Understanding Conflicting Interests of a Government and a Tobacco Manufacturer: A Game-Theoretic Approach

Md. Tanveer Ahmed
Business Analytics, Dow AgroSciences

Jun Zhuang
Department of Industrial and Systems Engineering
University at Buffalo

Changhyun Kwon
Department of Industrial and Management Systems Engineering
University of South Florida
(Corresponding Author, chkwon@usf.edu)

Abstract

Rice is the staple food of nearly half of the population of the world, most of whom live in developing countries. Ensuring a domestic supply of rice from outside sources is difficult for developing countries as less than 5% of the total world's production is available for international trade. Hence, in order to ensure domestic food security, e.g., food availability and access, governments provide subsidies in agriculture. In many occasions, public money used for the subsidy goes toward promoting undesirable crops like tobacco. Although the strategic interaction between governments and manufacturers is critical, it has not been studied in the literature. This study fills this gap by considering a game between a government (of a developing country) and a tobacco manufacturer in which the government decides on a mix of subsidies and the tobacco manufacturer decides on declaring a purchasing price of tobacco. We provide a numerical study to show that controlling the output harvest price is more effective in reaching the desired end result for both the government and the tobacco manufacturer. A subsidy in fertilizer results in the measurable increase in the government spending but does not have significant effect in reaching the production target. The fertilizer subsidy should be provided only when the output price is too high to be affordable for the population.

Keywords: Farming; Subsidy; Food security; Rice; Tobacco; Nash Equilibrium

1 Introduction

As part of Millennium Development Goals 2000, the world leaders committed to eradicate poverty and hunger, including "to halve the proportion of people who suffer from hunger" between 1990 and 2015 (United Nations General Assembly, 2000). However, 925 million people were still estimated to be undernourished in 2010 and represented 16% of the total population of developing countries, which is still well above the target (Food and Agriculture Organization, 2010). About 98% of undernourished people in the world live in developing countries. Accordingly, ensuring food security becomes a major challenge for these developing countries. Many countries, both developed and developing, are addressing the need for food security. As of 2011, 56 countries have constitutional provisions on the right to food;

among them 23 have explicit provisions (Knuth and Vidar, 2011). This list even includes many developed nations i.e., like the Netherlands, Germany, Finland and Brazil.

Food availability as well as food access constitutes food security (World Health Organizations, 2011). Food security can be ensured through an adequate supply of food at an affordable price. Due to limited availability from international sources, domestic food production is an important instrument in this regard. An adequate, balanced, affordable, and timely supply of fertilizer and other inputs of crop as well as reasonable price of harvest are necessary for higher domestic production of food. However, higher food price may lead to limited food access for the poor. The governments need to intervene in the market for maintaining a balance between producer and consumer interests, so that the overall progress in agricultural and food access for the poor are not compromised. For example, Japan, in 1999, spent at least 206 billion yen ($1.82 billion) as an incentive for rice production so that food availability was ensured (Fukuda et al, 2003).

There are some other benefits for subsidizing domestic rice production. First, governments, especially in developing countries need to build an inventory to provide food to the poor at a lower cost. For instance, in December 2012, the Indian Cabinet approved the 'Food Security Bill' that aimed at providing subsidized food grains to 75% of the rural population and about half of the urban households (BBC News India, 2011). Development of inventory under this bill will cost nearly $19 billion annually.

The governments also need to build up a sizable buffer of food to deal with emergency food crisis occurring during and after natural and man-made disasters. Since the availability of rice in the international market is limited, it is expensive and unreliable to depend on this as a major source food. If a country utilizes its domestic sources properly, it can ensure reliable and affordable food availability for the citizens.

In Appendix A, we provide general discussion for policy and farming issues related to rice and tobacco.

1.1 Debate on Agriculture Subsidy

For a long time, there has been a good amount of research, discussions, and debate on the issue of agriculture subsidies. The US Government's subsidies for agriculture range from $10 to $30 billion each year (Edwards, 2009). However, since the level and extent of agriculture subsidies varies between countries, it has been argued that subsidies have a trade-distorting potential and should be eliminated to create a level playing field for those who are involved in the trade of crops. While members of the WTO are unanimous in their endorsement of free trade, agriculture subsidy is being continued with developed countries being the leaders (Abboushi, 2007).

Should the countries continue to provide subsidy in agriculture? Wise (2004) examined the economic and policy aspects of the debate, and concluded that subsidy reduction will not solve the issue of trade-distortion. Rather, global and national level policy reforms are needed to end agricultural dumping, reduce global overproduction of key crops and decrease the power of agribusiness conglomerates. Gulati and Sharma (1995), Abboushi (2007) and Yusuf (2009) provided reasons against agriculture subsidy.

In a study on the effectiveness of subsidies on Egyptian agriculture, Von Braun and De Haen (1983) analyzed the effects of price and market intervention policies on agricultural income, the welfare of producers and consumers, and the government budget. According to

Wiggins and Brooks (2012), input (fertilizer, seeds, etc.) subsidies involve significant expenses to the nations and thereby need to be contemplated with caution, with a clear consideration of the costs and benefits. In many cases, input subsidies are difficult to justify and once in place are difficult to remove due to politics. Input subsidies, if necessary, should be targeted as effectively as possible, should work with the market, and be time-bound. Chambers and Quiggin (2005) investigated the effect of an output price subsidy on a farm encountering a stochastic output price and a stochastic technology. The impacts of risk-aversion, subsidy choice and choice of utility function on optimal farm planning were studied by Lien and Hardaker (2001) in Norwegian agriculture. Their study found that factors such as subsidy scheme and market conditions are more important on the optimal plans than farmers' risk preference or the choice of utility function. Therefore, subsidy policies can influence farmer's decision on the choice of crop.

1.2 Contributions of This Research

With all the debates about benefits and dis-benefits of subsidies, elimination of subsidies in agriculture may not be possible at all and the governments will continue to provide subsidies to agriculture. However, such significant subsidies will create a major challenge in achieving fiscal balance and a blanket subsidy may lead to sub-optimal outcome. Even worse, it may benefit those who do not need support for sustenance and/or promote undesirable crops like tobacco. Therefore, the mechanism of subsidies should be devised so that it can provide desired end results. In essence, the *interaction* between the governments and tobacco manufacturers through subsidies is critical and needs to be considered before making subsidy decisions. To our knowledge, there has not been any study about devising a subsidy mechanism considering this interaction so that optimal decisions can be made in this regard.

