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Market Concentration and Risk-Prevention Incentives: The Case of the Hard Disk Drive Industry

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Abstract*: This paper studies the impacts of market concentration on risk-prevention incentives by closely observing the changes in the price and quantity in the hard disk drive industry before and after the 2011 Thailand floods. The combination of high price and low quantity persisting after the floods indicates that the floods triggered the formation of a de facto cartel, and a shift in demand for hard disk drives alone is unable to explain the observed combination. Our findings have profound implications for Southeast Asia, since some firms may have perverse risk-prevention incentives at the expense of other parties, and consequently, the region's reputation being prone to natural disasters may discourage foreign direct investment.*

Keywords: cartel, Cournot oligopoly, risk prevention, Thailand floods
JEL Classification:D43, L13, L63

1. Introduction

This paper studies the effects of natural disasters on firm behaviour in an oligopolistic market by closely observing the changes in the price and quantity in the hard disk drive (HDD) industry before and after the 2011 Thailand floods. Contrary to the more common view that firms directly damaged by natural disasters are victims, we investigate if they instead gained from disasters by acting collusively.

Asia is the region that is hit by natural disasters most frequently in the world, while its economic growth especially in Southeast Asia is driven by foreign direct investment. Thus, to keep attracting foreign direct investment, it is very important to avoid unfavourable reputation built by frequent natural disasters that cause damage in the supply chain, such as destruction of production facilities or disruption in production.

However, if some firms may benefit from natural disasters by acting collusively, they may have weaker incentives to invest in risk prevention. Because of the interconnectedness of current businesses, such behaviour may cause disruptions to other firms located in the same or other regions in the event of a natural disaster.

This paper first reviews the HDD industry and the 2011 Thailand floods. It then introduces a static Cournot oligopoly model and extends it to a dynamic one by following Radner (1980).[1] The key question is the condition with which a cartel may be sustained, and the key prediction of Radner (1980) is that the difficulty or easiness of sustaining a cartel depends on the number of players when the industry-level demand is a function of the number of players, but is independent of the number of firms when the industry-level demand is also independent of the number of firms.

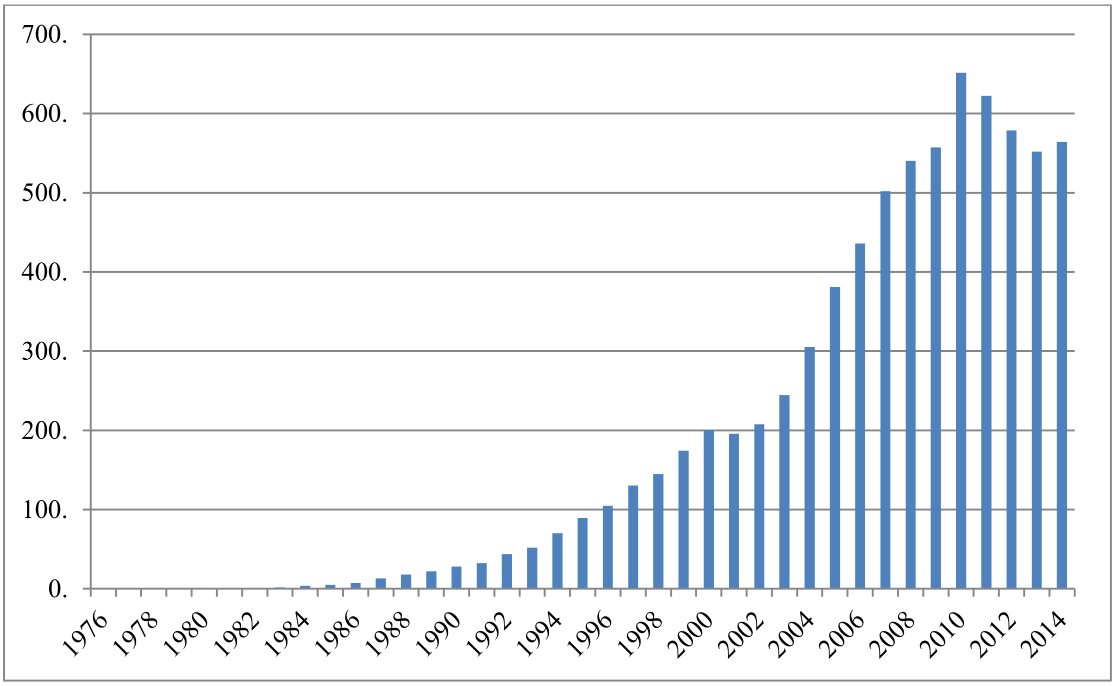
The observations about the price and quantity in the HDD industry before and after the 2011 Thailand floods are consistent with the case in which a cartel was formed after the floods. On the other hand, a shift in demand alone cannot explain the behaviour of price and quantity in the industry, although a shift in demand may have happened simultaneously with the formation of a cartel. Although this paper does not study directly if there was indeed a formation of a cartel in the HDD industry or a shift in demand, it discusses how the issues should be investigated empirically.

[1] Other works on cartels include *Green and Porter* (1984) and, more recently, a review of literature by Levenstein and Suslow (2001).

