome of a deterministic framework (i.e., there is no uncertainty in our model, firms can always adopt the new innovation provided they are willing to incur the cost). Rather, we show how the shakeout phenomena can be derived naturally from standard game-theoretic models of endogenous technology diffusion dating back to the work of Reinganum (1981).

A characteristic of the no shakeout equilibrium is that once firms enter at $t = 0$ there is no incentive for further entry at other dates or for firms to exit. However, the same variation in F and F_o that provided the conditions for firms to exit, also raises the

[10] Note that if $T_S < T_H$, then (22) implies that firms that stay in, but have yet to adopt, will make negative profits until they adopt.

possibility that firms might also 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 hi-tech firms to enter at or after T_H.*

Proof: 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.

A feature of Proposition 3 is that, following the shakeout, new firms will only enter the industry as high-tech firms.[11] 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.[12]

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

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

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

[12] 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.

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

$$n(t) = \frac{E}{(-X'(t)e^{rt} + F + rF_o)\sigma} \tag{24}$$

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

$$\frac{Fe^{-rT^e}}{r} + F_o e^{-rT^e} + X(T^e) = \frac{E}{\sigma}\int_{T^e}^{\infty} \frac{e^{-rt}}{n(t)}dt \tag{25}$$

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

$$\frac{F}{r} + F_0 + X(T_H) = \frac{E(1-e^{-rT_L})}{(n_p+n_d)\sigma r} + \frac{X(T_L)-X(T_H)}{\varphi^{\sigma-1}-1} + \frac{E(e^{-rT_H}-e^{-rT^e})}{n_p\sigma r} + \frac{E}{\sigma}\int_{T^e}^{\infty}\frac{e^{-rt}}{n(t)}dt \tag{26}$$

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

$$\frac{F}{r} + F_0 = \frac{E(1-e^{-rT_L})}{(n_p+n_d)\sigma r} + \frac{X(T_L)-X(T_S)}{\varphi^{\sigma-1}-1} + \frac{Fe^{-rT_S}}{r} \tag{27}$$

Using (27) and (25), (26) can be simplified to:

$$\frac{X(T_S)-X(T_H)}{\varphi^{\sigma-1}-1} + \frac{(e^{-rT_H}-e^{-rT^e})E}{n_p\sigma r} - \frac{(e^{-rT_S}-e^{-rT^e})F}{r} = X(T_H) - X(T^e) - F_o e^{-rT^e} \tag{28}$$

Note in particular that this is only a function of n_p. Therefore, to solve for n_d, (28) can be combined with (27). Figure 1 illustrates these conditions. To complete the description of the equilibrium, the distribution function needs to be derived. 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:

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \frac{-e^{-rt}E}{X'(t)n_p\sigma} - \frac{n_d+n_p}{n_p(\varphi^{\sigma-1}-1)} & \text{for } t \in [T_L, T_S) \\ \frac{-e^{-rt}E}{X'(t)n_p\sigma} - \frac{1}{\varphi^{\sigma-1}-1} & \text{for } t \in [T_S, T_H] \\ 1 & \text{for } t \in (T_H, \infty) \end{cases} \tag{29}$$

Figure 2 depicts this equilibrium distribution function. 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.

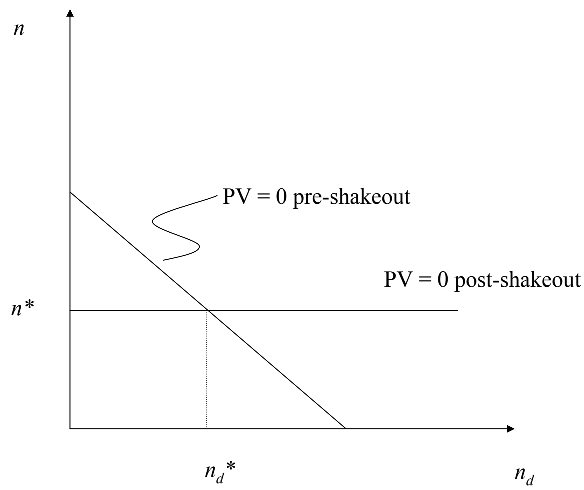

Figure 1:

