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THE EFFECT OF MARKET STRUCTURE ON ADAPTATION TO CLIMATE CHANGE IN AGRICULTURE

Sangjun Lee · Suzanne Thornsby

Department of Agricultural, Food and Resource Economics, Michigan State University

East Lansing, MI 48224-1039, USA

Leesan56@msu.edu

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Abstract

When assessing climate change impact, adaptation is an important behavioral response to reduce potential risk. But it has been widely recognized that there are barriers to adaptation. And attempts to estimate impacts may be biased when these barriers neglected. Potential barrier on adaptation decision from market structure have not been identified. We develop a theoretical model to evaluate adaptation incentives of farmers under climate change across various market structures. In agricultural production where acreage adjustment is costly, our theoretical model suggests that the “competition effect” plays an important role in determining incentives to adapt. The competition effect in the market may outweigh the production effect and reduce producer incentives to change production practices. Results also suggest that monopolists may have a higher incentive to adapt since the market is under their direct control with less competition even though these incentives are still much smaller than socially optimal levels. In contrast, there can be strategic interactions among players which can lead to inaction (not investing in adaptations) due to the threat of potentially higher competition in other market structures.

1. Introduction

There has been growing concern about the potential impact of climate change on human and natural systems such as agriculture, forests and wildlife, human health and recreation and tourism. Among various sectors which are vulnerable to climate change, agriculture is usually most sensitive since it is directly exposed to climate conditions. Numerous studies, using a variety of approaches, have estimated the economic impact of climate change on agriculture; however most simply assume a perfectly competitive market and ignore impacts from market structure (e.g. Reilly et. 2003; Deschênes and Greenstone 2007). Imperfectly competitive markets alter the link between agronomic and economic productivity under climate change, influencing individual decisions about adaptation strategies. The agronomic productivity changes that occur with climate adjustments are not directly translated to adaptation decisions when economic consequences are altered through price distortions that may occur

across different market conditions. Most previous studies only track yield reductions, increased variability in crop production, or (agronomic) productivity enhancing effects of adaptations and implicitly assume that if the perfectly competitive benefit from yield enhancing effect is greater than cost of adaptation (e.g., investment cost), the adaptation will take place (e.g., Njie et al. 2006). Hence, these studies only evaluate ability to adapt without consideration of the economic incentive to adapt in the market context.

In economic literature on evaluating adaptation options to climate change, benefit-cost analysis often employed. Specifically, cumulative sum of net cash flows, discounted back to the present using the opportunity cost of capital (net present value or NPV), determines whether or not to make an investment to adaptation measures. However, the adaptation studies in agriculture are particularly difficult since it includes not only diverse options but complex processes (Adger et al. 2007). Especially, the process in the agricultural market has not been well-identified. These previous adaptation studies on agriculture have usually focused on cost-effectiveness of adaptation options without consideration of market condition (Mizina et al. 1999) or relied on perfectly competitive market assumption (Butt et al. 2005).

The focus of this paper is to investigate willingness of individual decision-makers to adapt, given alternative market structure influence on their incentive. We develop a theoretical model to show that decision maker willingness to pay to undertake specific adaptation measures in response to impact from climate change in the production sector varies across market settings beyond perfect competition. Especially, we focus on incentives to adapt in an agricultural production system where acreage change is not easily achieved (e.g. perennial crop production). The inflexibility of land use represents a barrier to adapt which is not well-identified in the previous literature. Having focused on annual crop production, previous impact assessment might ignore the significance of this costly barrier. These systems are highly vulnerability to extreme events, which are increasingly recognized, as having strong implications for adaptation.¹

¹ For example, spring frost in Michigan killed all buds from tart cherry tree, which led to drastic drop (almost zero) in production in 2002.

This article is organized in the following manner. Section 2 provides a basic model and assumptions for our analysis. In section 3, a theoretical analysis on the relationship between market structure and adaptation incentive to climate change. Finally, we summarize our discussions and propose some future research perspectives in section 4.