2. The Hard Disk Drive Industry and the 2011 Thailand Floods

This section reports some basic facts about the HDD industry. Figure 1 illustrates annual global shipments of HDDs from 1976 to 2014. Exception for the dip around 2001—which happened at the time of the collapse of the information technology bubble—HDD shipments kept increasing exponentially until 2010 before the recent decline. Figure 2, on the other hand, reports quarterly global shipments of HDDs from the fourth quarter of 2010 until the fourth quarter of 2014, where we can see a sharp drop in the fourth quarter of 2011, reflecting the disruption of production in Thailand due to the floods.[2] The shipments however recovered quickly, and the level has been stable since then - albeit at a lower level than before the 2011 floods.

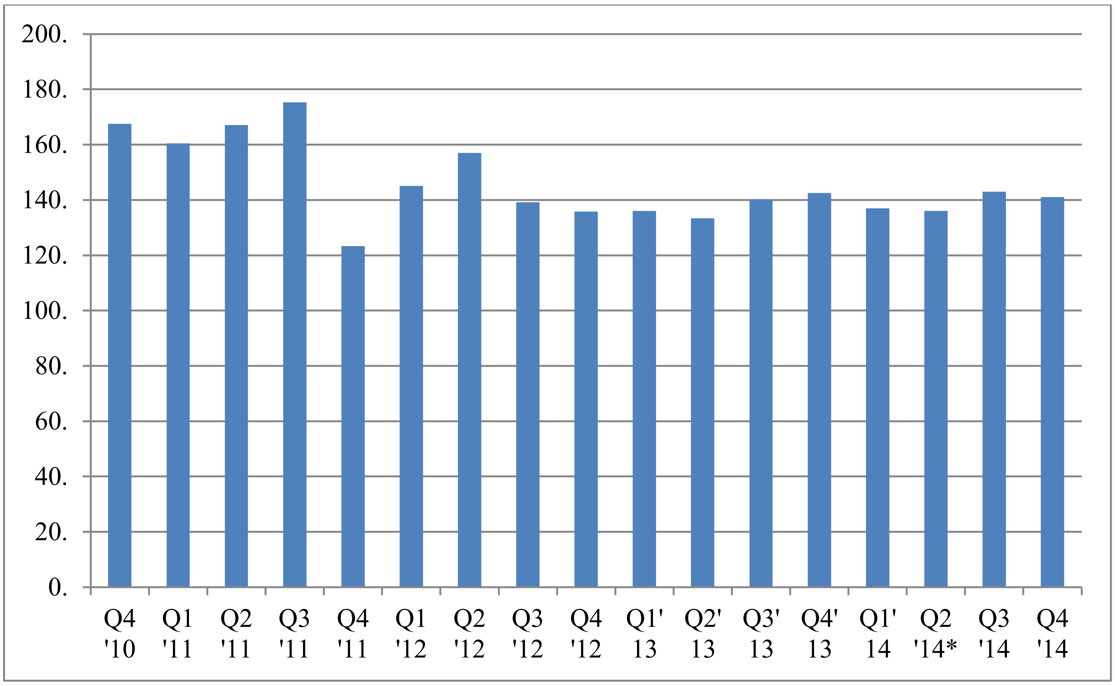
Figure 1: Annual Global Shipments of HDDs (in million)



HDD = hard disk drive.
Source: TrendFocus.

[2] Western Digital's production facility was greatly affected by the floods, halting production. See, for instance, Fuller (2011). Also, for more general discussion about the impacts of the 2011 Thailand floods, see Ministry of Economy, Trade and Industry (2012) and the World Bank (2012).

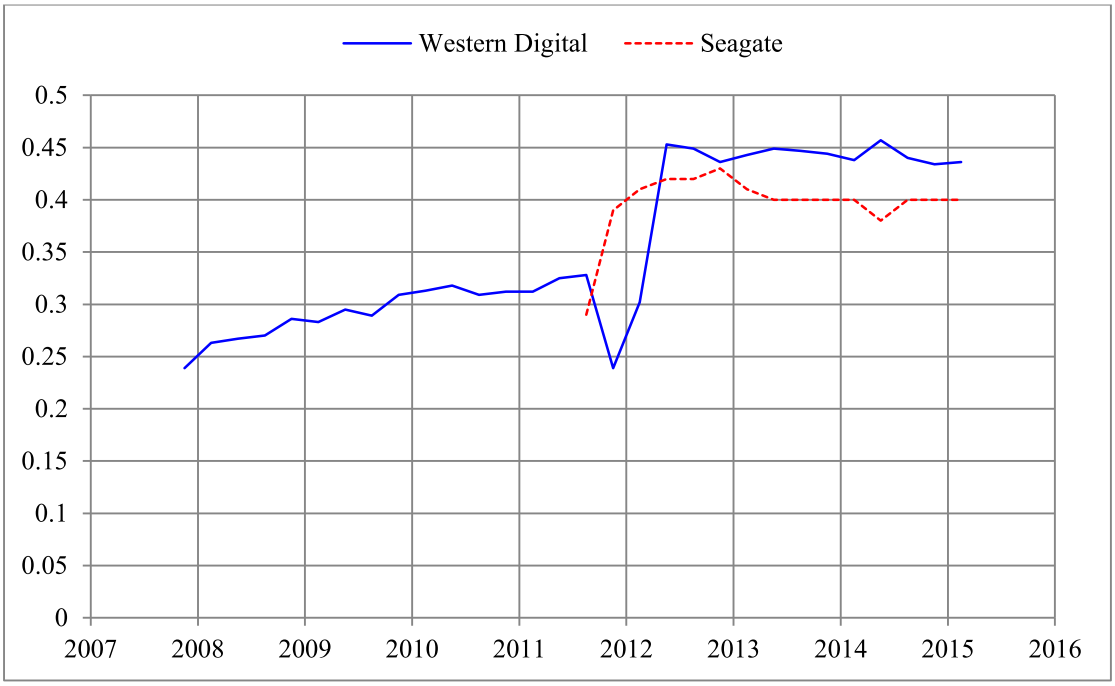
Figure 2: Quarterly Global Shipments of GDDs (in million)