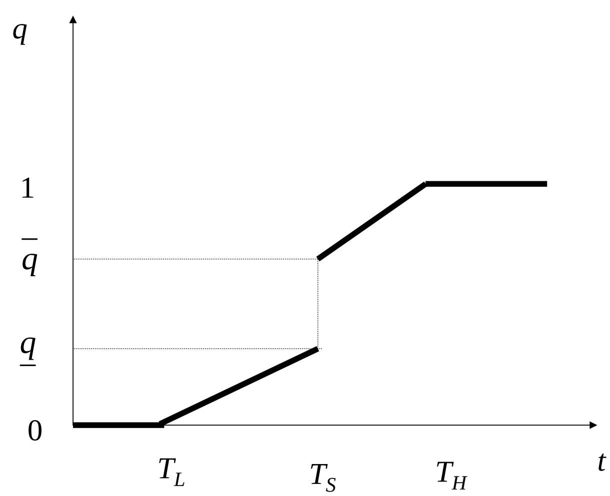

Figure 2:

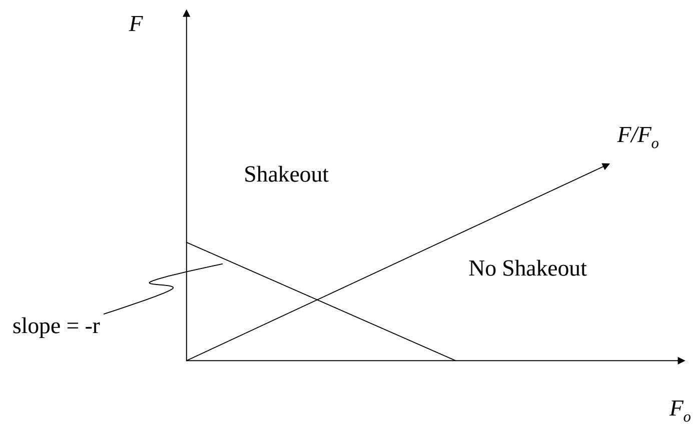

Figure 3:

3 Comparative Statics

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 be apparent from the discussion of the previous section that the basic parameters that determine whether a shakeout is likely to occur are the size of the sunk costs of entering the market relative to the recuring fixed costs of production. The interaction between these two variables in determining the occurrence of a shakeout are clarified in figure 3. To interpret figure 3 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 $-r$. Eventually, one will reach the point 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 is characterized by (19) and (20), 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 3 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. The intuition behind this division of the parameter space between no-shakeout/shakeout equilibria comes from the relative ease of entering the industry and the sensitivity of firms to technological change. 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 becomes.

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 3, this can be determined by calculating how changes in parameter values effect the F/F_o cut-off 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 *at* $F = 0$,

ii) *the elasticity of demand,* σ,

iii) *the innovative step,* φ.

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

Proof: A shakeout becomes possible when the following two conditions hold:

$$\overline{F} = \frac{E}{\varphi^{\sigma-1} n_p \sigma} \tag{30}$$

$$\overline{F}_o = [(1 - e^{-rT_L})\varphi^{\sigma-1} - (1 - e^{-rT_H})]\overline{F} + \frac{X(T_L) - X(T_H)}{\varphi^{\sigma-1} - 1} \tag{31}$$

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.

To assess the affect of changes in φ, σ and E on the $\overline{F}/\overline{F}_o$ at which a shakeout occurs, totally differentiate (30):

$$\begin{aligned} \frac{d\overline{F}}{d\varphi} &= \frac{-(\sigma-1)E}{\varphi(\varphi^{\sigma-1}-1)n\sigma} < 0 \\ \frac{d\overline{F}}{d\varphi} &= \frac{-Log(\varphi)E}{(\varphi^{\sigma-1}-1)n\sigma} < 0 \\ \frac{d\overline{F}}{dE} &= 0 \end{aligned}$$

Q.E.D.

