Offshoring as Process Innovation

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PRELIMINARY

Abstract

This paper studies offshoring (defined as a change in firms' own production location from north to south) and market structure. I develop a model of dynamic oligopoly with offshoring, and estimate it using data from the hard disk industry. The results suggest the incentive to offshore increases as more rivals offshore due to competitive pressure. The possibility of offshoring sets in motion the strategic industry dynamics in which firms become increasingly more likely to offshore or exit, thereby playing the role of a "drastic" innovation (Arrow 1962) in the long run. I then assess the effects of banning offshoring and industrial policy (in the future version).

Keywords: Industry Dynamics, Innovation, Market Structure, Offshoring

1 Introduction

Although widely recognized as the main driver of long-run economic well-being, not all innovations are welcomed by the general public, because they tend to displace the existing organization of production. Offshoring is one such example, by which firms move their facilities overseas to produce at lower costs.[1] In terms of production efficiency, it is hard to argue against the benefits of low-cost production (i.e., process innovation), whether or not it entails changing location of plants. However, most of the policy debates surrounding offshoring are

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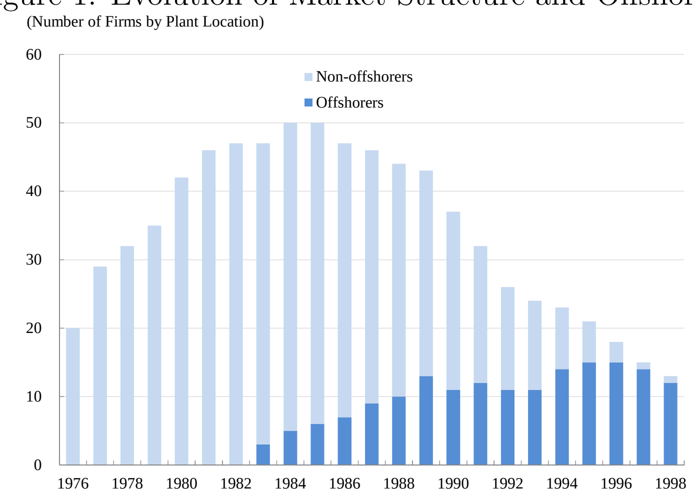
[1] A broader definition of offshoring would also include "outsourcing" of tasks to foreign firms, but this paper focuses on the shift of northern firms' own production to southern countries because of the latter's importance in the hard disk industry. Thus, I use the word offshoring with the "narrower" definition according to Feenstra's (2010) classification.

alarmists, because of the prospect of job destruction in home countries. Likewise, most of the academic work have focused on the labor-market effects of offshoring.[2]

Meanwhile, the product-market aspects of offshoring have hardly been studied, even though the literature on competition and innovation has documented some fundamental relationships between market structure and cost-reducing investments. This gap in knowledge is unfortunate because competition alters firms' incentives to offshore, understanding of which is essential for designing or evaluating policy interventions. Moreover, offshoring alters firms' cost structure, profitability, and their chances of survival as well as those of non-offshoring rivals. These product-market outcomes will affect labor market because, unless the latter is frictionless, the death of domestic producers means job destruction in home countries. Offshoring represents major economic phenomena, whose mechanisms need to be explained with microeconomic foundations.

For these reasons, this paper empirically studies the relationship between offshoring and product-market competition, using a structural model of industry dynamics and data from the global hard disk drive (HDD) industry, in which manufacturers from rich countries (notably California) frequently moved their plants to developing countries (mainly Singapore), to the extent that almost all of the world's HDDs were assembled in Singapore by 1998 (see Figure 1). Specifically, the paper focuses on the strategic industry dynamics of offshoring to assess how market structure affects the incentive to offshore, and to measure the impact of offshoring on firms' survival and the evolution of market structure.

Figure 1: Evolution of Market Structure and Offshoring



Note: Major firms only.

The results suggest the incentive to offshore increases as more rival firms produce overseas

[2]Feenstra and Hanson (1996, 1997, 1999, 2003), Autor et al (2003), Hsieh and Woo (2005), Feenstra (2010), Ottaviano et al (2010), Burstein and Vogel (2011), and Hummels et al (2011).

at a lower cost, because of the latter's business-stealing effect and downward pressure on the output price, which diminishes the profitability of high-cost operations by non-offshorers. Moreover, because some firms' offshoring reduces the profitability of other (non-offshoring) firms disproportionately, counterfactual simulations show offshoring sets in motion the strategic dynamics of market structure in which: (1) firms become increasingly more likely to start offshore production; (2) the number of non-offshorers declines over time because some of them offshore and others exit the industry (i.e., offshoring accelerates the "shake-out"); and (3) eventually offshorers comprise most of the surviving firms.

In the future version of the paper, I plan to evaluate the effectiveness and welfare consequences of public-policy interventions against and in favor of offshoring. Because both the incentives to offshore and the evolution of market structure are endogenous, I suspect government actions may result in unintended consequences of the opposite effects.

In the future version of the paper, I will summarize the related literature on: (a) offshoring, (b) industry dynamics, and (c) process innovation. See Igami (2010) for institutional details and exploratory data analysis of offshoring in the global HDD industry. See Igami (2013) for the strategic industry dynamics of product innovation in this industry.

I have organized the rest of the paper as follows. Section 2 shows descriptive evidence on the dynamics of offshoring and market structure in the global HDD industry. Section 3 presents my model of strategic offshoring dynamics to capture these data features. Section 4 explains my estimation approach and results. In section 5, I summarize and discuss my main empirical findings. Section 6 will evaluate public policies in terms of both keeping firms in home countries and improving social welfare, in the future version of the paper. Section 7 concludes.

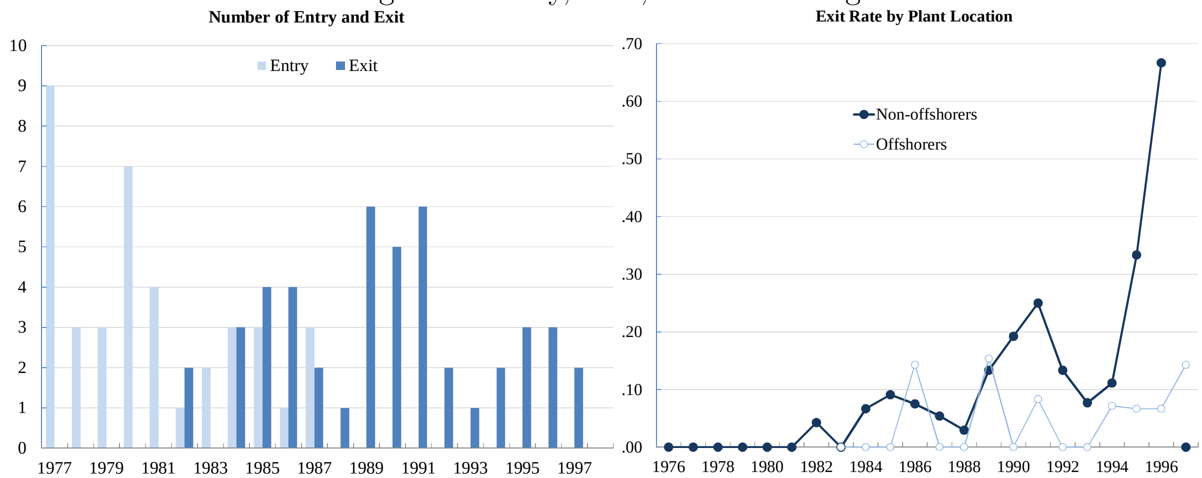
2 Descriptive Evidence

This section portrays the dynamics of offshoring and market structure in the global hard disk drive (HDD) industry, explaining its institutional and technological features where necessary.

2.1 Offshoring and Market Structure Dynamics

This industry witnessed waves of new entry during the first half of the sample period (1976–98), followed by mass exits during the second half. This pattern of initial rise and subsequent fall in the number of firm has historically been common to many industries ranging from banking to car manufacturing, but the increasing number and fraction of offshore producers (i.e., firms that are originally based in rich countries but subsequently moved production sites to developing countries) is a relatively recent phenomenon. These developments reflect rising rates of both exit and offshoring, as well as the tendency of offshorers to survive better than non-offshorers. This paper aims to explain the mechanism behind these data features.