HDD = hard disk drive, Q = quarter.
Source: TrendFocus.

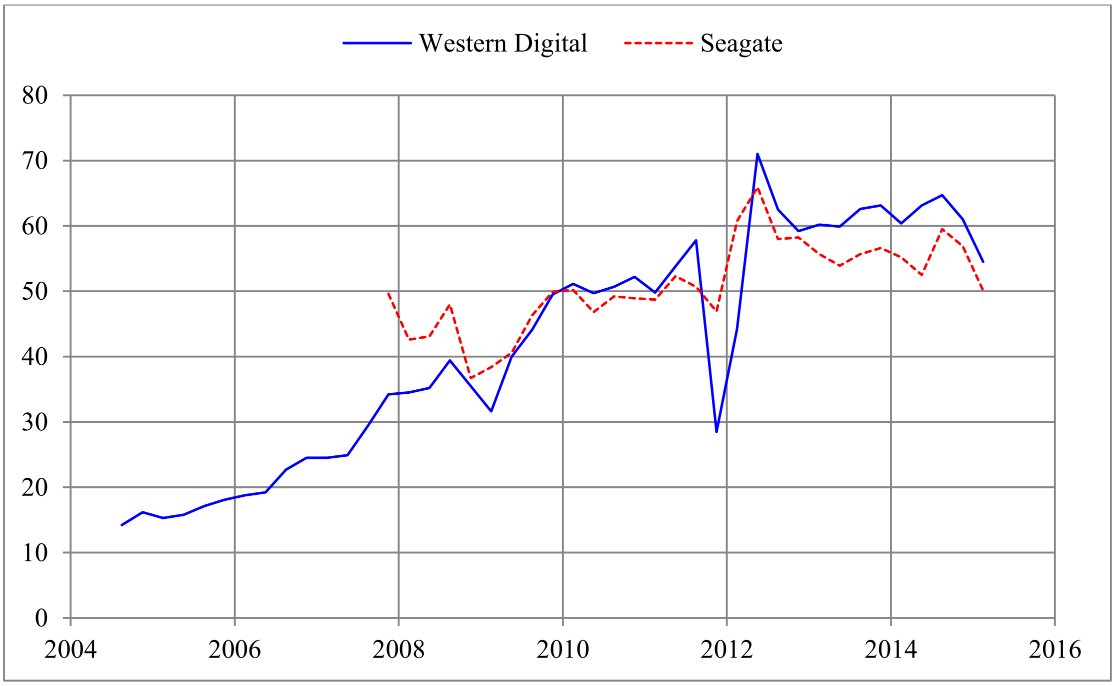
The HDD industry has been through a continuous consolidation process in the past 25 years. Currently, only three players remain in the industry: Western Digital, Seagate, and Toshiba, although the former two are dominant (Figure 3). Seagate purchased Maxtor in May 2006, Toshiba bought Fujitsu's HDD business in October 2009, Seagate acquired Samsung's HDD business in December 2011, and Western Digital obtained Hitachi's HDD business in March 2012, decreasing the number of players from seven to three in 10 years. By comparing Figures 3 and Figure 4, we can see that the market shares of Western Digital and Seagate have both risen after their acquisitions of the HDD business of Hitachi (Western Digital) and that of Samsung (Seagate) more than the general increase in their shipments.

Figure 3: HDD Market Share



HDD = hard disk drive.
Source: Financial statements of Seagate and Western Digital.