These results are illustrated in Figure 4. Note that an increase in either the step size of the innovation or an increase in the elasticity of demand increase the likelihood of a shakeout. Intuitively this is due to the fact that more important technological innovations or increased 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 effect the timing and magnitude of the shakeout. This intuition is borne out by the following two propositions:

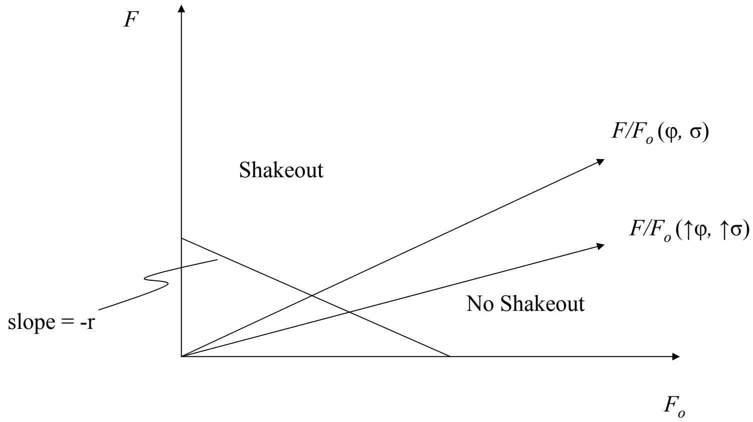

Figure 4:

PROPOSITION 5 *Given 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: 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:

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

Direct calculations reveal:

$$\frac{dT_S}{dF} = \frac{\varphi^{\sigma-1} - 1}{\partial(-X'(T_S)e^{rT_S})/\partial T_S} < 0$$

$$\frac{dT_S}{d\varphi} = \frac{F(\sigma - 1)\varphi^{\sigma-2}}{\partial(-X'(T_S)e^{rT_S})/\partial T_S} < 0$$

$$\frac{dT_S}{d\sigma} = \frac{F\varphi^{\sigma-1}Log(\varphi)}{\partial(-X'(T_S)e^{rT_S})/\partial T_S} < 0$$

$$\frac{dT_S}{dE} = 0$$

Q.E.D.

PROPOSITION 6 *Given $F_o = 0$ (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: 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 (29) 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.

The fact that increases in the size of the high-tech innovation and elasticity of demand cause shakeouts to be larger and 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 it has strong implications for the structure of shakeouts in an open economy. Specifically, a primary 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). Thus, the combined lesson of these Propositions is that, for a non-traded good, the shakeout phenomena should be quite similar across countries (i.e., shakeouts should occur at roughly equal times and be of equal magnitude). In the following sections, we convert our technology adoption model to an open economy setting to see how international trade affects this conclusion.

4 Shakeouts and International Trade

As identified earlier, there are a number of ways in which the introduction of international trade can influence the structure of the model. To narrow the focus, we study two types of asymmetries that international trade can introduce, asymmetries between firms within countries and asymmetries between countries themselves. With respect to the first type of asymmetry, the introduction of international trade adds the possibility that not all firms in the differentiated goods sectors are exporters. This exporter/non-exporter dichotomy within the same narrowly defined industry has been well documented in the trade literature (see Bernard and Jensen (1995), Bernard and Jensen (1999), Clerides et al. (1998), Baldwin and Gu (2003)). Assuming that countries are symmetric in all dimensions implies that the timing and magnitude of a shakeout will be the same across countries. This allows us to focus exclusively on the question of how variation in trade barriers affects the probability of a shakeout. The second type of asymmetry is more conventional in that countries have different technological capacity. The focus in this setting is the distribution of firm exits across countries in the event of a shakeout.

4.1 Symmetric Countries, Asymmetric Firms

In this section the basic question is whether international trade is a force for change or stasis in an industry. That is does increased exposure to trade increase the likelihood an industry will experience a shakeout? First, imagine the case where there are no costs to exporting (i.e., all firms produce for both the domestic and foreign market) and there exist two symmetric countries. In this situation, exposure to trade is equivalent to an increase in market size in the closed economy model. As we showed in the previous section, an increase in market size has no impact on the likelihood (or magnitude, or timing) of a shakeout. Thus, when there is complete symmetry and free trade, openness to trade has no impact on the evolution of the industry.