Figure 2: Entry, Exit, and Offshoring



Note: .

2.2 Offshoring as Strategic Process Innovation

What explains the growing popularity of offshoring and the superior survival rate of offshorers relative to non-offshorers? Some descriptive statistics help us conjecture the likely mechanisms based on low-cost production and business-stealing.

As shown in Figure 3, the growing aggregate output and falling price are the salient features of the HDD market during the sample period, which are also characteristic to a broader range of high-tech manufacturing industries such as semiconductors and household electronics. The fraction of outputs by offshorers rose significantly, as an increasing number of firms started offshore production since the early 1980s.

However, the changing numbers of offshorers and non-offshorers are only a part of the story. A closer look at the output per firm reveals offshorers produce at least twice as many HDDs than firms staying in home countries. Moreover, the firm-level output trajectory exhibits a discrete upward "jump" when the firm starts offshore production. Hence the higher output per firm among offshores seems driven by some intrinsic advantages of producing on a foreign soil, rather than a mere artifact of larger firms self-selecting into offshoring.

Firms engage in offshoring to reduce production costs (see Table 1), and standard models of production would associate a lower marginal cost with a higher output. Hence, one can

Figure 3: Rising Output, Falling Price, and Growing Share of Offshorers

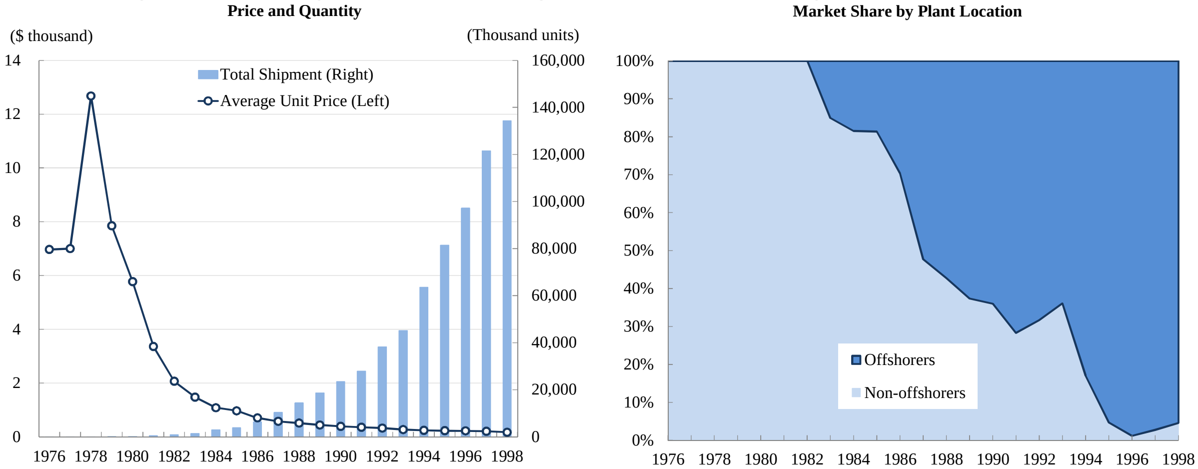


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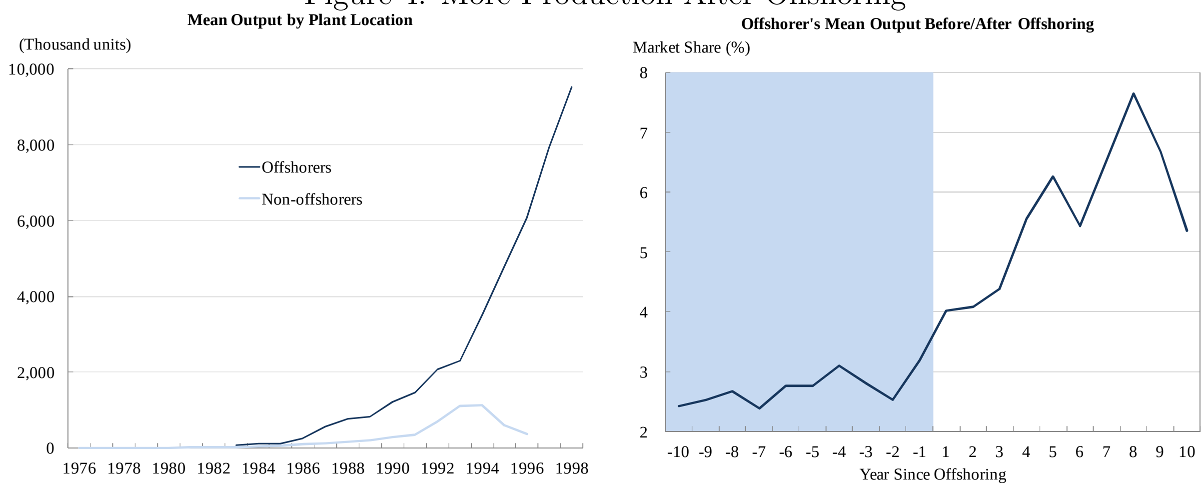
Figure 4: More Production After Offshoring



Note: .

easily rationalize the observed heterogeneity in outputs between offshorers and non-offshorers by their cost-heterogeneity. A careful analysis, however, would require further considerations of strategic interactions, both in the static and dynamic senses.

The coexistence of offshorers (low-cost firms) and non-offshorers (high-cost firms) over a decade is suggestive of imperfect competition, and, in such a product market, a given firm's investment in cost reduction (i.e., offshoring) would entail strategic repercussions in the following sense. First, in terms of spot-market competition in a given year, low-cost firms (i.e., offshorers) would capture greater market shares at the expense of high-cost firms (i.e., non-offshorers): the business-stealing effect. Second, in terms of firms' dynamic decisions to offshore, exit, and enter, the number of rivals would affect the incentives to take these

Table 1: Labor Cost Advantage of Offshoring

	1983	1985	1988	1990	1993	1995
Hourly Wage Rate for Manufacturing (US$)						
U.S.	8.83	9.54	10.19	10.83	11.74	12.37
Singapore	1.49	2.47	2.67	3.78	5.38	7.33
Malaysia	–	1.41	1.34	1.39	1.74	2.01*
Thailand	0.43	0.54	0.62	1.03	1.25	1.41
Philippines	0.59	0.55	0.74	1.02	1.07	–
Indonesia	0.13	0.3**	0.38	0.60	0.92***	–
(as a percent of U.S.)						
U.S.	100	100	100	100	100	100
Singapore	17	26	26	35	46	59
Malaysia	–	15	13	13	15	16
Thailand	5	6	6	10	11	11
Philippines	7	6	7	9	9	–
Indonesia	1	3	4	6	8	–

Note: *, **, and *** indicate data in 1994, 1986, and 1992, respectively.

Source: ILO, U.S. Department of Labor, and UNIDO, *cit in* McKendrick, Doner, and Haggard (1996: table 6.1).

actions, and some firms' acts of offshoring will, in turn, alter the market structure and the other firms' incentives to offshore, exit, and enter. Thus, to fully understand the mechanisms that drive the evolutions of market structure and incentives to offshore, we need to build a strategic model of entry, exit, and offshoring, which is the goal of the next section.

3 Model

This section presents my empirical model, which consists of demand, period competition, and dynamic game. The purpose is to develop an estimable model to explain the observed data patterns with simple economics, subject to the data constraint (e.g., no firm- or brand-level information on prices and quantities, due to confidentiality reasons).

Because the main data pattern of interest is the potentially endogenous evolution of offshoring and competition, my overall framework is dynamic game, in which oligopolistic firms make forward-looking decisions about entry, exit, and offshoring every year, taking into consideration future demand, cost, and rival firms' actions, and hence the evolution of market structure. Their expected payoffs at any moment are based on the stream of period profits, which are themselves functions of demand, the firm's production location (i.e., home or offshore), as well as market structure (i.e., the number on rivals in each location).