In particular, this paper considers a noncooperative game between the government and the tobacco manufacturer and provides a mathematical formulation for the corresponding Nash equilibrium problem. In this paper we do not consider a cooperative game because there is no natural collision to form, or collective payoffs to share, in the studied government-manufacturer context. Our formulation captures the interaction between the two players regarding the subsidy and other price decisions. Through a numerical study, we try to understand the best reactions of the government and the tobacco manufacturer and analyze the dynamics of equilibrium.

1.3 Outline

In this paper, we begin with the general framework of the game between the Government and the Tobacco Manufacturer (Section 2). In Section 3.1, the preliminaries of the farming decision model are introduced. We have the Government's problem and the Tobacco Manufacturer's problem in Section 3.2 and 3.3 respectively. We prove the existence and uniqueness of the Nash Equilibrium and propose a method to obtain the solution in Section 4. We provide numerical results in Section 5 which comprise of the best response study and the analysis of equilibrium dynamics (Sections 5.1 and 5.2 respectively). Next, we provide managerial insights (Section 6). Section 7 concludes the paper along with possible future research directions.

2 The Framework of the Noncooperative Game

In this study, we consider a farming situation in a developing country, in which we assume the government and the tobacco manufacturer plays a noncooperative game. Each farmer has a piece of land of unit size (one hectare). In making a decision about the choice of crop to farm, a farmer has three alternatives: (i) rice, (ii) tobacco, and (iii) other crops (cotton, jute, vegetables, non-conventional crops, etc.). We list the notations used in this paper in Table 1 and Figure 1 shows the farming alternatives available. To make sure that the margin for growing rice reasonable, farmers are given a subsidy in agricultural input to reduce the cost of farming. In this study, we consider that the Government provides a subsidy in fertilizer, the main input of rice farming. To protect farmers so that they get a reasonable return as well as to keep the market price of rice affordable for general people, the Government intervenes to influence the market price of rice. We assume that the purchase volume of rice is sizable so that the intervention is effective.

Index	
i	Index for crops; $i = r$ for Rice, $i = t$ for Tobacco
j	Index for fertilizer $j = 1, \ldots, n$
Parameter	
M	Total number (amount) of farmers (land available)
I_t	Unit cost (revenue) to out-source (export) tobacco
F_{ij}	Required amount of fertilizer j for crop i per unit land
Ψ_i	Cost of other agricultural input for crop i per land
Π_j	Sourcing cost of fertilizer j
q_i	Average expected production of crop i in a unit piece of land
α_r	Target rice production
β_r	Maximum allowable expected market price of rice
G_r	Government's Purchase target
ξ_t	Total amount of tobacco the Tobacco Manufacturer need
η_t	Minimum domestic tobacco sourcing target
λ_t	Fraction of domestic tobacco purchased by the Tobacco Manufacturer
Θ_i	Probability of farming crop i
Variables	
p_i	Declared unit purchase price of crop i (Decision variable)
π_j	Unit market price for fertilizer j (Decision variable)
ϕ_i	Market price of crop i (Random Variable)

Table 1: Index, Parameters and Variables

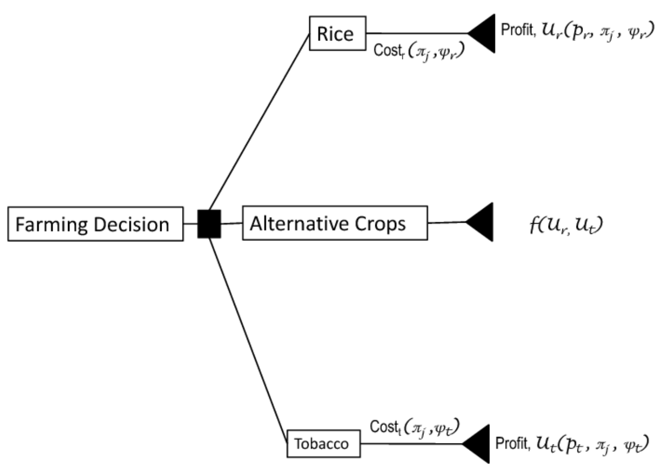

Figure 1: The Farming Alternatives

The Tobacco Manufacturer, on the other hand, wants tobacco farming purely from commercial intent. Because of market structure discussed in Section 1.3, we assume that the Tobacco Manufacturer has a monopoly at the country level. The Tobacco Manufacturer, simultaneously with the Government's decision on fertilizer price and rice purchase price, declares a maximum purchasing price of tobacco, which acts as the upper bound for market price of tobacco. If enough farmers do not go for tobacco farming, the Tobacco Manufacturer has to go to the international market and source the raw tobacco at a price determined by the world's supply and demand scenario. Figure 2 shows the general framework of this game.

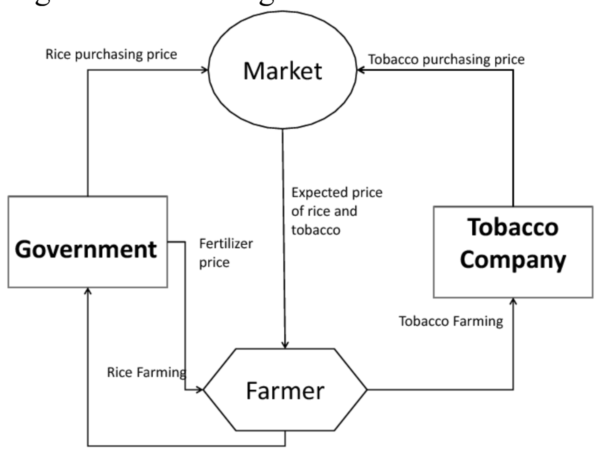

Figure 2: The Framework of the Game between the Government and Tobacco Manufacturer

3 Farming Decision Model

We consider a simultaneous game between the Government and a single Tobacco Manufacturer who has a country level monopoly of tobacco market. Both of them want to influence the farming decision of farmers. We assume that there are M farmers each owning a unit piece (one hectare) of land. Therefore, we assume that M hectares of land are available for farming. The government can set the level of subsidy on fertilizer $\pi_1, \dots, \pi_n$ and the declared purchasing price of rice p_r. The Tobacco Manufacturer, at the same time, declares the maximum tobacco purchasing price, p_t. These decisions play critical roles in the game we model and analyze.