However, now assume trade between the two symmetric countries is costly. Specifically, consistent with the empirical evidence on traded goods, assume that those firms that choose to export face not only per-unit costs (i.e., transportation costs or tariffs) but also some fixed (sunk) costs to the export decision.[13] The presence of such fixed costs result in an endogenous sorting of firms into exporters (those who produce for both the domestic and foreign markets) and non-exporters (those who produce for the domestic market alone).[14] As we show in the analysis that follows, the tendency of trade to sort firms into exporters and non-exporters has important implications for industrial evolution.

Thus, assume a one-time sunk cost, S to entering the export market. Given that profits decrease as more firms enter the export market, sunk export costs result in *ex ante* identical firms endogenously sorting themselves into exporters and non-exporters (we denote the fraction of firms that choose to export as s_x). In addition to this fixed export cost, we assume that exporting firms also face transport costs of the traditional iceberg form where $b > 1$ units of a good need to be shipped for one unit to arrive. Thus, 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

[13] For evidence on the sunk costs of exporting see Roberts and Tybout (1997) and Bernard and Jensen (2004).

[14] For other models that use sunk cots as a basis for sorting firms into exporter/non-exporters see Melitz (2003), Yeaple (2003) and Bernard, Schott, and Redding (2004).

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. In this setting it is straight forward to show, as is done in Ederington and McCalman (2004), that firms that export are the first to adopt. In addition, Ederington and McCalman (2004) show that the equilibrium distribution function (for $F = 0$) is now given by:

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

Thus, there now consist five phases of evolution. First, there is a steady state in which no firm adopts the new high-productivity technology. Then, starting at T_L, exporting firms begin to adopt the high-tech methods and, by $\underline{T}$, all the exporting firms will have become high-tech. Adoption for non-exporting firms is delayed until $\overline{T}$ with the final adopter once again adopting at time T_H.

As in the closed economy, one can consider starting from $F = 0$ and trading off F and F_o until the final (non-exporting) adopter is indifferent between exiting and staying (the cut-off point for a shakeout to occur). The question raised in this section is whether trade liberalization (a decrease in b) increases or decreases the likelihood of a shakeout. There might be a tendency to expect that trade, by creating a set of "vulnerable" non-exporters who adopt later in equilibrium, would increase the probability of a shakeout. After all, traditional models of the shakeout phenomena derive shakeouts by postulating the existence of a randomly generated set of less technologically-adept firms. However, this intuition is incorrect. As we show in the following Proposition, trade liberalization (announced at $t = 0$) is actually a force for stability in an industry as it reduces the probability of a shakeout.

PROPOSITION 7 *A shakeout is less likely (i.e. the critical F/F_o that divides the shake-out equilibria from the no-shakeout equilibria is higher) the lower are trade barriers.*

Proof: A shakeout becomes just possible when:

$$F = \frac{E}{(1 + s_x b^{1-\sigma})n\sigma} = \pi_L^{nx}(q = 1) \tag{32}$$

and

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

The zero-profit condition for non-exporters is defined by:

$$\Pi^{nx} = \Pi_1^{nx} + \Pi_2^{nx} + \Pi_3^{nx} + \Pi_4^{nx} - F_o - \frac{F}{r} - X(T_H) = 0 \tag{33}$$

where $\Pi_1^{nx} = \int_0^{T_L} e^{-rt}\pi_L^{nx}(q = 0)dt$; $\Pi_2^{nx} = \int_{T_L}^{\underline{T}} e^{-rt}\pi_L^{nx}(q(t))dt + \int_{\overline{T}}^{T_H} e^{-rt}\pi_L^{nx}(q(t))dt$; $\Pi_3^{nx} = \int_{\underline{T}}^{\overline{T}} e^{-rt}\pi_L^{nx}(q = s_x))dt$, and $\Pi_4^{nx} = \int_{T_H}^{\infty} e^{-rt}\pi_H^{nx}(q = 1)dt$. Totally differentiating (33) and applying the envelope theorem:

$$\frac{d\Pi^{nx}}{db} = 0 = \frac{d\Pi_1^{nx}}{db} + \frac{d\Pi_2^{nx}}{db} + \frac{d\Pi_3^{nx}}{db} + \frac{d\Pi_4^{nx}}{db} \tag{34}$$