3.1 Modeling Demand

A buyer h purchasing an HDD of category j in year t enjoys utility,[3]

$$u_{hjt} = \alpha_{0,t} + \alpha_1 p_{jt} + \alpha_2 g_j + \alpha_3 x_j + \xi_{jt} + \epsilon_{hjt}, \tag{1}$$

where p_{jt} is the price, g_j is the physical size (generation), x_j is the information storage capacity (quality), ξ_{jt} is the unobserved characteristics (most importantly, design popularity among buyers, as well as other unobserved attributes such as reliability), and ϵ_{hjt} is the idiosyncratic taste shock (i.i.d. type-1 extreme value). A "category" is defined by a generation-quality combination, and hence g_j and x_j do not vary over time for a given category j. The outside goods offer the normalized utility $u_{h0t} \equiv 0$, which represent *removable* HDDs (as opposed to *fixed* HDDs) and other storage devices.[4]

Let $\bar{u}_{jt} \equiv \alpha_{0,t} + \alpha_1 p_{jt} + \alpha_2 g_j + \alpha_3 x_j + \xi_{jt}$ represent the mean utility from a category-j HDD whose market share is

$$ms_{jt} = \frac{\exp\left(\bar{u}_{jt}\right)}{\sum_k \exp\left(\bar{u}_{kt}\right)}. \tag{2}$$

The shipment quantity of category-j HDDs is

$$Q_{jt} = ms_{jt} M_t,$$

where ms_{jt} represents the market share of HDDs of category j, and M_t is the size of the HDD market including the outside goods (removable HDDs and other storage devices). Practically, M_t reflects all computers to be manufactured globally in a given year.

Berry's (1994) inversion provides the linear relationship,

$$\ln\left(\frac{ms_{jt}}{ms_{0t}}\right) = \alpha_1 p_{jt} + \alpha_2 g_j + \alpha_3 x_j + \xi_{jt}, \tag{3}$$

where and ms_{0t} is the market share of outside goods (removable HDDs and other devices). The inverse demand is

$$p_{jt} = \frac{1}{-\alpha_1}\left[-\ln\left(\frac{ms_{jt}}{ms_0 t}\right) + \alpha_2 g_j + \alpha_3 x_j + \xi_{jt}\right]. \tag{4}$$

[3]The demand side is static in the sense that buyers make new purchasing decisions every year. This assumption is not restrictive because multi-year contracting is not common and there are hundreds of buyers (computer makers) during the sample period.

[4]Tape recorders, optical disk drives, and flash memory.

3.2 Modeling Period Competition

In each year, firms are Cournot competitors in the spot market, with each of them producing the composite HDD goods that represents the prevailing product portfolio in each year,[5] but at different costs depending on the location of production, $l \in \{\text{home, offshore}\}$. This is a necessary simplification to keep our analytical focus on the cost heterogeneity by location, mc_{lt}. Henceforth, I follow the notational convention in international economics to denote "foreign" variables by superscript (*), so, for example, mc_t and mc_t^* represent the year-t marginal costs in home and offshore locations, respectively.

Given the inverse demand $P(Q)$ and the marginal cost of production in location $l \in \{\text{home, offshore}\}$, firm i in location l in year t maximizes its period profit

$$\pi_{ilt} = (P_t - mc_{lt})\, q_{it}$$

with respect to shipping quantity q_{it}. Firm i's first-order condition is

$$P_t + \frac{\partial P}{\partial Q} q_{it} = mc_{lt}. \tag{5}$$

I assume constant returns to scale and common marginal cost across firms producing in each location. This formulation does not necessarily rule out all firm-heterogeneity within each location, but instead assumes that firm-level heterogeneity would sufficiently manifest themselves in the form of private cost/profit shocks in each year, as I will show in the next subsection. The key modeling consideration here is to let firms focus on the main heterogeneity of interest (cost advantage of offshore production) as the state variable (and location choice as the strategic control variable) in the dynamic game.

3.3 Modeling Dynamic Game

Time is discrete with infinite horizon $t = 1, 2, ..., \infty$. There are two types of firms ("incumbents" and "entrants") and two individual states ("home" and "offshore") for active firms.

At the beginning of each year, an infinite number of potential entrants consider the prospect of entry, having observed the incumbents' decisions at the end of the previous year.

[5]The assumption of composite goods competition abstracts away from subtle differences in product portfolio across firms, but captures this industry's secular trends toward both physically smaller sizes (e.g., from 14 to 2.5-inch diameter) and higher information storage capacities (e.g., from 30 megabytes to 4 gigabytes). And most firms produced in a wide range of product categories, with emphasis on the several most popular ones at the time. See Igami (2013) for more details of product innovation. By contrast, this paper focuses on heterogeneous costs of production based on location, and how the location decision interacts with entry and exit.

They enter sequentially until the expected value of entry (which is a decreasing function of the number of active firms including the contemporaneous actual entrants) falls short of the cost of entry, κ_t^{ent}. All actual entrants start production in home country.[6]

In any year, each of the incumbents producing in home country (non-offshorers) may take one of the three dynamic actions. First, the firm can start offshore production by paying a sunk cost, κ, thereby becoming "offshorer" from the next year. Second, it can stick to the home location, in which case it continues to be a "non-offshorer" in the next year. Third, it may exit the industry once and for all, in which case it collects a fraction ϕ of the enterprise value as the sell-off/liquidation value.

The spot-market competition takes place among active firms in the current year, *after* potential entrants finish entry and incumbents decide either to offshore, stay, or exit, but *before* these actions of incumbents are realized. Thus, all actual entrants of the year and continuing firms from the previous year constitute the set of active firms in the spot market, who earn the equilibrium period profits. Finally, the incumbents' dynamic decisions are realized and their individual states evolve accordingly.

To be more precise, each year proceeds according to the following timeline:

1. Potential entrants observe the set of continuing firms from the previous year and sequentially decide whether to enter the market. Those who decide to enter become active in the home country.

2. Each active firm observes its private cost shocks associated with exiting (ε_{it}^0), staying (ε_{it}^1), and offshoring (ε_{it}^2, if the firm is currently producing in home country) and simultaneously decides on one of these dynamic actions to maximize its expected present value. Their decisions incorporate the expected discounted values associated with each of these actions, where rational expectations are taken over all of the rivals' possible actions.

3. Active firms compete in the spot market and earn profits $\pi^l(N_t, N_t^*, W_t)$, where W_t represents the characteristics of demand and production costs, the evolution of which is common knowledge and exogenous to firms' actions.

4. Dynamic decisions are implemented and the states evolve. Specifically, exiting firms exit and receive a fraction ϕ of firm values plus ε_{it}^0 as their sell-off values. Staying firms

[6] In theory, firms may incorporate in foreign location from the beginning of their institutional life, but there are no such cases in the data, except for one fringe firm (founded by American nationals in Singapore) toward the end of the sample period. Industry sources suggest the reason is the exceptional appeal of Silicon Valley in terms of both human capital and venture funding.

receive profit shocks ε_{it}^{1} representing their (stochastic) cost heterogeneity. Offshoring firms pay $\kappa - \varepsilon_{it}^{2}$ and move their plant locations overseas.

Hence the Bellman equations for active firms in home and offshore locations are[7]

$$V_t(s_t) = \pi_t(s_t) + \max\left\{\begin{array}{c} \phi\beta E\left[V_{t+1}(s_{t+1})|s_t\right] + \varepsilon_{it}^{0}, \\ \beta E\left[V_{t+1}(s_{t+1})|s_t\right] + \varepsilon_{it}^{1}, \\ \beta E\left[V_{t+1}^{*}(s_{t+1})|s_t\right] - \kappa + \varepsilon_{it}^{2} \end{array}\right\}, \text{ and} \tag{6}$$

$$V_t^{*}(s_t) = \pi_t^{*}(s_t) + \max\left\{\begin{array}{c} \phi\beta E\left[V_{t+1}^{*}(s_{t+1})|s_t\right] + \varepsilon_{it}^{0}, \\ \beta E\left[V_{t+1}^{*}(s_{t+1})|s_t\right] + \varepsilon_{it}^{1} \end{array}\right\},$$

respectively, subject to the rationally perceived law of motion governing the industry state, s_t. $\pi_t(s_t)$ and $\pi_t^{*}(s_t)$ are the equilibrium period profits of a non-offshorer and an offshorer, respectively, given industry state (market structure) s_t. Likewise, V_t and V_t^{*} are non-offshorer's and offshorer's value functions.