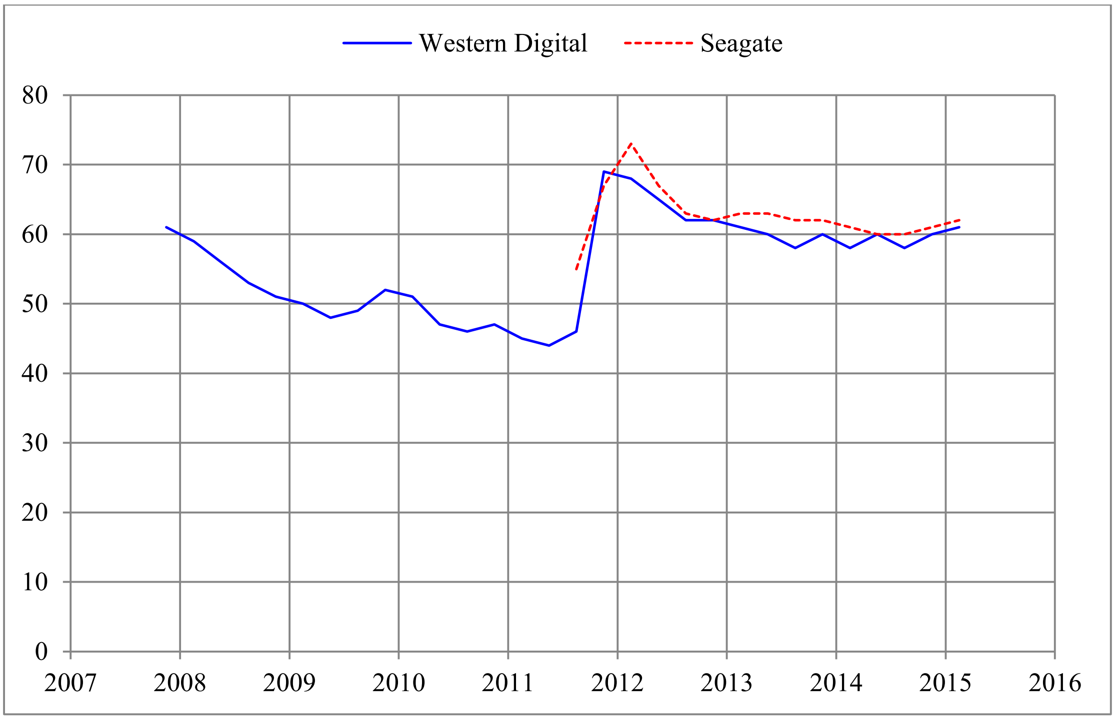
Figure 4: HDD Shipments (in million)



HDD = hard disk drive.
Source: Financial statements of Seagate and Western Digital.

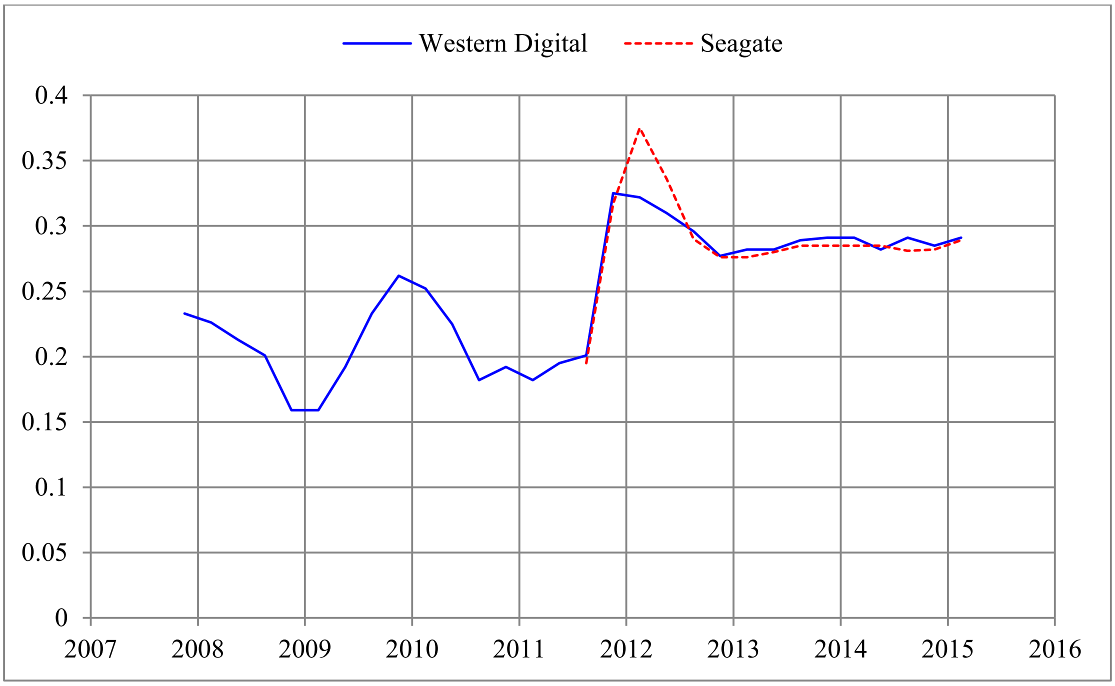
Figure 5 exhibits the average HDD selling price of Western Digital and Seagate. Before the 2011 Thailand floods (fourth quarter of 2011), the average HDD selling price had been in steady decline, at least for Western Digital, but shot up at around the time of the floods, both for Western Digital and Seagate. What is striking is that the average selling price has been staying at a higher level than the pre-flood level and is fairly stable. A similar pattern emerges for their gross margins (Figure 6).

Figure 5: Average Selling Price of HDD (US$)



HDD = hard disk drive.
Sources: Financial statements of Seagate and Western Digital.