By direct calculation, one derives that $\frac{d\Pi_2^{nx}}{db} > 0$. Thus, trade liberalization reduces non-exporter profits during the diffusion phases. Also note that profits in the steady state are proportional: $\Pi_1^{nx} = \frac{e^{-rT_H}}{1-e^{-rT_L}}\Pi_4^{nx}$. Thus, to ensure that the zero-profit condition for non-exporters is satisfied, from (34):

$$\frac{d\Pi_3^{nx}}{db} + [1 + \frac{e^{-rT_H}}{1 - e^{-rT_L}}]\frac{d\Pi_4^{nx}}{db} < 0 \tag{35}$$

The zero-profit condition for exporters is defined by:

$$\Pi^{x} = \Pi_1^{x} + \Pi_2^{x} + \Pi_3^{x} + \Pi_4^{x} - F_o - \frac{F}{r} - S - X(\underline{T}) = 0 \tag{36}$$

where: $\Pi_1^{x} = \int_0^{T_L} e^{-rt}\pi_L^{x}(q = 0)dt$; $\Pi_2^{x} = \int_{T_L}^{\underline{T}} e^{-rt}\pi_H^{x}(q(t))dt + \int_{\overline{T}}^{T_H} e^{-rt}\pi_H^{x}(q(t))dt$; $\Pi_3^{x} = \int_{\underline{T}}^{\overline{T}} e^{-rt}\pi_H^{x}(q = s_x))dt$, and $\Pi_4^{x} = \int_{T_H}^{\infty} e^{-rt}\pi_H^{x}(q = 1)dt$ Similar calculations reveal that $\frac{d\Pi_2^{x}}{db} < 0$ (i.e., trade liberalization results in increased profits for exporters in the diffusion phase) and $\Pi_1^{x} = \frac{e^{-rT_H}}{1-e^{-rT_L}}\Pi_4^{x}$. Thus, to ensure zero profits:

$$\frac{d\Pi_3^{x}}{db} + [1 + \frac{e^{-rT_H}}{1 - e^{-rT_L}}]\frac{d\Pi_4^{x}}{db} > 0 \tag{37}$$

From the respective profit functions, one derives that exporter profits are proportionaly higher than non-exporter profits, where the exporter advantage is magnified during the diffusion phase: $\Pi_4^{x} = (1+b^{1-\sigma})\Pi_4^{nx}$ and $\Pi_3^{x} = \varphi^{\sigma-1}(1+b^{1-\sigma})\Pi_3^{nx}$. Using these derivations, it is straightforward to show that both (34) and (37) can only be satisfied if:

$$\frac{d\Pi_4^{nx}}{db} < 0 \quad , \quad \frac{d\Pi_3^{nx}}{db} > 0 \tag{38}$$

Finally, it is direct to derive that $\frac{d\Pi_4^{nx}}{db} < 0$ implies that $\frac{d\pi_L^{nx}}{db}|_{q=1} < 0$. Thus, a reduction in trade costs, by (32), increases the F cut-off where the shakeout first becomes possible. Q.E.D.

This result is depicted in figure 5. As can be seen, a reduction in trade barriers increases the F/F_o cut-off at which a shakeout occurs and thus makes a shakeout less likely in the industry. An implication of this proposition is that those industries that are more open to trade are less likely to experience a subsequent shakeout than comparable industries.

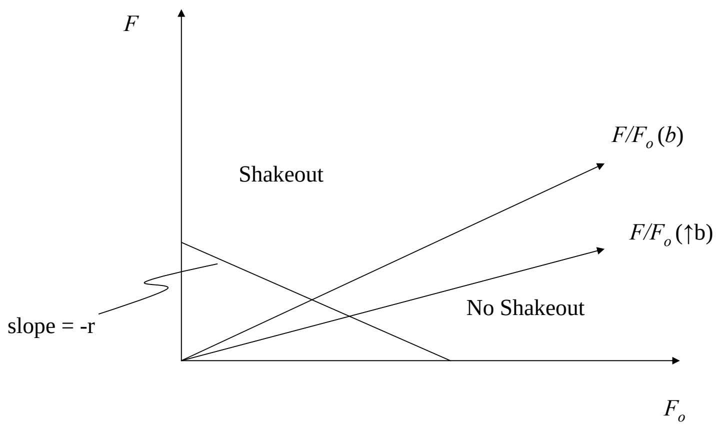

Figure 5:

Thus, trade acts as a force for stability in an industry. While the proof of this proposition parallels that given in Ederington and McCalman (2004) for why trade increases the speed of technology adoption, it is provided here in detail because it helps explain why trade may reduce the probability of a shakeout. Specifically, the result that $\frac{d\Pi_4^{nx}}{db} < 0$ (see 38), implies that trade liberalization has increased profits in the final steady state.[15] In other words, trade liberalization has changed the dynamic path of profits in such a way that profits are more back-weighted (i.e., profits have increased in the time periods toward the end of the industry lifetime). Given this result, it is not surprising that firms would be less likely to exit, since exiting would result in foregoing this period of increased profit.

4.2 Asymmetric Countries

In the symmetric setting all countries face the same probability of a shakeout and experience shakeouts of the same magnitude at the same time. While cases where the timing and relative magnitude of shakeouts are similar across countries have been documented, there

[15]The intuition behind this result is most transparent when considering two industries that differ only in terms of the trade barriers they face at $t = 0$. As barriers are reduced the n and s_x must change in such a way that profits increase for non-exporters (who are hurt by lower trade barriers) and profits decrease for exporters (who benefit from lower trade barriers) in order to satisfy the zero-profit conditions. This adjustment reduces profits during the diffusion phase (when the exporter profit advantage is highest) and increases profits in the steady states when the exporter profit advantage is lowest.

are also examples of asymmetry such as the synthetic dye industry.[16] In this industry, France, Germany and Britain all had non-trivial firm entry. However, only France experienced a shakeout in the period from the start of the industry (1857) to the First World War (1914). Over this period German firms came to dominate the synthetic dye industry, 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.[17]

4.3 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 now denote foreign variables by a star (*). To focus on the issue of the distribution of exits across countries we drop the assumption of a sunk cost of exporting, but we still maintain the assumption of symmetric iceberg transport costs, b. These transport costs are assumed to be sufficiently low that a foreign firm cannot remain in the market permanently.

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 home firm with an incentive to enter the industry would ever consider leaving. These conditions also imply that there are no foreign firms in the market. These incentives are challenged by trading-off $dF_o = -d\frac{F}{r} < 0$. However, as F/F_o is increased it is the foreign firms that are the first to respond to the changed incentives. This follows from the fact that a single foreign entrant has a higher per-period profit than a comparable low technology home firm. But foreign firms have no incentive to adopt the high tech methods (or stay in the market permanently as a low tech type). Therefore, exit first becomes likely when the foreign firm is capable of paying off the entry cost, F_o. Moreover, since home and foreign firms are paying off F_o at different rates, this implies that the exit occurs in the location where the low-tech firms are on average the most profitable. These results are summarized in the following proposition:

PROPOSITION 8 *Starting from an initial parameter configuration such that $n_p > 0$ and $n_p^* = n_d^* = n_d = 0$, then trading off F_o and F, according to $dF_o = -d\frac{F}{r} < 0$, makes Foreign the location where the exit conditions are satisfied first.*

[16]See Carroll and Hannan (1995) for evidence relating to the symmetry of shakeouts in the automobile industry across European countries and the US.

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

Proof: This follows from a comparison of the conditions that show the progress made paying off F_o in the home and foreign markets at T_H. For Home to have paid off F_o at T_H requires

$$F_o + \frac{F}{r} = \frac{2(1-e^{-rT_L})E}{n\sigma r} + \frac{X(T_L) - X(T_H)}{(\varphi^{\sigma-1}-1)} + \frac{Fe^{-rT_H}}{r}$$

While for Foreign to have paid off F_o at T_H requires:

$$F_o + \frac{F}{r} = (b^{\sigma-1} + b^{1-\sigma})\left[\frac{(1-e^{-rT_L})E}{n\sigma r} + \frac{X(T_L) - X(T_H)}{2(\varphi^{\sigma-1}-1)}\right] + \frac{Fe^{-rT_H}}{r}$$

However, these two conditions cannot hold simultaneously if $b > 1$. Since $(b^{\sigma-1}+b^{1-\sigma}) > 2$, the condition must hold with equality in Foreign and not be met in Home. Q.E.D.