For a potential entrant, the problem is simply a binary choice to enter or not,

$$\max\left\{V_t(s_t) - \kappa_t^{ent}, 0\right\}.$$

Free entry implies

$$V_t(s_t) \leqslant \kappa_t^{ent}. \tag{7}$$

I follow Rust (1987) to assume i.i.d. type-1 extreme value distribution for the firm's private cost shocks, $\varepsilon_{it} = (\varepsilon_{it}^{0}, \varepsilon_{it}^{1}, \varepsilon_{it}^{2})$. These logit errors and their (conditional) independence over time lead to a closed-form expression for the expected value at the beginning of year t (that is, before the firm observes ε_{it}). The ex-ante value of a non-offshorer is

$$E_{\varepsilon_{it}}\left[V_t(s_t, \varepsilon_{it})|s_t\right] = \pi_t(s_t) + \gamma + \ln\left\{\begin{array}{c} \exp\left(\phi\beta E\left[V_{t+1}(s_{t+1})|s_t\right]\right) \\ + \exp\left(\beta E\left[V_{t+1}(s_{t+1})|s_t\right]\right) \\ + \exp\left(\beta E\left[V_{t+1}^{*}(s_{t+1})|s_t\right] - \kappa\right) \end{array}\right\},$$

whereas that of an offshorer is

$$E_{\varepsilon_{it}}\left[V_t^{*}(s_t, \varepsilon_{it})|s_t\right] = \pi_t^{*}(s_t) + \gamma + \ln\left\{\begin{array}{c} \exp\left(\phi\beta E\left[V_{t+1}^{*}(s_{t+1})|s_t\right]\right) \\ + \exp\left(\beta E\left[V_{t+1}^{*}(s_{t+1})|s_t\right]\right) \end{array}\right\},$$

where γ is the Euler constant.

[7] For notational simplicity, I suppress ε_{it}^{0}, ε_{it}^{1}, and ε_{it}^{2} from $V_t^{\cdot}(s_t)$, where they should also be included as payoff-relevant individual state variables.

Given these characteristics of the dynamic programming problems, a non-offshorer's ex-ante choice probabilities (of exiting, staying in home country, and offshoring) are

$$\begin{aligned} pr\left(d_{it}=exit\right) &= \frac{\exp\left(\phi\beta E_{\varepsilon}V_{t+1}\left(s_{t+1}\right)\right)}{A}, \\ pr\left(d_{it}=stay\right) &= \frac{\exp\left(\beta E_{\varepsilon}V_{t+1}\left(s_{t+1}\right)\right)}{A}, \text{ and} \\ pr\left(d_{it}=offshore\right) &= \frac{\exp\left(\beta E_{\varepsilon}V^{*}_{t+1}\left(s_{t+1}\right)-\kappa\right)}{A}, \end{aligned}$$

where d_{it} denotes the firm's discrete choice, and

$$A\equiv\exp\left(\phi\beta E_{\varepsilon}V_{t+1}\left(s_{t+1}\right)\right)+\exp\left(\beta E_{\varepsilon}V_{t+1}\left(s_{t+1}\right)\right)+\exp\left(\beta E_{\varepsilon}V^{*}_{t+1}\left(s_{t+1}\right)-\kappa\right).$$

Similarly, an offshorer's optimal strategies (prior to observing ε_{it}) are

$$\begin{aligned} pr\left(d^{*}_{it}=exit\right) &= \frac{\exp\left(\phi\beta E_{\varepsilon}V^{*}_{t+1}\left(s_{t+1}\right)\right)}{B}, \text{ and} \\ pr\left(d^{*}_{it}=stay\right) &= \frac{\exp\left(\beta E_{\varepsilon}V^{*}_{t+1}\left(s_{t+1}\right)\right)}{B}, \end{aligned}$$

where

$$B\equiv\exp\left(\phi\beta E_{\varepsilon}V^{*}_{t+1}\left(s_{t+1}\right)\right)+\exp\left(\beta E_{\varepsilon}V^{*}_{t+1}\left(s_{t+1}\right)\right).$$

Expectations, E_{ε}, are over the rival firms' private cost shocks. That is, each firm forms rational expectations over all of the rivals' actions, and hence over the possible evolution of market structure (i.e., industry state s_{t+1}). Thus, for each industry state in each year (s_t), we are solving for a Bayesian Nash Equilibrium (BNE) of this one-shot entry/exit/offshoring game among offshorers and non-offshorers, which is similar to Seim's (2006) static entry model with private information.[8]

I characterize the environment as non-stationary to reflect what I observe to be the nature of offshoring in this high-tech manufacturing industry, and solve the dynamic game of 23 years (i.e., the sample period is 1976–98) for a Perfect Bayesian Equilibrium (PBE). Practically,

[8] Given this rather simple model, there is a unique BNE for each state-year under certain market structure. However, the uniqueness of equilibrium is not guaranteed under all payoff configurations, hence I further restrict my attention to a Ljapunov-stable BNE (i.e., one that I can numerically find by best-response iterations). Furthermore, to guarantee uniqueness for all state-years, I also solve and estimate an alternative model with a Stackelberg structure in phase 2 of the timeline, in which either offshorers or non-offshorers decide on dynamic actions as first-movers (in a collective, probabilistic sense), and then the other firms observe the first-movers choice probabilities and make their own decisions. The results suggest my estimation results are not very sensitive to these alternative assumptions (i.e., simultaneous or sequential moves).

this means I first calculate the continuation values of offshorers and non-offshorers as of 1998, the final year of my sample period, by projecting the discounted period profits in each state into infinite future, and then adding them to construct the present values associated with that state in 1998. Having determined the values in 1998, we may now solve the game in 1997 to find the equilibrium values and strategies in 1997. Continuing iteratively, we can solve the entire 23-year dynamic game, in the manner similar to solving an extensive-form game with complete information for a Subgame Perfect Equilibrium. This procedure is possible because the private cost shocks are i.i.d., and hence their past realizations at rival firms do not affect a firm's payoffs, which is a common feature of standard dynamic oligopoly models of the Ericson-Pakes (1995) class.

4 Estimation

This section explains my estimation approach, and present the estimation results for demand, as well as the costs of production, offshoring, entry, and exit. The equilibrium period profits, values, and strategies are also estimated along the way. I will discuss the economics of my main findings in the next section.

My overall estimation approach proceeds in the following three steps. First, I estimate the demand for HDDs, using a standard (static) discrete-choice model for differentiated products, and allowing for changes over time in the constant term and the unobserved product qualities. Second, I estimate the marginal costs of production for each year, using the firms' first-order conditions under the maintained hypothesis of Cournot period competition, allowing for cost-heterogeneity between home and offshore locations. These two steps proceed "off-line" (i.e., prior to the estimation of the dynamic game), and provide us with the estimates for the equilibrium period profits for both home and offshore producers (π_t, π_t^*) given any market structure (N_t, N_t^*).

Third, I use these estimated period profits to calculate the home and offshore firms' discounted present values, to solve the dynamic offshoring for a Perfect Bayesian Equilibrium[9] and to estimate the dynamic parameters (i.e., the costs of offshoring, entry, and exit). This last step employs the nested fixed-point (NFXP) algorithm as in Rust (1987).

[9] The solution concept is trivially Perfect Bayesian because private cost shocks are i.i.d. across firms and over time. Hence the solution proceeds exactly like a backward induction for a Subgame Perfect Equilibrium, in which, for each industry state in each year, I solve one-shot entry/exit/offshoring game with private information (as in Seim 2006) for a Bayesian Nash Equilibrium.

4.1 Estimating Demand

The goal of demand analysis is to estimate the relationship between the quantities and prices of HDDs, which, together with the costs of production (subsection 4.2), will determine how many firms can profitably operate in this market.