2. The basic model and assumptions

In the industrial organization literature, it is well-known that a firm's incentive to conduct research and development (R&D) varies by the market structure. Using a simple framework, we can easily show that monopolist gains less from innovating than does a competitive firm due to replacement effects (Tirole 1988). While the basic intuition behind this paper is to investigate the implications from the research in adaptation to climate change, the model implicitly assumes that firms can adjust production quantity to attain additional profit without cost. As we will see, incentives to adapt will be different from the standard results if the change in production quantity is not flexible.

In addition, our model needs to include uncertainties in production. Also, we don't know with certainty about the potential benefit and cost from adaptation. If we consider multiple agents, uncertainty also arises about others' action. Sandmo (1971) examined a firm's production decision under price uncertainty based on expected utility framework. Smit and Trigeories (2004) analyze dynamic games where the value of investment depends on competitive interactions. However, these models pay attention to uncertainty only in demand which will have different implication from supply uncertainties. We turn our focus to uncertainty in production instead in our model.

Suppose that there are n -farms competing with quantity of homogeneous product. Since agricultural production is directly exposed to climate or weather, realized production often fluctuates by climate

condition. Under the state-contingent production nature², supply of firm i can be represented as following multiplicative form.

$$(1) \quad q_i = \theta_i A_i$$

where q_i and A_i are quantity produced and area planted (acreage) of firm i . The supply also depends on a random yield parameter, θ_i which can be interpreted as yield variation under climate condition. For total

market supply we can write
$$Q = \sum_i q_i = \sum_i \theta_i A_i$$

Suppose that market demand is linear and there is no marginal cost of production. Further we assume that there is no stochastic component in the demand. Specifically, the demand function can be written as

$$(2) \quad P(Q) = 1 - Q = 1 - \sum_i \theta_i A_i$$

Under the demand and supply conditions above, firms choose optimal amount of acreage to maximize their expected profits.³ We examine two-period problem including pre- and post-climate change. In the first period, farms operate under traditional production conditions without climate change. Suppose that the yield parameter follows almost deterministic distribution with unit mean and infinitesimally small variance, ε^2 .

$$(3.1) \quad \theta_i^{\text{pre}} \sim (1, \varepsilon^2)$$

² State-contingent production theory has advanced prominently in agricultural economics literature. Refer to Chambers and Quiggin (2000) for detail.

³ Since we assumed that farms maximize the expected profit, we don't account for risk-aversion in our model. Hence, we consider risk-neutral case only.

where $\epsilon \cong 0$. Suppose further that farms cannot project future yield shock in this period. Hence, optimal acreage decisions will be equivalent to typical deterministic solutions under given market conditions. In the second period, the potential yield shock is realized and identified by the agents. In our model, climate change impact is represented as catastrophic yield shock with yield parameter, θ_i^{NA} , which is identically distributed with Bernoulli distribution.

$$(3.2) \quad \theta_i^{NA} = \begin{cases} 1 & \text{with Prob} = \frac{1}{2} \\ 0 & \text{with Prob} = \frac{1}{2} \end{cases}$$

where $E(\theta_i^{NA}) = \frac{1}{2}$ and $Var(\theta_i^{NA}) = \frac{1}{4}$, respectively.⁴ The distribution of θ_i^{NA} 's are correlated with $[Cov(\theta_i^{NA}, \theta_j^{NA})] = \rho$. The distribution indicates that farmers can produce normal yield only with a half chance. On the other side, the farmers could possibly have zero harvest due to weather shock. The correlation coefficient indicates linkage of climate change impact between farms. Specifically, if ρ is close to one or negative one, it implies the impact is realized as same or opposite direction as other farms respectively. If ρ is close to zero, in contrast, the impact is uncorrelated each other.