Therefore, trading off F_o and F creates an incentive for foreign firms to enter the market at $t = 0$ but also exit sometime before T_H. It is not immediately obvious that exit in the foreign country must take the form of a shakeout, especially since firms are asymmetric across countries and trade barriers serve to partially isolate the foreign country from the process of technology adoption. This suggests that it might be possible for foreign firms to leave the industry gradually, maintaining the zero per-period profit condition over some interval of time. However, exit of foreign firms increases the incentive for home firms to adopt, encouraging further exit. This feedback mechanism operates to generate a shakeout in the foreign country, though the size of trade barriers do play a role in shaping this pattern of exit. The following proposition characterizes the behavior of foreign firms:

PROPOSITION 9 *If trade barriers are sufficiently low, then all foreign firms that exit do so at the same date, T_S^*.*

Proof: Since the profits of low tech firms are declining as more firms adopt the hi tech methods, low tech firms have an incentive to exit provided they have paid-off their entry costs and their per-period profits are non-positive. Since foreign firms have an incentive to exit, it must be the case that:

$$\pi_L^*(q(T_S^*)) + b^{1-\sigma}\pi_L(q(T_S^*)) = F \tag{39}$$

where $\pi_L^*(q)$ are a low tech firms profits in the foreign market and $\pi_L(q)$ are the profits of a low-tech firm serving the home market. Since the incentive to exit arises as home firms are adopting the advanced technology, the first order conditions imply:

$$(\varphi^{\sigma-1} - 1)(b^{1-\sigma}\pi_L^*(q) + \pi_L(q)) \quad = \quad -X'(T_S^*)e^{rT_S^*}$$

Using (39), this first order condition can be simplified to:

$$(\varphi^{\sigma-1} - 1)(b^{1-\sigma}F + (1 - b^{2(1-\sigma)})\pi_L(q)) \quad = \quad -X'(T_S^*)e^{rT_S^*}$$

Solving for the share of home firms that have adopted the high-tech methods at T_S^* yields:

$$q(T_S^*) = \frac{1 - b^{2(1-\sigma)}}{n(-X'(T_S^*)e^{rT_S^*} - b^{1-\sigma}F(\varphi^{\sigma-1} - 1))} - \frac{n + b^{1-\sigma}n^*}{n(\varphi^{\sigma-1} - 1)} \tag{40}$$

Note that for $q(T_S^*) \in [0, 1]$ requires:

$$-X'(T_S^*)e^{rT_S^*} > b^{1-\sigma}F(\varphi^{\sigma-1} - 1) \tag{41}$$

Substituting (40) into (39) gives:

$$n^* = \frac{1}{F + \frac{X'(T_S^*)e^{rT_S^*}b^{1-\sigma}}{(\varphi^{\sigma-1}-1)}} + \frac{1}{F + \frac{X'(T_S^*)e^{rT_S^*}b^{\sigma-1}}{(\varphi^{\sigma-1}-1)}}$$

If b is close to 1 (low trade barriers) and (41) holds, then $n^* < 0$ (i.e., no foreign firms can survive after T_S^*). Q.E.D.

Together these two propositions illustrate a potential identification problem for empirical work based solely on national data. If the only data collected is for the advanced country, then this would indicate that no-shakeout took place in this industry, even though the conditions do generate a shakeout. In this case, identification of the factors that generate a shakeout would be undermined because the information on the less advanced country is not included. Thus, in contrast to the closed economy model, shakeouts are not generated by domestic factors, but by actions taken by firms from abroad. Nevertheless, due to international trade, the advanced country has been able to avoid any shakeout with the whole burden of adjustment taking place in the less advanced country.

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.

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 is 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 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 when countries are symmetric, trade can introduce an additional source of asymmetry between firms within a country. Now firms can differ not only in terms of their relative technological position but also in terms of whether or not they participate in the export market. 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 an 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 becomes 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 the industrial dynamics of industries.

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