I use the estimates from Igami (2013), which employs the logit model of demand for differentiated goods with various IVs for prices. The instrumentation strategy relies on the evolutions of product portfolios (à la Bresnahan and BLP) and unobserved product qualities (as in Sweeting), as well as some geographical variation in data (à la Hausman and Nevo), all of which are outside my model (section 3) to form exclusion restrictions.

Table 2: Logit Demand Estimates for 5.25- and 3.5-inch HDDs

Market definition:	Broad		Narrow	
Estimation method:	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
Price ($000)	-1.66^{***}	-2.99^{***}	$-.93^{**}$	-3.28^{***}
	(.36)	(.64)	(.38)	(.58)
Diameter = 3.5-inch	$.84^{**}$	.75	1.75^{***}	$.91^{**}$
	(.39)	(.50)	(.27)	(.36)
Log Capacity (MB)	.18	$.87^{***}$	.04	1.20^{***}
	(.25)	(.31)	(.22)	(.27)
Year dummies	*Yes*	*Yes*	*Yes*	*Yes*
Region/user dummies	–	–	*Yes*	*Yes*
Adjusted R^2	.43	.29	.50	.27
Number of obs.	176	176	405	405
Partial R^2 for Price	–	.32	–	.16
P-value	–	.00	–	.00

Note: Standard errors in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

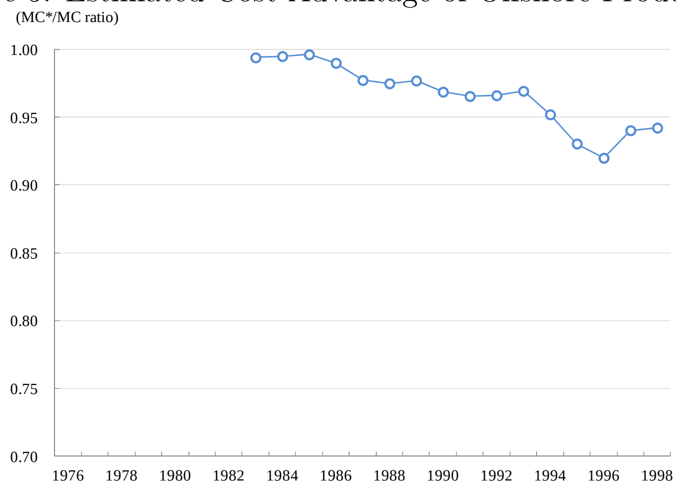
These estimates are based only on the data about 5.25- and 3.5-inch HDDs. Nevertheless, I expect the results are representative enough, because these two sizes accounted for the lion's share of the entire HDD market. In the future version of this paper, I plan to estimate a slightly extended demand system (i.e., also including 14-, 8-, 2.5-, and 1.8-inch HDDs) to better suit the product lineups in the sample period of this paper, which is several years longer than that of Igami (2013).

4.2 Estimating Production Costs and Period Profits

The goal of cost estimation is to recover the implied heterogeneous marginal costs of production for firms producing in home and offshore locations, (mc_t, mc_t^*), and hence the cost advantage of offshoring. I use the firms' first-order conditions and the demand estimates from the previous subsection to obtain the marginal cost estimates.

Figure 5 shows the cost advantage of offshore production gradually increased over time, because the marginal cost of production in offshore locations decreased relative to that in home location. Although the specific components of these costs are beyond the scope of this paper, I suspect the primary cause of this development is the secular improvements in the communications and transport technologies during the 1980s and 1990s.

Figure 5: Estimated Cost Advantage of Offshore Production



Note: .

Another observation is about the overall magnitude of cost-advantage, which is not as drastic as the labor-cost difference between Singapore and California (i.e., in the order of three to four times during the 1980s, according to Donner et al). The other cost factors may offer possible explanations, such as physical capital, primary and intermediate inputs, and the additional communications and transport costs in offshore locations. The costs of the first two factors are likely to be more equalized across the border than labor, due to a higher mobility of capital and other inputs than that of labor. And offshore production may entail additional costs of communication and transports on top of the regular costs of manufacturing. Hence, to the extent that these other factors matter to the overall marginal costs, the benefits of offshore production would look less pronounced than the wage gap between countries.

These marginal cost estimates and the demand estimates from the previous subsection allow us to impute the equilibrium period profits of both home and offshore producers (π_t, π_t^*), under any market structure (N_t, N_t^*). Let us take an example of firms producing in year 1990, as shown in Figure 6 (left panel). As the number of offshore rivals grows, both offshorers' and non-offshorers' profits decline precipitously, but the latter group suffers disproportionately. Non-offshorers' profits approach zero when they compete against more than 5 offshorers. By contrast, offshorers can better withstand such competitive pressure from fellow offshorers, thanks to their own low-cost operation abroad.

The main identification assumption is the mode of period competition: Cournot with heterogeneous costs, which I believe is a reasonable approximation to the actual market characteristics. That is, dozens of firms manufacture high-tech commodity goods and seem to earn some profits, albeit with razor-thin price-cost margins, and the production capacities cannot be adjusted flexibly within a short period of time. This identification assumption also keeps the empirical task tractable under the data constraint that firm- or brand-level prices and quantities are not published due to confidentiality reasons.[10]

4.3 Estimating the Sunk Cost of Offshoring

Having estimated demand, production costs, and hence the equilibrium period profits for each state-year, we may now proceed to estimate the sunk costs of offshoring (κ), as well as the thresholds for entry (κ_t^{ent}) and exit (ϕ). To do so requires solving the dynamic game and finding the parameter values $(\kappa, \kappa_t^{ent}, \phi)$ that best rationalizes the actual patterns of offshoring, entry, and exit in data. Specifically, I employ maximum likelihood estimation, which boils down to rationalizing the observed choice probabilities of these dynamic actions by choosing the pair (κ, ϕ) that maximizes the likelihood function,

$$L(\kappa, \phi) = \log \left(\prod_{t=1}^{T-1} P(O_t, X_t, X_t^*) \right),$$

where

$$\begin{aligned} P(O_t, X_t, X_t^*) \quad = \quad & \binom{N_t}{X_t} \binom{N_t - X_t}{O_t} pr\left(d_{it} = exit\right)^{X_t} \\ & \times pr\left(d_{it} = stay\right)^{N_t - X_t - O_t} pr\left(d_{it} = offshore\right)^{O_t} \\ & \times \binom{N_t^*}{X_t^*} pr\left(d_{it}^* = exit\right)^{X_t^*} pr\left(d_{it}^* = stay\right)^{N_t^* - X_t^*}. \end{aligned}$$

Only κ and ϕ explicitly enter the likelihood function as arguments, because the sequence of entry costs $\{\kappa_t^{ent}\}_t$ can be inferred from the free entry condition in equation (7), inside the inner loop of the NFXP algorithm.

The estimates in Table 3 suggest firms have to incur a sizeable sunk cost of about \$3 billion to start offshore production, equivalent to almost a half of their average enterprise

[10]Thus, although firm- or brand-heterogeneities can be easily added to the model as a matter of theoretical exercise, such extra features will not be identified from the data.

value (approximately \$6 billion in the middle of the sample period). The estimated costs of entry are near this \$6 billion mark because my model allows free entry in all years, and hence the entry costs should be high enough to explain the fact that only a limited number of firms actually entered in each year. The estimated fraction of sell-off value seems reasonable at 48%, which means firms can recover about a half of their enterprise values upon exit. Qualitative evidence indicates such sell-off values materialize in the form of asset sales either before or after bankruptcy (via private negotiations or auctions held by courts), or through mergers and acquisitions.