Now we allow for farmers to do something to reduce the yield shock. There are many types of adaptation strategies which could be specified. Specifically, farmers can make an investment to an adaptation measure (e.g. irrigation). Modifications of management practice can be a mean of adaptation. In addition, farmers can adjust acreage, A to maximize the expected profit under the risk. We preclude this case in our model since we are describing industry in which it is costly to adjust amount of production. For example, it is hard to immediately adjust amount of production by increasing or reducing

⁴ Hereon superscripts 'A' and 'NA' indicate with and without adaptation respectively.

number of trees planted in perennial crop industry.⁵ Hence, we assume that the quantity determined in the first period is maintained in the second period. All adaptation measures provide a way to reduce the negative risk by changing climate. We assume that producers can make a fixed investment to reduce the risk. We assume that once adaptation measure is exercised, the distribution of the yield parameter will be modified so the negative shock is reduced. Specifically, as a result of adaptation the new yield parameter, θ_i^A can be presented as the following.

$$(3.3) \quad \theta_i^A = \begin{cases} 1 & \text{with Prob} = \frac{1}{2} \\ \alpha & \text{with Prob} = \frac{1}{2} \end{cases}$$

where $0 < \alpha < 1$. With the adaptation investment, $E(\theta_i^A) = \frac{1+\alpha}{2}$ and $\text{Var}(\theta_i^A) = \frac{1-\alpha^2}{4}$. Hence, the measure is mean increasing and variance reducing. However, we assume that the correlation coefficient will remain the same as before.⁶

Under distributional assumptions, the amount a farmer is willing to pay for the adaptation depends on potential additional expected profit that the farm can accrue. Profit incentive denoted by Δ can be represented with expected profit differential with and without the adaptation measure which is defined as

$$(4) \quad \Delta \equiv E\pi_i^A - E\pi_i^{NA}$$

⁵ For example, in tart cherries industry, returns are not realized until 3-6 years after initial investment and capital recovery can take as long as 25 years.

⁶ Since climate change is out of farmer's control, this assumption is plausible.

where $E\Pi_i^A$ and $E\Pi_i^{NA}$ are farm i 's expected profits with and without adaptation. If the adaptation incurs fixed cost denoted by $\kappa (> 0)$, the farmer will adapt when $\Delta > \kappa$. Under these settings, we derive the thresholds which make the adaptation profitable to the producer under various market structures.

3.1 Social planner's incentive to adapt

Before evaluation of market structure, we investigate the social planner's incentive to adapt as a benchmark case. Equivalent to profit incentive of a farm as defined above, a social planner's incentive to adapt is net social welfare attributable to the adaptation. Before climate change is realized, the social planner solves the following maximization problem in the first period.

$$(5) \quad \text{Max}_A \text{EW} = E \int_0^{\theta A} (1 - \theta s) ds$$

where W is total social welfare. We can easily show that the optimal solutions for the maximization problem are

$$(6) \quad \begin{cases} A_s = 1 \\ \text{EW}_s = \frac{1}{2} \end{cases}$$

where A_2 and EW_2 denote optimal acreage and expected net social welfare in the first period respectively. As noted above, quantity determined in the first period is transferred to the second period. Naturally, second period problem becomes a decision to invest. In order to examine the investment decision in the second period, we need to specify expected welfare with and without investment. Let EW^A and EW^{NA} be expected net social welfare with and without investment, respectively. The social planner's expected welfare with and without investment can be derived by plugging in (6) into welfare function (5) using mean and variance of distributions (3.2) and (3.3).

$$(7.1) \quad E\Pi_2^{NA} = \frac{1}{4}$$

$$(7.2) \quad E\Pi_2^A = \frac{1}{4} + \frac{2\alpha}{4} - \frac{\alpha^2}{4}$$

Let Δ_2 to be the social planner's profit incentive to adapt. By definition, social planner's incentive to adapt can be written as

$$(8) \quad \Delta_2 = E\Pi_2^A - E\Pi_2^{NA} = \frac{\alpha(2 - \alpha)}{4}$$

Hence, we can derive following properties from the incentive function of social planner

Property 1

Under assumptions (1)-(3.3),

$$(a) \quad \Delta_2 > 0$$

$$(b) \quad \frac{d\Delta_2}{d\alpha} > 0 \quad \text{and} \quad \frac{d^2\Delta_2}{d\alpha^2} < 0$$

The part (a) of the properties above indicates that the adaptation always has the potential to increase the social welfare to some extent, which would yield positive incentives to adapt, but not guaranteeing that adaptation investment take place. Specifically, the social planner will adapt if $\Delta_s > x$. The results in part (b) imply that the incentive increases but marginal incentive drops as α goes to one. That is, the incentive function is monotone and concave in the domain. Increasing incentive with α seems plausible since greater α implies better adaptation outcome.