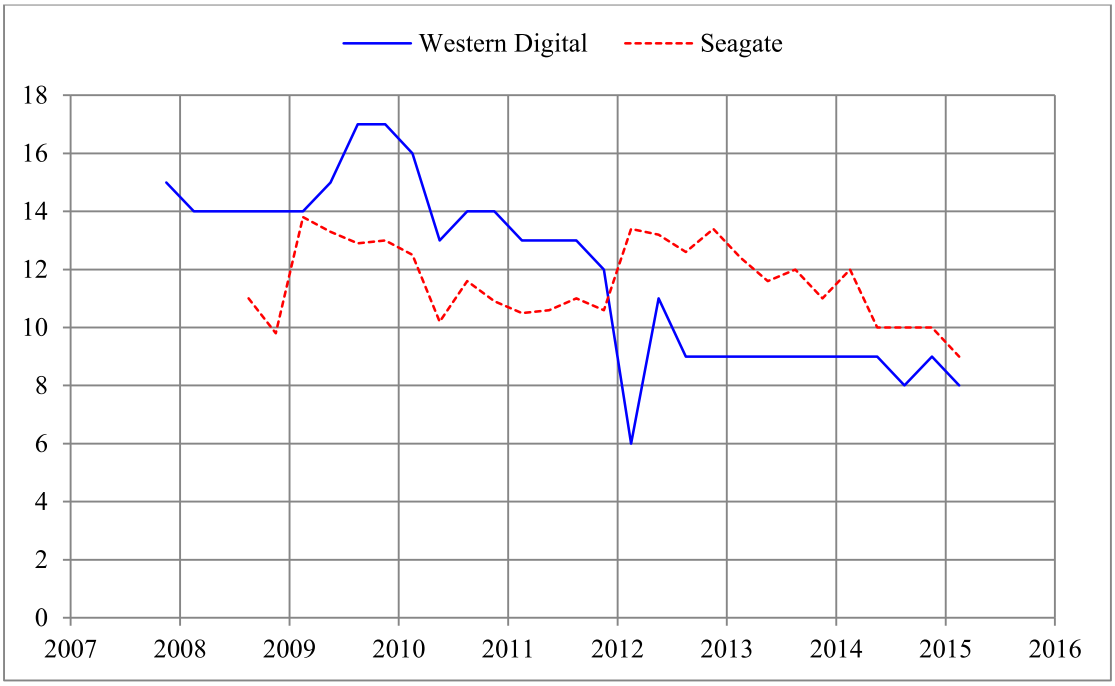
Figure 6: Gross Margin



Sources: Financial statements of Seagate and Western Digital.

To summarise, the HDD shipments have fallen slightly and the price (and the gross margins) have gone up substantially after the 2011 Thailand floods. Figure 7 illustrates the inventory turns of the two major players. Western Digital's inventory turns dropped sharply in the first quarter of 2012, probably reflecting the temporary closure of its production facilities in Thailand, although it had been gradually declining before the 2011 floods, and has been at a low level since the third quarter of 2012. In contrast, Seagate's inventory turns increased substantially in the first quarter of 2012, but has been slowly declining since then and is converging to the inventory turns of Western Digital.

Figure 7: HDD Inventory Turns, by Manufacturer



HDD = hard disk drive.
Sources: Financial statements of Seagate and Western Digital.

3. Analysis

In what follows, we first present a standard Cournot oligopoly model, and then extend it to a dynamic one with a finite horizon by following Radner (1980). Then, we use the theoretical framework to analyse the case of the HDD industry to evaluate the effects of the 2011 Thailand floods.

3.1. Static Model

Consider an industry in which there are n firms (or players) indexed by $i = 1, 2, \ldots, n$ and there is little or no product differentiation. Each firm i can choose its production level Q^i directly but not the price of its product, i.e. the industry is in a Cournot oligopoly, and the firms are facing an inverse demand function

$$P = \alpha - \beta Q,$$

where P denotes the price and Q is the aggregate quantity of the product produced, i.e. $Q = \sum_{i=1}^{n} Q^i$. By letting $Q^{-i} \coloneqq \sum_{j \neq i} Q^j$, we can express $Q = Q^i + Q^{-i}$, i.e. the aggregate production is decomposed into firm i's production and that of all other firms. The cost function of the firms is assumed to be identical and that of constant returns to scale, $(Q^i) = cQ^i$, where the parameter c is both the marginal and average cost. We assume $\alpha > c$.

Each firm solves the following optimisation problem:

$$\max_{Q^i} P(Q^i + Q^{-i}) \cdot Q^i - cQ^i \text{ subject to } Q^{-i} \text{ given.}$$

It is straightforward to show that the solution to this problem $\hat{Q}^i(Q^{-i})$ is

$\hat{Q}^i(Q^{-i}) = \frac{\alpha - c}{2\beta} - \frac{Q^{-i}}{2}$ if this is non-negative and zero otherwise.