3.1 Preliminaries

We consider a situation where a farmer needs to decide whether he should go for rice or tobacco production or not producing either of these two. It is reasonable to assume that a farmer makes a decision for planting any specific crop on the basis of his assessment of profit and loss. We propose that the farming decision on a specific crop depends on the monetary utility of farming that crop and potential loss of opportunity for not choosing the alternatives. We assume the utility of farming a crop is comprised of expected market price of harvest, cost and required amount of fertilizer and other inputs of farming. In particular, we could assume the following linear expected utility function for farming crop $i \in \{r, t\}$:

$$U_i(p_r, p_t, \pi_1, \dots, \pi_n) = \Phi_i q_i - \sum_{j=1}^{n} F_{ij}\pi_j - \Psi_i \tag{1}$$

where Φ_i is the expected market price of crop $i \in \{r, t\}$. In particular, we define Φ_r and Φ_t in the following way:

$$\Phi_r = \mathbb{E}[\phi_r | \phi_r \geq p_r] = \int_{p_r}^{\infty} \frac{\phi_r f_r(\phi_r)}{1 - \int_0^{p_r} f_r(\phi_r) d\phi_r} d\phi_r \tag{2}$$

$$\Phi_t = \mathbb{E}[\phi_t | \phi_t \leq p_t] = \int_0^{p_t} \frac{\phi_t f_t(\phi_t)}{\int_0^{p_t} f_t(\phi_t)} d\phi_t \tag{3}$$

where $f_i(\phi_i)$ is the probability density function of market price of crop $i \in \{r,t\}$. $f_i(\phi_i)$ can be obtained by analyzing the historical price of rice and tobacco. For rice, p_r is the guarantted price for framers, while for tobacco, p_t is the maximum price.

For $i \in \{r,t\}$, we have the following lemma to specify the change of expected price Φ_i with respect to p_i.

Lemma 1 *The expected market price of $i \in \{r,t\}$ ϕ_i increases as p_i increases, i.e.,* $\frac{\partial \Phi_i}{\partial p_i} \geq 0$.

Proof. The proof is found in Appendix. In the rest of this paper, all omitted proofs are also found in Appendix.

Let $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ and $\Theta_{-i}(p_r, p_t, \pi_1, \dots, \pi_n)$ denote the probability of farming crop i and $k \neq i$ respectively . In order to characterize Θ_i, we begin with the following definition.

Definition 1 *A mapping F from $K \subset \mathbb{R}^n$ to $\mathbb{R}^n$ is contractive and Lipschitz continuous with modulus L if there exists a constant $0 \leq L < 1$ such that:*

$$||F(x) - F(y)|| \leq L||x - y||$$

for all $x, y \in K$.

Assumption 1 *For each $i = \{r,t\}$, $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ satisfies the following regularity properties:*

(a) $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ is contractive, Lipschitz continuous, and differentiable.

(b) $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ is increasing with U_i i.e., $\frac{\partial \Theta_i}{\partial U_i} > 0$.

(c) $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ is increasing with U_{-i} i.e., $\frac{\partial \Theta_i}{\partial U_{-i}} < 0$ where U_{-i} is the utility of farming crop $k \neq i$.

Assumption 1(a) is made so that the change in $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ is not larger than the change in the utility function. In other words, this assumption states that the market does not behave abnormally. Assumptions 1(b) and 1(c) are standard. The widely used random utility model could be used as a reasonable choice to model $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$. In particular, the following function satisfies Assumption 1:

$$\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n) = \frac{\exp\left(\frac{-k_i}{U_i(p_r, p_t, \pi_1, \dots, \pi_n)}\right)}{1 + \sum_{i=r,t} \exp\left(-\frac{k_i}{U_i(p_r, p_t, \pi_1, \dots, \pi_n)}\right)} \tag{4}$$

where k_i is a constant and U_i is defined by Equation (1). In this study, we will use the random utility model defined by Equation (4) to specify the decision process of the farmers. With Assumption 1, we have the following lemma:

Lemma 2 *For each $i \in \{r,t\}$, $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ increases as p_i increases and decreases as p_{-i} increases, i.e.,* $\frac{\partial \Theta_i}{\partial p_i} > 0$ *and* $\frac{\partial \Theta_i}{\partial p_{-i}} < 0$ *where p_{-i} is the declared purchase price of crop*

$k \neq i$.

Assumption 2 *For each* $i \in \{r, t\}$, $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ *is strictly concave with respect to* p_i, *i.e.,* $\frac{\partial^2 \Theta_i}{\partial p_i^2} < 0$.

Assumption 2 states that Θ_i increases at a decreasing rate as p_i increases. This is reasonable if we assume rational market behavior which follows Assumption 1 and Lemma 2. Again, the random utility model specified by Equation (4) satisfies Assumption 2.

Note that as π_j increases, both U_r as well as U_t decreases. Also, as $\Theta_r + \Theta_t < 1$, at least one of Θ_i and Θ_{-i} will be decreasing. Whether Θ_i is decreasing or increasing, the sign of $\partial\Theta_i / \partial\pi_j$ is expected to remain same. Hence, we assume the following:

Assumption 3 *For each* $i \in \{r, t\}$, $\Theta_i(p_r, p_t, \pi_1, \dots, \pi_n)$ *is monotone in* π_j *for all* $j = 1, \dots, n$.

The random utility model defined by Equation (4) also satisfies Assumption 3

3.2 Government's Problem

The Government intends on minimizing expense and while fulfilling the obligation of food availability and food access. This can be achieved through minimizing the cost of purchasing rice as well as the subsidy of fertilizer that is used for production of rice and tobacco. The production should meet production targets and a desired market price of rice. The problem can be formulated as:

$$\begin{aligned}\min_{p_r, \pi_1, \dots, \pi_n} \ & \mathbf{Gv}(p_r, p_t, \pi_1, \dots, \pi_n) \\ = \ & \underbrace{p_r G_r}_{\text{purchase cost (rice)}} + \underbrace{M c_r q_r \Theta_r(p_r, p_t, \pi_1, \dots, \pi_n) \textstyle\sum_{j=1}^{n} F_{rj}(\Pi_j - \pi_j)}_{\text{fertilizer subsidy (rice)}} \\ & + \underbrace{M c_t q_t \Theta_t(p_r, p_t, \pi_1, \dots, \pi_n) \textstyle\sum_{j=1}^{n} F_{tj}(\Pi_j - \pi_j)}_{\text{fertilizer subsidy (tobacco)}} \end{aligned} \tag{5}$$

subject to

$$M q_r \Theta_r(p_r, p_t, \pi_1, \dots, \pi_n) \geq \alpha_r \tag{6}$$

$$\Phi_r = \mathbb{E}[\phi_r | \phi_r \geq p_r] \leq \beta_r \tag{7}$$

$$0 \leq \pi_j \leq \Pi_j \qquad \text{for} \quad j = 1, \dots, n \tag{8}$$

$$p_r \geq 0 \tag{9}$$

where c_r and c_t are constants. Also, we assume $c_r < c_t$ as a subsidy for tobacco is less preferable than that of rice. The Government objective Function (5) consists of total rice purchase cost, fertilizer subsidy for rice and fertilizer subsidy for tobacco. Constraint (6) specifies that the rice production target is met while Constraint (7) ensures that the expected market price of rice does not exceed the Government's intended price limit. As the Government should not make a profit in a fertilizer subsidy, Constraint (8) is introduced. The last constraint refers to non-negativity of decision variable p_r. Constraint (7) could be used to obtain the upper bound of p_r and hence we make the following proposition:

Proposition 1 *For any values of* p_t *and* π_j, *there exists a unique* $\tilde{p}_r$ *such that:*

$$\Phi_r = \int_{p_r}^{\infty} \phi_r f_r(\phi_r | \phi_r \geq \tilde{p}_r) d\phi_r = \beta_r \tag{10}$$

Differentiating $\mathbf{Gv}(p_r, p_t, \pi_1, \dots, \pi_n)$ with respect to p_r, we obtain:

$$\mathbf{Gv}'_r = G_r + M c_r q_r \frac{\partial \Theta_r}{\partial p_r} \sum_{j=1}^{n} F_{rj}(\Pi_j - \pi_j) + M c_t q_t \frac{\partial \Theta_t}{\partial p_r} \sum_{j=1}^{n} F_{tj}(\Pi_j - \pi_j) \tag{11}$$

where $\mathbf{Gv}'_r$ denotes first order differentiation of $\mathbf{Gv}$ with respect to p_r. Following Lemma 2, the second part of $\mathbf{Gv}'_r$ is positive while the last part is negative. Note that, we assume that the Government as a buyer can influence the market price of rice. Therefore, the value of G_r is fairly large and we can make the following assumption:

Assumption 4 *The value of G_r is large enough so that we have*

$$\mathbf{Gv}'_r|_{p_r \leq \tilde{p}_r} > 0$$

Now, differentiating $\mathbf{Gv}$ with respect to π_j, we obtain:

$$\mathbf{Gv}'_j = M\Big[c_r q_r \sum_{j=1}^{n} F_{rj}(\Pi_j - \pi_j) \frac{\partial \Theta_r}{\partial \pi_j} + c_t q_t \sum_{j=1}^{n} F_{tj}(\Pi_j - \pi_j) \frac{\partial \Theta_t}{\partial \pi_j} - \sum_{i=\{r,t\}} c_i q_i F_{ij} \Theta_i\Big] \tag{12}$$

Note that at least one of the first two terms in Equation ((12)) is negative while the last two terms are negative. To avoid extreme (and unrealistic) values of parameters, we may assume that $\mathbf{Gv}'_j < 0$ for all $j = 1, \dots, n$.

Assumption 5 *The Government's objective function $\mathbf{Gv}$ is strictly monotone in p_r and π_j for all $j = 1, \dots, n$. In particular, $\mathbf{Gv}$ is increasing in p_r and decreasing in π_j for all $j = 1, \dots, n$.*

3.3 Tobacco Manufacturer's Problem

The Tobacco Manufacturer simply wants to minimize cost of sourcing tobacco while fulfilling a minimum sourcing target volume of tobacco. With this end in view, his goal is to minimize the total cost of sourcing the required amount of tobacco. The problem is formulated as follows:

$$\min_{p_t} \mathbf{Tc}(p_r, p_t, \pi_1, \dots, \pi_n) = \underbrace{p_t \lambda_t M q_t \Theta_t(p_r, p_t, \pi_1, \dots, \pi_n)}_{\text{sourcing cost (domestic)}} + \underbrace{I_t\{\xi_t - \lambda_t M q_t \Theta_t(p_r, p_t, \pi_1, \dots, \pi_n)\}^+}_{\text{out-sourcing cost}} - \underbrace{I_t\{\lambda_t M q_t \Theta_t(p_r, p_t, \pi_1, \dots, \pi_n) - \xi_t\}^+}_{\text{export earnings}} \tag{13}$$

subject to

$$\lambda_t M q_t \Theta(p_r, p_t, \pi_1, \dots, \pi_n) \geq \eta_t \tag{14}$$

$$0 \leq p_t \leq I_t \tag{15}$$

where $x^+ = \max(x, 0)$. The first part of Tobacco Manufacturer's objective function (13) is the cost of sourcing tobacco from the domestic market. The second part is the cost to out-source tobacco to cover up the shortage. The last part represents the earnings through exporting excess tobacco. Due to a blend recipe, which constitutes a minimum amount of domestic tobacco and to keep a domestic base of tobacco production, the Tobacco Manufacturer, in general, sets a minimum domestic sourcing target, η_t. Constraint (14) specifies this condition. It is not reasonable to set the domestic price of tobacco higher than the international sourcing price as pricing in the international market is based on commercial farming cost and shipping cost. The domestic sourcing does not involve shipping and may be subsidized (if any). For this, the last Constraint (15), along with non-negativity, specifies that $p_t \leq I_t$.

The Tobacco Manufacturer's objective Function (13) could be written in the following way:

$$\mathbf{Tc}(p_r, p_t, \pi_1, \dots, \pi_n) = I_t\xi_t + (p_t - I_t)\lambda_t M q_t \Theta_t(U_t, U_r) \tag{16}$$

To define the behavior of $\mathbf{Tc}(p_r, p_t, \pi_1, \dots, \pi_n)$, we propose the following:

Proposition 2 *Under Lemma 2 and Assumption 2(a), the function* $\mathbf{Tc}$ *in* (16) *is strictly convex on* $p_t \in [0, I_t]$.

4 Properties and Computation of Nash Equilibrium

Let us define the following:

$\Omega_r = [0, \tilde{p}_r]$

$\Omega_j = [0, \Pi_j]$ for $j = 1, \dots, n$

$\Omega_t = [0, I_t]$

$\Omega = \Omega_r \times \Omega_j \times \Omega_t$ for $j = 1, \dots, n$

$\omega \in \Omega = [p_r, \pi_1, \dots, \pi_n, p_t]^T$

We may write its optimality condition as the following variation inequality problem: to find $p_r^* \in \Omega_r, \pi_j^* \in \Omega_j \ \forall j = 1, \dots, n,\ p_t^* \in \Omega_t$ such that:

$$\frac{\partial \mathbf{Gv}}{\partial p_r}(p_r - p_r^*) \leq 0 \quad \forall p_r \in \Omega_r \tag{17}$$

$$\frac{\partial \mathbf{Gv}}{\partial \pi_j}(\pi_j - \pi_j^*) \leq 0 \quad \forall \pi_j \in \Omega_j \quad \text{andfor} \quad j = 1, \dots, n \tag{18}$$

$$\frac{\partial \mathbf{Tc}}{\partial p_t}(p_t - p_t^*) \leq 0 \quad \forall p_t \in \Omega_t \tag{19}$$