Table 3: Estimated Offshoring Cost, Entry Cost, and Sell-off Value

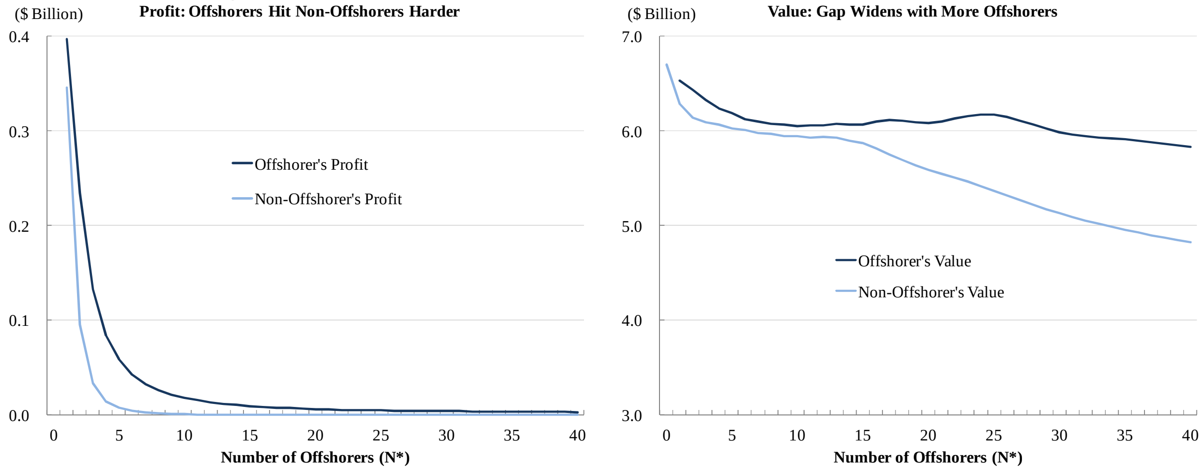
Parameter	Unit	Maximum Likelihood Estimate
Sunk Cost of Offshoring (κ)	Billion \$	3.20
Sunk Cost of Entry $\left(\kappa^{ent}\right)$	Billion \$	5.47*
Sell-off Value (ϕ)	Fraction of Firm Value	.48

Note: * annual average over the sample period. Standard errors are not available because of a step function-like shape of likelihood, which is typical of dynamic discrete games and leads to either zero or very large standard errors.

The ultimate purpose of estimating this dynamic game is to understand the relationships between offshoring and market structure, which I will analyze in the next section by examining the estimated optimal offshoring strategies and counterfactual simulations. Nevertheless, the estimated values functions (by-products of estimating the dynamic parameters) are already foreshadowing the final outcomes. Figure 6 (right panel) shows the value of a non-offshorer (i.e., the value of staying in the industry as a non-offshore producer) is decreasing in N_t^*, the number of offshore rivals, which implies these firms become more inclined to exit in the growing presence of offshorers. Moreover, the figure also shows the difference between the values of offshorers and non-offshorers (i.e., $V_t^* - V_t$) increases with N_t^*, which implies the incentive to offshore increases when more rivals are producing offshore. The mechanism behind this pattern is the business-stealing effect (i.e., negative externality) that offshorers inflict on non-offshorers, and, more precisely, the fact that the presence of an additional offshore rival hurts non-offshorers disproportionately more than the other offshorers. We can trace back the origin of this mechanism to Figure 6 (left panel: how π_t and π_t^* vary with N_t^*), because V and V_t^* are dynamic counterparts to π_t and π_t^*.

Before proceeding to the analysis of the relationships between market structure and the incentives to offshore, three technical notes are in order. First, I use maximum likelihood estimation with an NFXP algorithm because one can use the same model for both estimation and counterfactual simulations, and because my model is simple enough for the repetitive

Figure 6: Effects of Market Structure on Profits and Values



Note: .

computation of solution for each set of candidate parameter values.[11]

Second, game-theoretic models often entail multiple equilibria, which would complicate identification. Fortunately, my model is simple enough and its strategic essence boils down to the class of static entry games with private information as in Seim (2006), in which she found uniqueness under certain market structures.[12]

Third, even in the absence of multiple equilibria, game-theoretic models tend to result in non-smooth likelihood functions, because an equilibrium strategy profile under certain parameter values may look quite different from that under slightly different parameter values. A non-smooth likelihood renders its maximization difficult and lead to unreliable standard errors (either too small or large). Regarding the former issue, I attempted multiple starting points for numerical optimization in order to avoid local maxima. Indeed, the solver often stopped at different solutions (candidate parameter values), but all of these solutions are extremely close to each other. Thus, I believe the potential localness of the solution would not affect my estimates in an economically significant manner.[13]

[11] An alternative estimation approach would be a two-step estimator, which reduces the computational burden but requires more data than available for a global high-tech industry such as HDD manufacturing. An alternative computational approach would be mathematical programming with equilibrium constraints (MPEC), which also reduces the computational burden. However, the non-stationary nature of my model renders the task less amenable to this reformulation, because the number of argument variables and equilibrium constraints will be multiplied by the number of periods, which would make the optimization problem too large even for contemporary memories.

[12] Conceptually, however, there still remain possibilities of multiple equilibria for some state-years. To investigate the severity of this issue, I conducted sensitivity analysis (see Appendix, in the future version of the paper) by estimating alternative models in which either offshorer or non-offshorers make dynamic decisions first, so that this sequential-move assumption rules out multiple equilibria. The results looked qualitatively similar.

[13] Regarding the latter issue, I know of no practical approaches in constructing more reasonable standard

For more sensitivity analysis, see Appendix (currently under construction), in which I present estimation results from various other specifications.

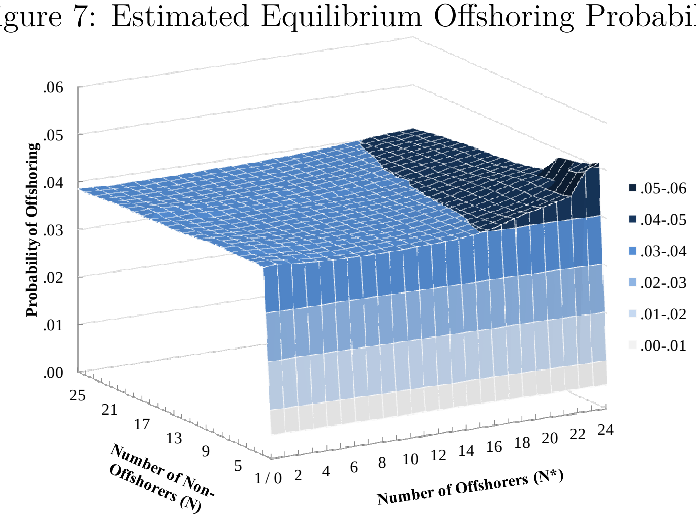
5 Empirical Findings

This section reports and discusses empirical findings on: (1) how market structure affects the incentives to offshore, (2) how, in turn, the possibility of offshoring affects the industry dynamics of entry and exit, and (3) how both market structure and the incentives to offshore evolve over the industry lifecycle.

5.1 Effect of Market Structure on Incentives to Offshore

Figure 7 shows the incentives to offshore (measured by the estimated equilibrium choice probability of offshoring) increases with the number of offshorers (N_t^*), initially increases and then decreases with the number of non-offshorers (N_t), and therefore mostly increases with the ratio of offshorers to non-offshorers (N_t^*/N_t) for a given total number of firms (i.e., with $N_t^* + N_t$ fixed at some $\bar{N}$). The three-dimensional graph contains all of these findings, but let us examine each of them at a time with simpler graphs and tables in the following.

Figure 7: Estimated Equilibrium Offshoring Probability



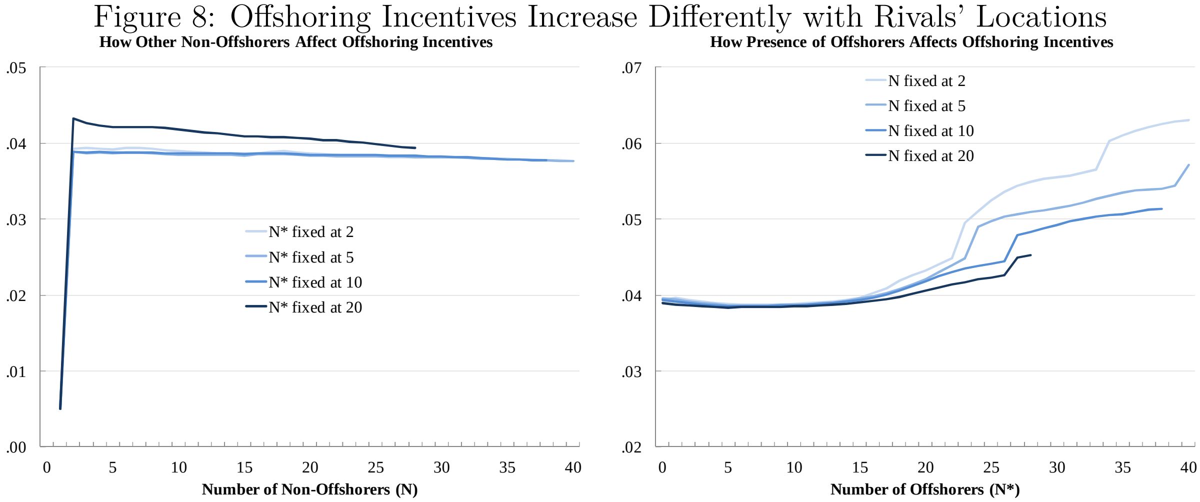
Note: .