3.2 Incentives to adapt in monopoly

General intuition behind monopoly problem is monopolists produce smaller amount than socially optimal level in order to appropriate rent. The monopolist maximization problem can be written as

$$(9) \quad \text{Max}_T(A) \quad [E\Pi = E(\theta)A - E(\theta^2)A^2 - \dots]$$

Let A_m and $E\Pi_m$ are optimal acreage and expected profit in the first period respectively. If we ignore small variance ($\varepsilon=0$), we can easily derive solutions to the first period problem by solving the maximization problem.

$$(10) \quad \begin{cases} A_m = \frac{1}{2} \\ E\Pi_m = \frac{1}{4} \end{cases}$$

For the second period problem, let $E\Pi_m^{NA}$ and $E\Pi_m^A$ to be expected profit of monopolist with and without adaptation measure, respectively. Since acreage in the first period is directly transferred to the second period, the monopolist's expected profit with and without adaptation can be derived by plugging in acreage of the first period in (10) with distribution (3.1) and (3.2) into profit function in (9).

$$(11.1) \quad E\Pi_m^{NA} = \frac{1}{8}$$

$$(11.2) \quad E\Pi_m^A = \frac{1}{8} + \frac{\alpha}{4} - \frac{\alpha^2}{8}$$

The monopolist's profit incentive to adapt can be calculated using same manner as social planner's problem.

$$(12) \quad \Delta_m = E\Pi_m^A - E\Pi_m^{NA} = \frac{\alpha(2 - \alpha)}{8}$$

The incentive function of monopolist exhibit same pattern to social planner's problem such as monotonicity and concavity in the domain. Similarly, monopolists will adapt if $\Delta_m > \kappa$. The properties of the incentive function can be summarized as

Property 2

Under assumptions (1)-(3),

$$(a) \quad \Delta_m > 0$$

$$(b) \quad \frac{d\Delta_m}{d\alpha} > 0 \quad \text{and} \quad \frac{d^2\Delta_m}{d\alpha^2} < 0$$

3.3 Incentive to adapt in oligopoly

We finally examine competition in the market using oligopoly model. As a representative case, we employ duopoly model with Cournot type (quantity) competition. Compared to previous cases, the duopoly model has different characteristics in that it considers strategic interaction between farms. Hence, the interaction could play a role in our model. Let 1 and 2 denote two homogeneous farms in the market. In the first period, we also assume that two firms only compete with quantity which means standard Cournot competition. In these setting, the firms' maximization can be written as

(13)

$$\text{Max}_{A_{it}} \left[\mathbb{E} \Pi_{it} = \mathbb{E}(\theta_{it}) A_{it} - \mathbb{E}(\theta_{it}^2) A_{it}^2 - \mathbb{E}(\theta_{it} \theta_{jt}) A_{it} A_{jt} \right] \quad i = 1, 2$$

Let A_1 and A_2 to be solution to the maximization problem (13) by each firm. And let $\mathbb{E} \Pi_1$ and $\mathbb{E} \Pi_2$ to be associated profit with the solution. We have symmetric Nash Equilibrium from the problem. The solution is given by

$$(14) \quad \begin{cases} A_1 = A_2 = \frac{1}{3} (= A_c) \\ \mathbb{E} \Pi_1 = \mathbb{E} \Pi_2 = \frac{1}{9} (= \mathbb{E} \Pi_c) \end{cases}$$

As noted above, the strategic interaction plays an important role in these setting. The decision to invest during the second period in this duopoly model becomes an adaptation game between farms. In order to construct payoffs, we need to examine expected profit of each firm given the other's decision. We need to note here that we assume θ_i 's are correlated with each other. When the correlation coefficient is ρ , we can show the following results hold.