For the Government and Tobacco Manufacturer, we obtain the following variational inequality formulation for the equilibrium problem: to find $\omega^* \in \Omega$ such that

$$H(\omega^*)^T(\omega - \omega^*) \geq 0 \quad \forall \omega \in \Omega \tag{20}$$

where

$$H(\omega) = \left[\frac{\partial \mathbf{Gv}(\omega)}{\partial p_r}, \frac{\partial \mathbf{Gv}(\omega)}{\partial \pi_1}, \dots, \frac{\partial \mathbf{Gv}(\omega)}{\partial \pi_n}, \frac{\partial \mathbf{Tc}(\omega)}{\partial p_t}\right]^T$$

Proposition 3 (Existence and Uniqueness of Nash Equilibrium) *Under Assumption 5 and Proposition 2, a Nash equilibrium exists and it is unique.*

The variational inequality problem (20) is equivalent to the following fixed-point problem (Harker and Pang, 1990):

$$\omega = P_\Omega[\omega - \alpha H(\omega)] \tag{21}$$

where $\alpha > 0$ and $P_\Omega[\cdot]$ is the projection on Ω. In particular, $P_\Omega[x]$ can be defined as:

$$P_\Omega[x] = \text{argmin}_{y\in\Omega}||y - x|| \quad (22)$$

where $||.||$ is the norm (distance).

Note that (22) is a convex quadratic minimization problem, which can be easily solved. Based on (21), we will use the following basic projection (fixed point) algorithm:

$$\omega^{k+1} = P_\Omega[\omega^k - \alpha H(\omega^k)] \quad (23)$$

at each iteration k. Even though the fixed point algorithm proposed in (23) is considered slow for a large dimensional problem, it is simple and efficient for low dimensional problems like (20) (Jofre et al, 2005).

5 Numerical Results

In the numerical study, we consider a random utility model defined by equation (4) to evaluate Θ_i. We consider the case of only one fertilizer, i.e., $j = 1$. For the numerical experiments, the baseline parameter values are given in Table 2.

Parameter	Values	Unit	Parameter	Values	Unit
M	1000	hectare	I_t	1.5	$
F_r	150	kg/hectare	q_r	3440	kg/hectare
F_t	100	kg/hectare	q_t	2820	kg/hectare
α_r	1×10^6	kg	ξ_t	3×10^5	kg
G_r	1.2×10^4	kg	η_t	2×10^5	kg
β_r	0.75	$	Ψ_r	200	$
Π	0.5	$	Ψ_t	450	$
π	$\in [0.1, \Pi]$	$	λ_t	0.3	-
k_r	900	-	c_r	0.5	-
k_t	1000	-	c_t	1.2	-

Table 2: Baseline Parameter values

We assumed that both ϕ_r and ϕ_t are uniformly distributed with supports $\phi_r \in [0.3,1]$ and $\phi_t \in [0.5,1.5]$ respectively. From Constraint (7), we obtain $p_r \in [0.3,0.6]$. Also, we have $p_t \in [0.5,1.5]$.

5.1 Best Response of the Government and the Tobacco Manufacturer

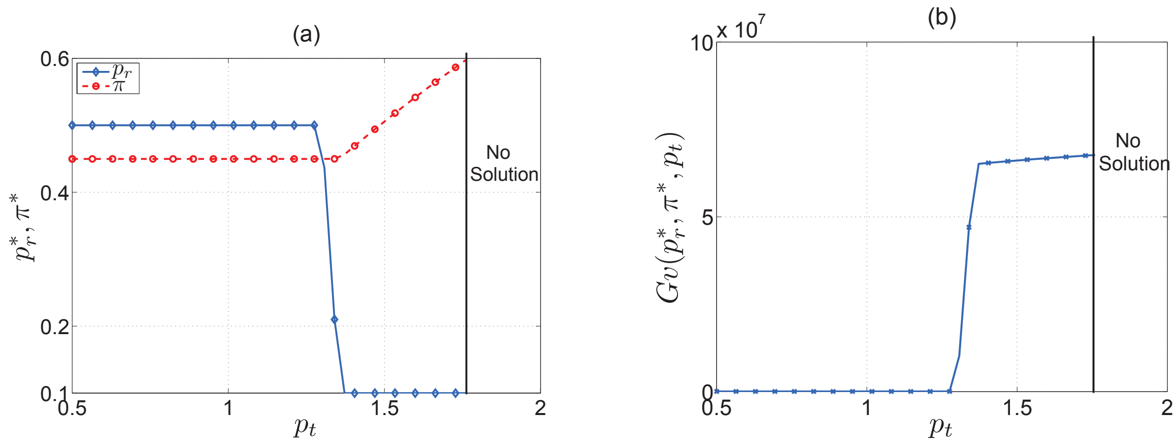

Figure 3: Best Responses (a) and the objective function value (b) of the Government as the price of tobacco changes

Figure 3(a) shows Government's best response (p_r^*, π^*) in response changes in tobacco price (p_t). For low values of p_t, the fertilizer price (π^*) is at the maximum, resulting in the minimum Government's fertilizer subsidy. As p_t increases, the best response for Government is lowering the fertilizer price (π^*) significantly to the lowest possible value. Similar to the fertilizer price, the optimal price of rice p_r^* remains the same for lower values of p_t. However, p_r^* starts to increase (almost linearly) to its maximum as p_t increases. There exists a tobacco price (p_t) beyond which there is no best response solution for the government. Figure 3(b) shows the corresponding objective function values of the Government where $\mathbf{Gv}^*$ increases as p_t increases. Note that there is a sudden increase on the value of $\mathbf{Gv}^*$ when the Government needs to provide fertilizer subsidy to reach the production target.