First, the firm's incentive to offshore initially increases but then decreases as the number of non-offshore rivals increases. Specifically, as Figure 8 (left panel) shows, when the firm is

errors. In recognition of this limitation, this paper focuses on analyzing the economic relationships between the incentives to offshore and market structure, rather than trying to make direct statistical inferences on the dynamic parameter estimates per se.

the only non-offshorer (i.e., $N_t = 1$), it hardly wants to start offshore production because, in the absence of non-offshore rivals, there is no race to start low-cost production overseas (i.e., no strategic timing decision). Under such circumstances, Arrow's (1962) "replacement effect" (Tirole 1988) dominates. In other words, the firm can afford to wait until the benefits of offshoring becomes large enough, without fear of more rivals preemptively offshoring and stealing its own businesses. However, the strategic landscape changes drastically once there are two (non-offshore) firms (i.e., $N_t = 2$), raising the incentives to offshore to the highest level due to competitive pressure. The firm cannot procrastinate any longer because, if the rival firm starts offshore production first, that will harm the non-offshorer's profitability in the immediate future. And this fear is mutual, thereby creating a race between the duopolists. In this strategic situation, Gilbert and Newbery's (1982) "efficiency effect" (Tirole 1988) dominates. With more than two (non-offshore) firms (i.e., $N_t > 2$), the offshoring incentive gradually decreases with N_t, because the expected profits from offshoring becomes competed away among numerous (potential) offshorers. Nevertheless, it is north noting that the optimal offshoring probabilities for all $N_t > 2$ remain substantially higher than for $N_t = 1$. This observation suggests broadly pro-innovation (pro-offshoring) effects of competition.

Figure 8: Offshoring Incentives Increase Differently with Rivals' Locations



Note: .

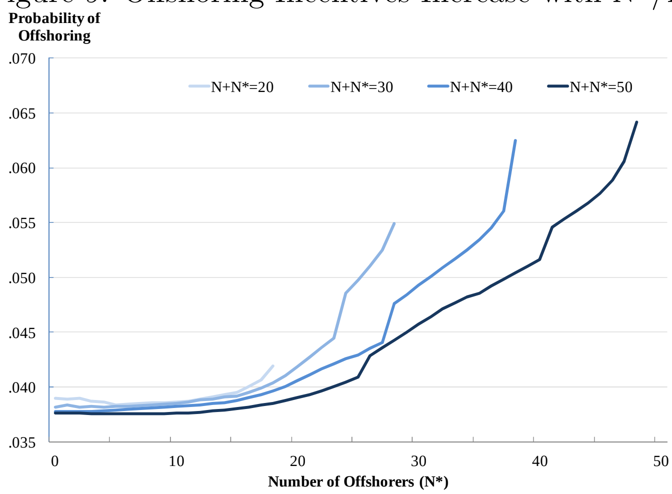
My second finding from the estimated equilibrium offshoring strategy is that the incentives to offshore increases with the number of offshore rivals (i.e., firms who have already started offshore production). As Figure 8 (right panel) shows, the optimal offshoring probability monotonically increases in N_t^*.[14]

[14]Except for some very high N_t^* (e.g., $N_t^* \approx 50$), which is a likely artifact of my computational limit. That is, my computational implementation accommodates at most 59 firms in total (i.e., $N_t^* + N_t \leqslant 59\ \forall t$), and hence may generate some non-monotonic behaviors that are extraneous to my analytical model.

This outcome reflects the strong business-stealing effect of offshore rivals on non-offshore firms, which pressures the latter into choosing between "fly or die" (i.e., to offshore or exit), because the increasing presence of low-cost producers (offshorers) harms disproportionately the profitability of high-cost firms (non-offshorers).

These findings lead to my third finding on the offshoring incentives. The effects on the incentives to offshore/innovate of increased competition (i.e., a higher number of firms) work in the opposite directions depending on the offshoring/innovation status of rivals. The effect of competition among *non-offshorers* is negative (for $N_t > 2$), whereas that of competition from *offshorers* is positive, and hence the effect of N_t^*/N_t is mostly positive for any fixed total number of firms (20, 30, 40, and 50, in the examples shown in Figure 9). Therefore, to study the effect of competition on offshoring (a process innovation), the relevant measure of competition is not exactly the total number of firms in the market ($N_t^* + N_t$); a more informative measure is the ratio of those who have already offshored (innovated) and those who have not (N_t^*/N_t).

Figure 9: Offshoring Incentives Increase with N*/N



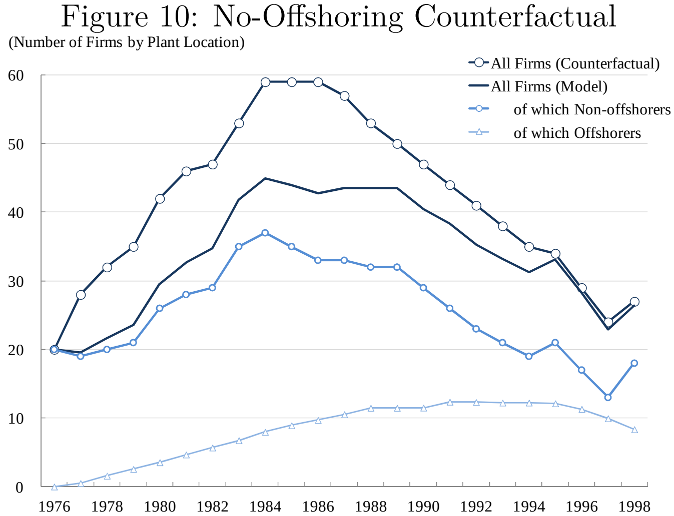
Note: .

5.2 Effect of Offshoring on Industry Dynamics

Whereas the previous sub-section examined the effect of market structure on offshoring, this sub-section investigates the reverse causal link: the effect of offshoring on the evolution of market structure and competition. Because firms' offshoring decisions are themselves endogenous to the dynamics of entry/exit and hence market structure, we cannot simply regress the number or propensity of entry/exit on the number of offshorers or some other measures related to offshoring. Instead, we would simulate a counterfactual experiment in which the cost of offshoring is prohibitively high, to the extent that practically no firms can afford the choice of offshoring at any time. I then compare and contrast the evolutions of market structures in the counterfactual, “no offshoring” world with the real world in which offshoring is feasible.

Figure 10 carries three messages. First, the comparison of the (actual and counterfactual) numbers of non-offshorers (i.e., N_t and $\tilde{N}_t$) reveals the availability of offshore location decreases the maximum number of firms producing at home by as much as 37.2% (in year 1984), through the following two channels. The first channel is by discouraging new entry. Because the market is more competitive with the presence of low-cost incumbents (i.e., offshore producers), potential entrants find this industry less attractive to enter, which is why the peak level of N_t (37 in 1984) is much lower than $\tilde{N}_t$ (59 in 1984–86). The second channel is by pressuring non-offshorers to either fly or die, both of which would decrease N_t. In this sense, the availability of offshore location accelerates the start and progress of “shake-out,” which is a large decrease in the number of firms that is characteristic of an industry before maturing.

Figure 10: No-Offshoring Counterfactual



Note: .