$$(15.1) \quad "E(" \theta_{1i}^1 NA \theta_{1i}^1 NA) = 1/4 \rho + 1/4$$

$$(15.2) \quad "E(" \theta_{1i}^1 A \theta_{1i}^1 NA) = "E(" \theta_{1i}^1 A \theta_{1i}^1 NA) = ((1 - \alpha))/4 \rho + ((1 + \alpha))/4$$

$$(15.3) \quad "E(" \theta_{1i}^1 A \theta_{1i}^1 A) = (1 - \alpha)^2/4 \rho + (1 + \alpha)^2/4$$

Using the results in (15.1)-(15.3), we can easily derive farms' second period payoffs as usual. The payoffs of each firm can be summarized as the following.

$$(16.1) \quad E\Pi_i(NA, NA) = \frac{1}{36}(3 - \rho) \quad i = 1, 2$$

$$(16.2) \quad E\Pi_1(A, NA) = E\Pi_2(NA, A) = \frac{1}{36}[3 + 5\alpha - 2\alpha^2 - (1 - \alpha)\rho]$$

$$(16.3) \quad E\Pi_1(NA, A) = E\Pi_2(A, NA) = \frac{1}{36}[3 - \alpha - (1 - \alpha)\rho]$$

$$(16.4) \quad E\Pi_i(A, A) = \frac{1}{36}[3 + 4\alpha - 3\alpha^2 - (1 - \alpha)^2\rho] \quad i = 1, 2$$

Since farms are interdependent each other, a farm's incentive also depends on the other's decision. Specifically, there are two types of incentives by the other's decision. Without loss of generality, we can only consider farm 1's incentives. Since we assumed homogeneous firms, Farm 2's incentives are equivalent. By definition, farm 1's incentives can be represented as follows.

$$(17.1) \quad \Delta_1(A, NA) = E\Pi_1(A, NA) - E\Pi_1(NA, NA) = \frac{1}{36(5\alpha - 2\alpha^2 + \alpha\rho)}$$

$$(17.2) \quad \Delta_1(A, A) = E\Pi_1(A, A) - E\Pi_1(NA, A) = \frac{1}{36}[5\alpha - 3\alpha^2 + \alpha(1 - \alpha)\rho]$$

Property 3

Under assumptions (1)-(3),

- (a) $\Delta_1(A, NA) > 0, \quad \Delta_1(A, A) > 0$
- (b) $\frac{d\Delta_1(A, NA)}{d\alpha} > 0, \quad \frac{d^2\Delta_1(A, NA)}{d\alpha^2} < 0$
- (c) $\frac{d\Delta_1(A, A)}{d\alpha} > 0$ if $0 < \alpha < \frac{\rho+5}{2(\rho+3)}$
- $\frac{d\Delta_1(A, A)}{d\alpha} < 0$ if $\frac{\rho+5}{2(\rho+3)} < \alpha < 1$
- $\frac{d^2\Delta_1(A, A)}{d\alpha^2} < 0$
- (d) $\frac{d\Delta_1(A, NA)}{d\rho} > 0, \quad \frac{d\Delta_1(A, A)}{d\rho} > 0$

Part (a) and (b) of the properties provide similar pattern as monopoly and social planner's case. However, part (c) provides different shape from previous cases. Most importantly, the incentive function is not monotone within its domain. When the other farm invest, the incentive will decrease if

$\frac{\rho+5}{2(\rho+3)} < \alpha$. This implies that even if the adaptation measure provides better outcome which is close to normal yield ($\alpha \cong 1$), the firm will less willing to invest in the range. We can interpret the result as a "competition effect" in the market. The higher gain from an investment could increase supply to the market, which could decrease price. Due to price drop, the gain from investment is offset by competition in the market so net gain will not cover investment cost. In addition, we can infer that the range in which