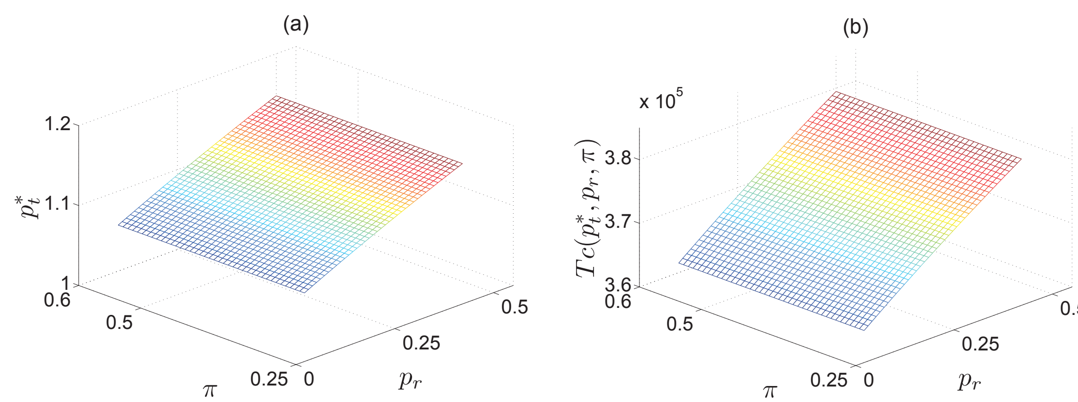

Figure 4: Best Response of the Tobacco Manufacturer

The Tobacco Manufacturer's best response p_t^* for different values of p_r and π is shown in Figure 4(a). In this case, we find that the Tobacco Manufacturer is highly sensitive to changes in p_r i.e., p_t^* increases as p_r increases. On the other hand, p_t^* is almost insensitive to π. Note that as the Government is constrained by the expected price of rice β_r, there is exists

p_t^* for any values of p_r unless π is extremely large. The corresponding objective values of the Tobacco Manufacturer is represented in Figure 4(b).

For the Government, a source level (input) subsidy is very expensive and this instrument should be used only if either high fertilizer prices deters farmers away for rice farming or market level subsidy is not enough to keep the market price of rice within reasonable limit (Figure 3) which conforms to the findings of Wiggins and Brooks (2012). The Government needs to increase the purchasing price of rice and on some occasions, decrease the fertilizer price when the price of tobacco increases. On the other hand, as we see in Figure 4, the price of fertilizer has very negligible effect on the Tobacco Manufacturer's decision even though he benefits from subsidy to the fertilizer. But, as the price of rice significantly affects the volume of tobacco production, the Tobacco Manufacturer needs to increase the tobacco purchasing price if the price of rice increases.

5.2 Analysis of Equilibrium Dynamics

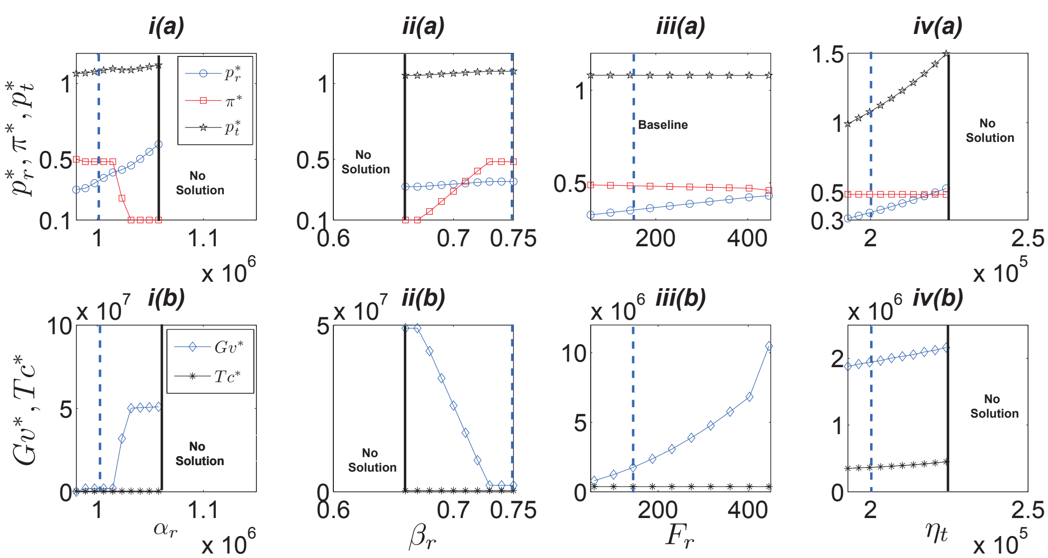

Figure 5: Equilibrium behaviors, sensitive to α_r, β_r, F_r, and η_t, with baseline values $\alpha_r = 1\times10^7$, $\beta_r = 0.5$, $F_r = 150$, $\eta_t = 2\times10^5$

Figure 5 shows the equilibrium behavior of the Government and the Tobacco Manufacturer for different values α_r, β_r, F_r, and η_t respectively. In particular, Figures 5i(a) to 5iv(a) show the changes in the decisions variables, while Figures 5i(b) to 5iv(b) shows the changes in the objective function values of the Government and the Tobacco Manufacturer. As we can see in figures 5i(a) to 5iv(a), the optimal rice price (p_r^*) changes as values of all parameter changes. However, p_r^* changes rapidly for α_r followed by η_t, F_r, and β_r respectively. The optimal tobacco price (p_t^*) increases rapidly as η_t increases (Figure 5iv(a)). Increase in α_r, also has similar effect on increase in p_t^* to a lower extent (Figure 5i(a)). Changes in β_r has a very small effect on p_t^* while F_r almost have no effect at all

(Figures 5ii(a) and 5iii(a)). For lower values of α_r, the optimal fertilizer price (π^*) remains same but π^* decreases suddenly as the rice production target α_r increased to cross a threshold value and then remains same for higher values of α_r (Figures 5i(a)). From figure 5ii(b), π^* increases as the allowable maximum rice price β_r increases. The optimal fertilizer price π^* is almost insensitive to changes in F_r, and η_t (Figures 5iii(a) and 5iv(a)). Note that for the given range of values for all parameters except F_r, for certain parameter values (higher values for α_r, η_t and lower values for F_r,), there is no equilibrium best response solution.

Note that the price of rice increases as the production target α_r as well as expected market price β_r increases which also results in increase of tobacco purchasing price [Figures 5i(a) and 5ii(a)]. However, as the required quantity of fertilizer F_r increases [Figure 5iii(a)], the Government needs to reduce the fertilizer subsidy by increasing price of fertilizer while increasing in purchasing price of rice marginally. At the same time, the increase of purchasing price of tobacco is almost negligible. In Figure 5iv(a), we see that the purchasing price of tobacco increases as the minimum requirement of tobacco η_t increase which has significant effect on the purchasing price of rice while the effect on fertilizer price is negligible.

6 Conclusion

For the governments, subsidies are a vital policy instrument in promoting agriculture to secure a strong domestic supply of food at a reasonable output price so that a sustainable food security is obtained. For this, subsidies are required both at the source (farming) level and at the user (consumer) level. Rice, being at the center of food security for a large population of the world, requires special attention and often subsidies are provided for rice farming. However, even though subsidies at the source may be necessary to achieve the production target as well as keeping the market price of rice within the reach of the poor, it may promote an undesirable crop, tobacco. Therefore, the interaction between the government and the tobacco manufacturer needs consideration in making decisions regarding the allocation and mix of subsidies so that it can achieve production target with minimum cost. Even though the subsidy decision considering government-industry interaction is crucial for a successful agricultural policy, this problem is yet to be studied in the literature of Operations Research.