Thus, in the symmetric Cournot-Nash equilibrium, $\hat{Q}_c^{-i} = (n-1)\hat{Q}_c^i$ holds, where subscript c indicates that the quantity is in a Cournot-Nash equilibrium. It follows that each firm's equilibrium quantity is $\hat{Q}_c^* = \frac{\alpha - c}{(n+1)\beta}$, and the equilibrium price is $\hat{P}_c = \frac{\alpha + nc}{n+1}$. Thus, the equilibrium aggregate quantity is $\hat{Q}_c = \frac{n}{n+1} \cdot \frac{\alpha - c}{\beta}$, which converges to $\frac{\alpha - c}{\beta}$ as the number of firms goes to infinity, i.e. the equilibrium quantity in a competitive equilibrium, in which the price equals the marginal cost.

Now consider the case in which all firms in the industry form a cartel so that they behave as though they are in a monopoly. This case can be described above by setting $n = 1$ for the aggregate quantity and for the price, i.e. $\hat{Q}_m = \frac{\alpha - c}{2\beta}$ for the aggregate quantity and $\hat{P}_m = \frac{\alpha + c}{2}$, where m indicates monopoly. Thus, the aggregate quantity $\hat{Q}_m$ is smaller than $\hat{Q}_c$, i.e. $\hat{Q}_m < \hat{Q}_c$ in the symmetric Cournot-Nash equilibrium and the equilibrium price $\hat{P}_m$ is higher than $\hat{P}_c$, i.e. $\hat{P}_m > \hat{P}_c$ when $n \geq 2$. Each firm will produce $\hat{Q}_m^* = \frac{\alpha - c}{2n\beta}$, which is smaller than $\hat{Q}_c^*$, i.e. $\hat{Q}_m^* < \hat{Q}_c^*$ for all i when $n \geq 2$.

3.2. Finite-Horizon Dynamic Case

We now consider a dynamic case with a finite horizon by following Radner (1980). Let T denote the number of periods, and we assume that the firm's payoff is the average of the T one-period profits. Each firm plays a sequential T-period game in which the one-period game is repeated T times.

As noted by Radner (1980), in every perfect Cournot-Nash equilibrium of the T-period game, each firm produces $\hat{Q}_c^*$ in each period. Radner (1980) then considers the following strategy: firm i produces $\hat{Q}_m^*$ ($< \hat{Q}_c^*$) in each period as long as all other firms have been doing the same; thereafter firm i produces $\hat{Q}_c^*$ in each period. This strategy is denoted by C_T, which is defined formally below. First define D_i as follows:

$$D^i = \begin{cases} \infty & \text{if } Q_t^j \text{ for all } t \text{ and all } j \neq \text{i}, \\ \min\{t\colon \hat{Q}_t^j = \hat{Q}_m^* \text{ for some } j \neq i\}, & \text{otherwise.} \end{cases}$$

The strategy C_T is defined by

$$Q_t^i = \begin{cases} \hat{Q}_m^* & \text{if } t \leq D^i, \\ \hat{Q}_c^* & \text{if } t > D^i. \end{cases}$$

More generically, for any integer k between 0 and T, define the strategy C_k as follows:

$$Q_t^i = \begin{cases} \hat{Q}_m^* & \text{if } t \leq \min(D^i, k), \\ \hat{Q}_c^* & \text{if } t > \min(D^i, k). \end{cases}$$

Radner (1980) further considers a more general class of strategies below, which he called *trigger strategies of order* k. Let Q^D some (defection) production level. If $D^i \geq k$, then

$$Q_t^i = \begin{cases} \hat{Q}_m^* & \text{if } t \leq k, \\ Q^D & \text{if } t = k+1, \\ \hat{Q}_c^* & \text{if } t \geq k+2. \end{cases}$$

If $D^i \leq k$, then

$$Q_t^i = \begin{cases} \hat{Q}_m^* & \text{if } t \leq D^i, \\ \hat{Q}_c^* & \text{if } t > D^i. \end{cases}$$

With these trigger strategies, Radner (1980) shows the following:

Proposition 1 (Radner, 1980): *Suppose all firms other than firm i use the same trigger strategy of order $k > 0$ with some defection production level $Q^D > \hat{Q}_m^*$. Then, firm i's best response is a trigger strategy of order $(k-1)$, with defection production level equal to*

$$\widetilde{Q} := \frac{(\alpha-c)(n+1)}{4n\beta}.$$

An important implication of this result is that the advantage to any one firm of defecting from the cartel one period before the end of the game approaches zero as the number of periods $T \longrightarrow \infty$ provided that all other firms use trigger strategy of order T. The result can be verified by comparing the average profit per firm when using a trigger strategy of order $(T-1)$ and the cartel profit per firm.