the incentive decline is wider for higher ρ , i.e. $\frac{d}{d\rho} \left[\frac{\rho+5}{2(\rho+3)} \right] < 0$. Hence, the competition effect will be steeper when the distributions are positively correlated. We also find that when ρ goes to negative one, $\frac{\rho+5}{2(\rho+3)}$ converges to one. This indicates that when the distributions exhibit perfect negative correlation, there is no competition effect. In case of the perfect negative correlation, the other farm's adaptation

investment outcome is in place oppositely. Hence, a farm's adaptation outcome does not coincide with the other's outcome in the market so the competition effect goes away. However, zero competition effect does not guarantee higher incentive to adapt. From part (d), we can find that the incentive increase as ρ increase. When ρ is smaller and becomes closer to negative one, other player's normal outcome is highly likely although there is little competition effect by the other's adaptation. Therefore, there is little room to accrue additional profits by investing to adaptation.

The properties discussed above do not provide any information whether a firm will adapt or not. When the adaptation cost is κ , we can show following propositions for Nash equilibrium hold.

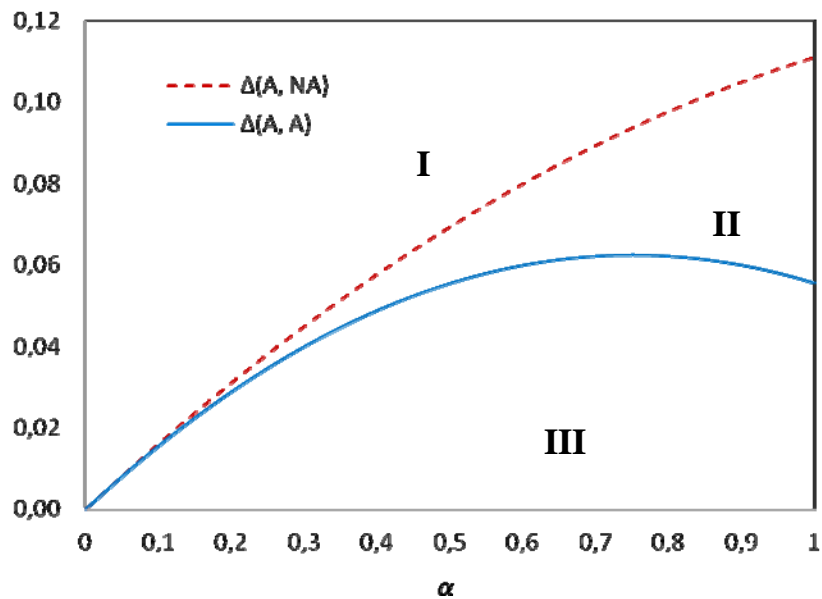
Proposition 1

- (a) If $\kappa > \Delta_1(A, NA)$, then NA is a dominant strategy for each farm. Hence, (A, A) is a unique Nash equilibrium (Area I).
- (b) If $\Delta_1(A, NA) > \kappa > \Delta_1(A, A)$, then (A, NA) or (NA, A) are Nash equilibriums (Area II).
- (c) If $\kappa < \Delta_1(A, A)$, A is a dominant strategies for each farms. Hence, (NA, NA) is a unique Nash equilibrium (Area III).

Figure 1 depicts a farm's incentive to adapt when $\rho=1$. Also it provides boundaries for Nash equilibrium. These boundaries can be interpreted in two ways. For fixed κ , it shows threshold of α for which certain Nash equilibrium holds. For fixed α , it provides threshold of adaptation cost. If the adaptation cost is sufficiently high, both farms will not adapt. In order to lead both farms to invest, in contrast, we found that the adaptation should guarantee higher effectiveness for given adaptation cost (Area I). If the other invests, a firm will be more stringent to the investment because it could increase competition in the market. Finally, given that the other does not invest, a farm will have loose thresholds. Naturally, if the other does not invest, the potential threat of competition will shrink. Then the firm could care more about own production risk, which lead more incentive to invest. Especially, as shown in the

figure, (A, NA) or (NA, A) are easily attainable relatively when the adaptation is highly effective (α is large) due to the competition effect.