In this study, we considered a game between a government and a tobacco manufacturer. The government decides on a mix of subsidies so that the farming of rice has a reasonable return on investment while the output price does not exceed a certain level so that total amount of subsidy is minimized. The input subsidy is provided by the changing price of fertilizer, the main input of agriculture. The government intervenes and manipulates the market price of rice so that the output level subsidy can be used in this regard. On the other hand, minimizing the sourcing cost of tobacco is the sole intent of the tobacco manufacturer. As the tobacco manufacturer has a monopoly on country level, the price of tobacco can be manipulated to minimize the cost of sourcing tobacco. Due to recipe of blends, we assumed that the tobacco manufacturer needs to meet the minimum domestic sourcing target.

In summary, the purchasing prices of rice and tobacco have significant impact on the farming decision. The price of fertilizer, at least when we consider two options, namely, rice and tobacco, has very little impact even though fertilizer has a large impact in the volume of the government subsidy. Therefore, the government, when avoidable, should try to minimize any fertilizer subsidy. On the contrary, the tobacco manufacturer has negligible effect on the price of fertilizer.

Along with the subsidy level of fertilizer and the prices of rice and tobacco, the farming decision may depend on many issues, i.e., the historical price of crops, the effects of natural disaster of specific crops, the risk attitude of the farmers, and the return on farming of other crops. The historical price of rice and tobacco may be used to assume the probability distribution of the price. In order to consider a game that incorporates a natural disaster, we need to include both the probability of the disaster and its consequences or impacts. In making the farming decision, the risk-attitude of the farmers may be considered. However, the authors expect similar results in that study. The choice of the random utility model to describe the probability of farming rice and tobacco partly captures the option of the alternative crops. However, an explicit consideration of alternative crops in future research may lead to interesting results and provide more insights.

As a future research direction, we can collect and analyze large data related to public health, agriculture and trade and commerce to understand the impact of public policy on agriculture, business environment and change of strategy by tobacco manufacturers to adapt to policy evolutions. Analysis on this data is now possible with ever increasing computational and storage capability. This can be used to validate and augment the understanding this research.

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Appendix

A. Background

A.1 Rice as a Cereal

Rice is the most popular cereal in the world, and serves 39 countries with nearly half of the world population as a stable food (Juliano, 1993). Rice is produced on all continents except Antarctica and produced in more than 100 countries (Dexter, 1998). Developing countries, of which 92% are in Asia, account for about 95% of the world's rice production (Juliano, 1993). Less than 5% of rice produced in the world is traded in international markets (Dexter, 1998). As a result, ensuring a domestic supply of rice is very risky and could be very expensive. Therefore, developing countries need to make sure that the domestic rice production is sufficient.

For many developing countries, food security means self-sufficiency in rice production and stability in the market price of rice (Hossain et al, 2005). As a result, rice occupies the center stage of food security concerns for the developing countries. The developing countries focus on increasing the production of rice to keep the market price of rice affordable. For example, in Bangladesh, rice occupies 71% of the gross crop area and accounts for over 94% of food grain production (Rahman and Khan, 2005). Its contribution to total per capita calorie and protein intake is 74% (Hossain et al, 2005). Consequently, the Government of Bangladesh takes a lot of policy actions around the production, supply and price of rice.

A.2 Subsidy for Food Security

Fertilizer is one of the key inputs for increasing rice yields and its contribution to rice production is about 50-60% (Kafiluddin and Islam, 2008). Therefore, the availability and affordability of this key input (fertilizer) have become critical prerequisites for sustaining productivity. To address this important issue, the governments of the developing countries have taken the necessary initiatives to ensure production, import, distribution and marketing of fertilizer. To make fertilizer affordable for farming, developing countries often provide subsidies so that the price of fertilizer is within a reasonable limit. Such *indirect* subsidies raise returns on farm investment by reducing input cost and help the farmers obtain a reasonable profit even when the market price for rice is low. In Bangladesh, for example, the 2011 farm level unit (per ton) prices of urea, muriate of potash (MoP) and diammonium phosphate (DAP) were about \$194, \$208 and \$375 respectively while in the international market, these three fertilizers were trading around \$377, \$390 and \$600 (The Daily Star, 2010, 2011; Fertilizer International Blog, 2011). For fiscal year 2010–2011, the estimated fertilizer subsidies of Bangladesh amounted to nearly \$1 billion (The Daily Star, 2011).

Due to public health concerns surrounding tobacco use, the rapid depletion of soil nutrients and the environmental hazards during tobacco planting and processing, the governments do not want to encourage tobacco farming. However, banning tobacco farming may not be legally possible, as it is not considered an illegal drug. To make things worse for the governments, the *indirect* (fertilizer) subsidies also benefit tobacco farming and thereby public money is used for subsidizing an undesirable crop, tobacco. Also, the input level (fertilizer) subsidy may induce the over-production of rice creating imbalance between supply and demand. This may lower the market price of rice reducing profit margin for the farmers.

To mitigate the issue of a low market price of rice, the developing countries intervene by announcing a direct purchase price from farmers and fulfill a procurement target. However, such intervention may raise the market price of rice and could affect the affordability to the general people. The governments also want to run a balanced budget with limited funds and a large subsidy allocation may crowd out spending in other important areas. To avoid this, the governments need to control subsidy expenditures. Therefore, it is reasonable that efforts should be made such that food availability as well as food access is ensured while the amount of the subsidies are as low as possible.

A.3 Farming and Market Characteristics of Tobacco

Tobacco farming, in recent years, is shifting to developing countries where there is less ability to influence production practices (World Wildlife Fund, 2011). Cultivated in over 100 countries, developing countries produce more than 80% of the world's tobacco (van Liemt, 2002). This trend creates a significant environmental, socio-economical and public health challenge for these countries. Clearing forests to make way for tobacco farming as well as sourcing wood for drying tobacco causes serious environmental damage. For example, the WWF (Wolrd Wildlife Fund, 2011) reported that about 200,000 hectares of woodlands are cut every year to support tobacco farming in South Africa alone. Continuous inhalation of the tobacco smoke may lead to illness like dizziness, nausea and vomiting. Dermal absorption of nicotine during harvesting often causes 'green tobacco sickness'.