The second message of Figure 10 comes from comparing the actual and counterfactual numbers of all firms (i.e., $N_t + N_t^*$ and $\tilde{N}_t$) which suggests the prospect of offshoring dampens the total number of firms as well, that is, not only the number of non-offshorers. Here again, the presence of low-cost producers (offshorers) discourages new entry, but the number of total firms hovers around its peak level (between 42 and 45) for as long as seven years instead of three in the no-offshoring counterfactual. During these seven years, a few firms continue to enter every year, some of which subsequently decide to offshore while other exit, keeping the total number of firms in balance. Eventually, the increased presence of offshorers (over a dozen of them by 1991) starts to exert enough competitive pressure to discourage further entry and drive the remaining non-offshorers out of the market.

The third and final message from the no-offshoring simulation is the pro-competitive effect of offshoring. Despite our earlier observations that the possibility of offshoring creates a more concentrated market (i.e., fewer numbers of firms) and a higher markup (for offshorers, at least), the market is more "competitive" in the dynamic sense that firms are racing to offshore and lower the production costs, which in turn reinforces the pressure on the remaining non-offshorers to either offshore or exit. The "pro-competitive" effect of offshoring in this sense becomes more evident toward the end of the sample period, in which the total numbers of firms converge to approximately 30, in both the actual and counterfactual trajectories. Although the total numbers are similar from around year 1995, nearly a half of all firms are low-cost offshore producers in the actual path, whereas all of the counterfactual firms stays home as high-cost producers by construction. Because of this cost advantage, the economy with offshoring performs better than the counterfactual economy without offshoring in terms of the aggregate output, price, and social welfare, as summarized in Table 5-2-1.

(Table 5-2-1: Welfare Impact of Offshoring)
[Under construction]
(Note: "Circa 1995" snapshot, & over the entire history.)

5.3 Evolution of Market Structure and Incentives to Offshore over Industry Lifecycle

The preceding analyses of the intricate relationships between market structure and offshoring have prepared us to understand the mechanisms that drive their simultaneous evolution over the course of industry lifecycle, as displayed in Figure 10. Initially, the incentives to offshore start at a relatively low level, because the demand for hard disks is still small, and so too is the benefits from low-cost production.

However, toward the middle of the 1980s, some firms start to offshore as the demand keeps growing, and the presence of these low-cost rivals (i.e., an increase in N_t^*/N_t), in turn, reinforces the incentives to offshore for the remaining firms at home, whose profits are squeezed due to the offshorers' business-stealing effects and the downward pressure they exert on the output price. At this point, let us recall from subsection 5.1 that the equilibrium offshoring probability is increasing in N_t^*/N_t. By the middle of the 1990s, the remaining non-offshorers have been increasingly forced to choose between offshoring and exiting, which further raises N_t^*/N_t.

Thus, we can summarize the industry lifecycle with a radical process innovation such as offshoring as in Table 4, which exhibits changes over time of the incentives to offshore and exit, as well as the numbers of home and offshore firms. These patterns imply the impact of public policy (either pro- or anti-offshoring) will depend on the timing of government intervention. The next section will investigate their effectiveness and welfare consequences, in the future version of the paper.

Table 4: Evolution of Market Structure and Offshoring/Innovation Incentives

Phase	$Pr(offshore)$	$Pr(exit)$	$Entry$	N	N^*	$N+N^*$	N^*/N
I. Early	Low	Low	Many	↑	↑	↑	⟶
II. Middle	Medium	Medium	Few	↓	↑	⟶	↑
III. Later	High	High	None	↓	⟶	↓	↑

Note: Based on estimates and descriptive statistics.

6 Welfare Analysis of Policy Interventions

In the future version of the paper, I plan to: (1) discuss the "no offshoring" counterfactual in subsection 5.2 from the viewpoint of anti-offshoring policy in north, (2) simulate anti-offshoring policies at different industry phases, (3) simulate a unilateral ban on offshoring when other northern countries remain pro-offshoring, (4) demonstrate the "positive" impact of pro-offshoring policy in terms of both "keeping jobs at home" (i.e., increasing and maintaining a large N_t) and overall welfare performance, and (5) simulate host countries' "industrial policies" to reduce mc_t^*.

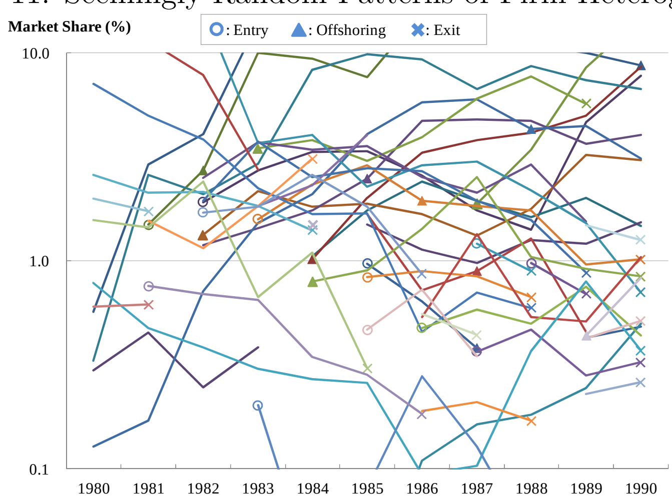
7 Conclusion

Offshoring represents a new method of organizing production at a lower cost, and hence a process innovation of radical nature. Investments in such a new "technology" have ample strategic implications in the product-market competition. Namely, when a new method of organizing production processes arises, it often displaces the existing one: creative destruction. Job destruction is only a part of this broader picture, and hence a deeper understanding of the phenomena requires investigations into the incentives to offshore and its impact on the survival of firms, with analytical focus on product-market competition. This paper aims to present one such concrete example.

Appendix: Within-Location Firm Heterogeneity

The baseline model assumes homogeneity of firms within each location (home and offshore) *up to private cost shocks* that are i.i.d. across firms and over time. One obvious question is to what extent such formulations may capture the actual data patterns of firm heterogeneity. Figure 11 plots the transition of market share, with each line representing a unique firm, during the crucial decade of 1980s. The overall pattern indicates a high variability of market shares across firms, as well as its high volatility over time, both of which are broadly consistent with the way firm heterogeneity manifests itself in the model (i.e., via idiosyncratic shocks to production costs and hence period profits, ε_{it}^{1}). To say there is no persistence in individual market shares would be an overstatement, because some firms seem to stay above 1% and others below 1%, for example. Nevertheless, firms change their ranks so frequently and significantly that it would seem difficult even to think of a reasonable measure of persistent productivity ranking.

Figure 11: Seemingly Random Patterns of Firm Heterogeneity



Note: Log scale.

Another related question is whether more (or less) productive firms self-select into offshoring (or exit). Let us look at Figure 11 again, which marks with triangles the years in which firms decide to offshore. These triangles are scattered everywhere, showing no particular tendencies. That is, some firms fly early whereas others delay; some firms enjoy relatively high market shares before going offshore, but others serve less than 1% of the market when they offshore. By contrast, a growth *after* offshoring appears more salient than *before* it, which is one of the motivating facts of this study in the first place (see Figure 4, right panel). Likewise, exits (marked by crosses) occur all over the place, showing no clear patterns. Some firms exit despite their respectable market shares, whereas others shrink below 1% and subsequently disappear. The latter trajectory becomes more frequent toward the end of the 1980s, with the growing competitive pressure from offshore rivals, which is one of the main data features that my endogenous offshoring/exit model tries to explain. Table 5 further confirms these impressions, by showing the lack of clear relationships between firms' market share and their propensity to either offshore or exit.

Table 5: Do Better Firms Self-Select into Offshoring?

Quartile based on 1976–85 market share	Number of Firms	% offshored by 1991	% exited by 1991 (without offshoring)
1st quartile	11	36.4	36.4
2nd quartile	11	27.3	63.6
3rd quartile	11	36.4	36.4
4th quartile	11	18.2	63.6

Note: .

Thus, these observed relationships (or lack thereof) between market shares and the propensity to offshore or exit seem to agree with the modeling of firm heterogeneity via choice-specific i.i.d. shocks (i.e., ε_{it}^0, ε_{it}^1, and ε_{it}^2).

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