[Figure 1] A farm's incentive to adapt in duopoly ($\rho=1$)



Now we can summarize magnitude of the incentives across various market structures in the following proposition.

Proposition 2

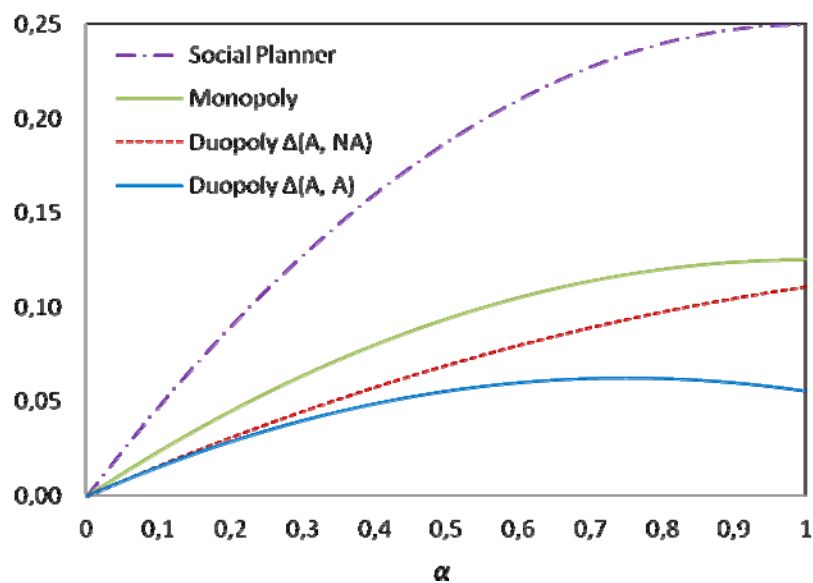
Under assumptions (1)-(3),

$$\Delta_{\pi} > \Delta_m > \Delta_1(A, NA) > \Delta_1(A, A)$$

The proposition indicates monopolist has higher incentive to adapt (figure 2). Since the monopolist has sole control of the market, the effect of adaptation is directly translated to additional profit stream. This result is comparable to R&D investment incentive in the industrial organization literature. In the

traditional studies, the monopolist gains less since it replaces itself by innovating (Tirole 1988). However, the replacement effect plays a positive role in our model. Specifically, monopolist put highest efforts to adapt since it directly recovers its profit loss under climate change. However, the competition and strategic interaction may lower additional profit potentials which lead less incentive to adapt in the oligopoly. However, as shown in figure 2, although the monopolist has highest incentive to adapt, the magnitude is much smaller than socially optimal level. Finally, we shortly consider the incentives in perfectly competitive market. A farm in the competitive market has very small incentive to adapt if land use is inflexible as shown in our model. In the competitive market, a farm only produce tiny amount of the total market supply. If the farm cannot expand business along with adaptation investment, there is little potential to obtain additional profit by adapting. Hence, the farm will not adapt even with small adaptation cost.

[Figure 2] A farm's incentive to adapt across market structures ($\rho=1$)



4. Conclusion

When accounting for adaptation strategies to climate change, previous studies normally focus on pure benefit (e.g., yield enhancing effect) or pure cost (e.g., investment cost). We showed that this benefit and cost accounting has ignored potential gain or loss in the market context. Using theoretical model, we showed that the thresholds which lead farmers to adapt vary across market structure. Hence, the competition effect in the market should be taken into consideration. Especially, our model provides strong implications for the agricultural production where land use change is inflexible. For example, our model suggests that adaptation in perennial crop production could be limited by market structure.

Our model could be extended in several aspects. First, agricultural product markets are regulated in some manner. For example, policy tools such as price floor or ceiling could have implications for competition effect. Presence of marketing board or marketing order could also give us some insights on the competition in the market. Second, adaptation strategies are seldom implemented in response to climate change alone (Adger et al., 2007). Hence, an adaptation measures could have interaction with other variables in the production or they could have externalities outside production. We could extend our result by taking the problem into consideration. Finally, we have just examined homogeneous firms, however, firm heterogeneity is an important factor affecting firm adaptation decisions.

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