Radner (1980) then introduces an equilibrium concept that is looser than the standard Nash equilibrium: epsilon-equilibrium, which is defined as follows:

Definition (Epsilon-equilibrium; Radner, 1980): *For any positive number ε, an ε-equilibrium is an n-tuple of strategies, one for each firm, such that each firm's average profit is within ε of the maximum average profit it could obtain against the other firms' strategies.*

Radner (1980) applies this definition to the dynamic case by extending the concept of perfect Cournot-Nash equilibrium, which is called a perfect ε-equilibrium. One central ε-equilibrium of interest is the one in which each firm produces its cartel output level for exactly k periods, i.e. combination (C_k) of trigger strategies. Furthermore, two cases are considered: (a) The fixed-demand case, and (b) the replication case. In the former case, the aggregate demand is independent of the number of firms, while it is a function of the number of firms in the latter case— more specifically, $Q = \left(\frac{\alpha - P}{\beta_1}\right) \cdot n$. The following two results are shown by Radner (1980). First, for the fixed-demand case:

Proposition 2 (Radner, 1980; Fixed-demand case): Consider the fixed-demand case. *For every $\varepsilon > 0$ and $T \geq 1$ there is a number $B(\varepsilon, T)$ such that for every $n > 1$ and every ε-equilibrium the following are all bounded by $B(\varepsilon, T)$:*

$\left|Q_t^i - Q_c^*\right|$,

$\left|\sum_{i=1}^{n} Q_t^i - nQ_c^*\right|$,

$\left|\left(\alpha - c - \beta Q_t^{-i}\right) \cdot Q_t^i - \beta \cdot \left(Q_t^i\right)^2 - \frac{1}{\beta} \cdot \left(\frac{\alpha - c}{n+1}\right)^2\right|$,

for $i = 1, 2, \dots, n$, $t = 1, 2, \dots, T$. *In addition, for every* T,

$$\lim_{\varepsilon \to 0} B(\varepsilon, T) = 0.$$

The first line states that the deviation of firm-level production from the Cournot-Nash equilibrium firm production level is bounded by $B(\varepsilon, T)$. Similarly, the second line is regarding the industry-wide production level and the third line is on the firm's profit. Next, for the replication case:

Proposition 3 (Radner, 1980; Replication case): Consider the replication case. *For every* $\varepsilon > 0$, $T \geq 1$ *and* $n > 2$, *there is a number* $B(\varepsilon, T, n)$ *such that for every* $n > 1$ *and every* ε*-equilibrium the following are all bounded by* $B(\varepsilon, T, n)$*:*

$\left|Q_t^i - Q_c^*\right|$,

$\left|\sum_{i=1}^{n} Q_t^i - nQ_c^*\right|$,

for $i = 1, 2, \dots, n$, $t = 1, 2, \dots, T$*; the bounds* $B(\varepsilon, T, n)$ *may be chosen so that for every* $\varepsilon > 0$, $T \geq 1$,

$\frac{B(\varepsilon, T, n)}{n^{0.5}}$ *is uniformly bounded in* n,

and for every $T \geq 1$ *and* $n > 2$,

$$\lim_{\varepsilon \to 0} B(\varepsilon, T, n) = 0.$$

The main difference between the two cases is that the bound in the fixed-demand case is not a function of the number of firms n, while it is the case in the replication case. However, in both cases, when the deviation ε is sufficiently small, the cartel collapses and the ε- equilibrium will be the same as the static Cournot-Nash equilibrium effectively. Also, Radner (1980) shows that *for any fixed* ε *and number of* *periods T, the cartel cannot survive at all if the number of firms n is sufficiently large in the replication case, while it is irrelevant for the survival of the cartel in the fixed-demand case.*

3.3. Hypotheses

Casual observations above have provided us with the general direction that the price has become higher and the quantity has decreased slightly after the 2011 Thailand floods. Thus, we propose the following hypotheses that could explain the mechanism that brought the higher price and slightly lower quantity.

Hypothesis I: *The 2011 Thailand floods caused a shift in the (inverse) demand function— in particular, α went up.*

Hypothesis II: *The 2011 Thailand floods triggered the formation of a de facto cartel between Western Digital and Seagate (and possibly with Toshiba, too).*

We claim that these two hypotheses hold simultaneously for the current HDD industry. Hypothesis I is simple. Since the Cournot-Nash equilibrium price is $\hat{P}_c = \frac{\alpha + nc}{n+1}$ and the Cournot-Nash equilibrium firm production level is $\hat{Q}_c = \frac{n}{n+1} \cdot \frac{\alpha - c}{\beta}$, an increase in α will bring both the price and the production level higher. This means that Hypothesis I alone is unable to offer a consistent prediction with the actual observations, i.e. a higher price level and a lower production level.

As for Hypothesis II, there are two separate cases possible: the fixed-demand case and the replication case (or a more generic case in which the industry-level demand is a function of the number of firms). In the fixed-demand case, the difficulty of forming a cartel is independent of the number of firms; thus, that the market consolidation happened almost simultaneously at the time of the Thailand floods through Seagate's acquisition of Samsung's HDD business and Western Digital's purchase of Hitachi's HDD business should be irrelevant to the formation of cartel, and the shock due to the Thailand floods is the only trigger for the formation. In contrast, in the replication case (or a more generic case), the market consolidation would have made the formation of the cartel easier.

In the fixed-demand case, the cartel price will be higher than the Cournot-Nash equilibrium price, and each firm's production will be fewer than the Cournot-Nash equilibrium production level. In the replication case, the decrease in production will be even greater since a smaller number of firms in the industry directly decreases the industry-level demand for and production of the product, while the prediction about the price is essentially the same as in the fixed-demand case. Thus, the observed facts, i.e. the higher price level and lower production level sustained after the 2011 floods may be explained by Hypothesis II in both fixed-demand and replication cases, i.e. whether or not the aggregate demand is a function of the number of firms or not does not matter with this regard.

3.4. Discussion

We saw above that a shift in demand alone would not be able to explain the observed behaviour of price and quantity after the 2011 Thailand floods, but a formation of a de facto cartel would be needed to explain the behaviour. Also, unless the industry-wide demand is independent of the number of firms within the industry, Radner (1980) showed that it is easier to sustain a cartel when there are fewer firms. Thus, it may well be that the on-going consolidation of the HDD industry before the floods paved the way for a formation of a cartel with the floods acting as a trigger for it.

The fact that the average price and the gross margins of both Western Digital and Seagate rose substantially after the floods suggests that industries with fewer players may act collusively to exploit the temporary supply shortage caused by a natural disaster. Thus, natural disasters may induce a welfare loss due to collusive behaviours of firms, causing further losses in addition to the direct losses.

However, to show that HDD firms indeed formed a cartel in the aftermath of the floods require a more detailed empirical analysis based on micro data. In so doing, we need to evaluate the scale of the price pass-through to the clients, which correspond to an increase in α in our model. Also, we need to measure the possible increase in the market power of the firms after the floods. These two effects need to be isolated so as to claim that a de facto cartel was indeed formed. To this end, the industrial organisation literatures on the measurement of market power and cartel should be followed closely.[3]

4. Implications

4.1. Risk Prevention Incentives and Moral Hazard

We have seen above that natural disasters may not cause losses to directly affected firms but may even benefit some firms. If a price rise follows a disaster as a result of a shift in the demand function or by a formation of a cartel, the costs of natural disasters would not be borne by the directly affected firms. Instead, their clients, consumers, and taxpayers pay the costs. Also, if a natural disaster triggers a shock to the industry so that a cartel is formed, there will be efficiency/welfare loss to the economy as a whole, which provides rent to the directly affected industry and welfare losses to other parties.

Although it is not obvious if firms believe ex ante that they might benefit from natural disasters when they are hit by them, this is still potentially a reason for such firms to spare investment in risk prevention. Also, firms would pay no particular attention to potential natural disasters in determining locations of factories if they believe no large losses would be incurred from natural disasters, but would instead benefit from them. Thus, a perverse incentive may have been given to firms; thus, serious moral hazard issues may arise.

4.2. Policy Implications

Southeast Asia has seen a rapid economic development through industrialisation in the past couple of decades. In many cases, public and private industrial estates/parks are developed to attract foreign direct investments. The industrial estates hit by the 2011 Thailand floods were concentrated in the Chao Phraya basin where the

[3] For instance, Stigler (1964), Salant (1976), Bresnahan and Reiss (1991), Nevo (2001), and a survey by Andrade et al. (2001).

production facilities of the globally important electronics industry, including the HDD industry, are located.

Even if some industries may benefit from natural disasters, as we saw above, it is very harmful to the economic development of the region if its reputation of being prone to natural disasters become so widespread that foreign firms would reconsider direct investment in the region. Thus, it is important for the region to quickly improve its resilience against natural disasters, in particular in many industrial estates which, although developed in convenient places with good access to water transport, are at the same time prone to flooding or other natural disasters such typhoons, strong winds, and tsunamis.

Southeast Asia may pursue two directions to improve resilience against natural disasters: (1) implement a public policy that directly prepares for natural disasters, e.g. conduct detailed geographical surveys to develop extensive hazard maps, implement better land use planning, improve infrastructure such as drainage system, dikes, and power grids with back-ups; and (2) provide firms with incentives to invest in risk prevention. To this end, one possible policy is to grant tax breaks or advantages if the firms make such investment. Such preferential set-ups is a common practice to invite foreign firms to invest in factories, but a similar arrangement should be put in place to incentivise investment in risk prevention.

5. Conclusion

This paper examined the possible effects of the 2011 Thailand floods on the HDD industry. Contrary to the common idea that the firms hit directly by floods are victims, the major HDD firms benefited instead from the floods by maintaining a higher price or gross margins than before the floods. This implies that firms expecting to benefit from natural disasters may have perverse incentives regarding investment in risk prevention. We also found that the industry-wide shipment has become consistently lower than what it was before the floods, which cannot be explained by the shift in demand. The combination of a higher price and a lower quantity suggests that the floods may trigger a formation of a cartel, i.e. the firms act collusively, according to the predictions of our theoretical framework based on Radner (1980). Cartel formation may well be easier when the industry is more consolidated; thus the degree of market concentration may be an important factor that drives incentives to invest in risk-prevention measures.

The implications for Southeast Asia are profound, for its economic development has been driven by foreign direct investment, while it is the region most frequently hit by natural disasters. Even though some firms may benefit from natural disasters, as we saw in this paper, their gains are losses of other parties. Thus, frequent natural disasters combined with limited risk-prevention measures by some members of the economy could dissuade foreign firms from investing in the region. Upon such considerations, we made policy recommendations in two directions: public policy that directly prepares for natural disasters, and a policy that incentivise firms to invest in risk prevention.

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