An extensive report by Otanez (2008) highlighted the worldwide negative experience of tobacco farming. Each tobacco crop requires nine times as much work as in bean production, namely 200 days per person every year. In a nine-month growing season, each tobacco farmer may take care of 400,000 individual leaves. As seasonal workers in agriculture are almost impossible to find, farmers are inclined to use their families, especially children. About 82% of the 6 million children work in agriculture in Bangladesh. They cultivate tobacco and monitor the drying barns at night, for free. The tobacco industry is one of the largest contributor to the government treasury. As a result, the government of Bangladesh does not want loose the revenue from this source. However, the direct and indirect costs of tobacco-related diseases and social dis-benefit offset the revenue from this crop. Also, the subsidies given for farming input, especially fertilizer used for farming tobacco, add to the benefit of tobacco farming as well.

Hence the government's actual gain in tobacco related activity is far less than the apparent tax obtained from this sector. However, banning tobacco farming through legal instruments is not possible, as tobacco is not recognized as an illegal drug. Rather, governments should develop policies and act accordingly to curb tobacco farming.

No other product has stimulated the demand for tobacco as much as the cigarette. Now, over 80% of tobacco grown is used for cigarettes and around 72% of the world's smokers live in developing countries (van Liemt, 2002). The world market for cigarettes is dominated by a small and steadily diminishing number of suppliers. In 1999, three companies (CNTC at 30%; Philip Morris at 17%, and BAT at 16%) controlled close to two-thirds of the world's cigarette production. At a country level, the supply of cigarettes is almost a monopoly in many cases (van Liemt, 2002). As a result, the dominant supplier, at the national level, becomes a force to be reckoned with.

The cigarette manufacturers, henceforth termed as the tobacco manufacturers, make intensive use of domestic tobaccos. To ensure a domestic source of tobacco at a low price, they strive to build a class of (registered) farmers in the country. These registered farmers receive seed, fertilizer, pesticides, and other inputs from the companies as a loan, so that the farmers do not require any significant investment. The farmers who are not registered, grow tobacco considering their own assessment of cost, revenue and other risks. On top of that, the tobacco manufacturers guarantee the price of tobacco so that the registered farmers' expected return of tobacco farming is attractive and predictable.

A.4 Public Policy and Market Strategy of Firms

In shaping and implementing public policy regarding trade, representative democracies consider both public opinions and the influence of the special interest groups (Grossman and Helpman, 1992). Even though the policy makers are expected to act according to the will of majority of the population, the influence of special interest groups in public policy formulation is inevitable and widely recognized. Research on political economy in shaping trade policy tries to understand the equilibrium policy outcome considering the effect of both public opinions and interventions by the special interest groups.

The survey by Hillman (1989) identified two different approaches in understanding the public policy making process. In the first approach, pre-election policy commitments of competing political parties are considered by the special interest groups and they provide financial and other supports to the party with the policy they prefer. Increased resources enhance the favored party's chance of winning which eventually increases the chance of policy formulation desired by the special interest groups. The second approach, first proposed by Stigler (1971), considers incumbent governments who set policies in order to maximize political support. The implementation of these policies creates benefits to the special groups and a loss the general society.

As public policies regarding structure and functioning of the markets affect the performance of firms. These firms need to consider both market and non-market strategies (Baron, 2001). In most cases, non-market strategies target, among others, policy makers in order to get favorable policies regarding business regulation and market structures. In fact, the existence of the tobacco industry may be attributed to the success of its non-market strategies (Saloojee and Dagli, 2000). While the theory of market strategy is advanced due to extensive research in the discipline of economics of industrial organization, theory of non-market strategies lacks desired attention and is yet to be matured. Baron (2001) was first known to propose theories to provide the foundations for non-market strategies. In this study, we consider the market strategy of a tobacco manufacturer who wants to minimize the sourcing cost of tobacco.

The resultant public policy obtained through the political process (as a result of consideration of public opinion and special interest groups) obligates the policy implementation. This study involves the formulation of optimal operational policies based on the strategic policies that come through the political process. In a similar way, the food security laws that are enacted in many countries obligate the governments to shape operational policies to ensure food security. Examples include intervening in the market to keep food affordable while keeping the producers' margin reasonable. Reasonable domestic food production can be another policy objective that can be obtained by decreasing farming of undesired crops like tobacco.

In this study, we consider a democratic government who is obligated to ensure food security through market intervention so that the food supply at an affordable price in ensured while minimizing the total cost of such intervention. We also consider a cigarette manufacturer who wants to minimize the raw material (tobacco) sourcing cost by responding to the decisions of the government.

B. Proofs of Lemmas and Propositions

B.1 Proof of Lemma 1

Proof.

We define $\mu_r = \mathbb{E}[\phi_r] = \int_0^\infty \phi_r f(\phi_r) d\phi_r$.

Case 1: Rice $(i = r)$

$$\frac{\partial \Phi_r}{\partial p_r} = \frac{\partial}{\partial p_r} \int_{p_r}^{\infty} \frac{\phi_r f(\phi_r)}{1 - \int_0^{p_r} f(\phi_r) d\phi_r} d\phi_r$$

$$= \frac{\partial}{\partial p_r} \left[\frac{\int_0^\infty \phi_r f(\phi_r) d\phi_r - \int_0^{p_r} \phi_r f(\phi_r) d\phi_r}{1 - \int_0^{p_r} f(\phi_r) d\phi_r} \right]$$

$$= \frac{\partial}{\partial p_r} \left[\frac{\mu_r - \int_0^{p_r} \phi_r f(\phi_r) d\phi_r}{1 - \int_0^{p_r} f(\phi_r) d\phi_r} \right] = \frac{f(p_r) \int_{p_r}^{\infty} (\phi_r - p_r) f(\phi_r) d\phi_r}{\left\{ \int_{p_r}^{\infty} f(\phi_r) d\phi_r \right\}^2} \geq 0$$

Case 2: Tobacco $(i = t)$

$$\frac{\partial \Phi_t}{\partial p_t} = \frac{\partial}{\partial p_t} \int_0^{p_t} \frac{\phi_t f(\phi_t)}{\int_0^{p_t} f(\phi_t)} d\phi_t$$

$$= \frac{\left(\int_0^{p_t} f(\phi_t) d\phi_t \right) p_t f(p_t) - \left(\int_0^{p_t} \phi_t f(\phi_t) d\phi_t \right) f(p_t)}{\left\{ \int_0^{p_t} f(\phi_t) d\phi_t \right\}^2}$$

$$= \frac{f(p_t) \int_0^{p_t} (p_t - \phi_t) f(\phi_t) d\phi_t}{\left\{ \int_0^{p_t} f(\phi_t) d\phi_t \right\}^2} \geq 0$$

B.2 Proof of Lemma 2

Proof. By Lemma 1, Φ_i increases as p_i increases. By definition of utility in Equation (1), U_i increases as Φ_i increases. Therefore, Θ_i increases as p_i increases by Assumption

1(b).

Similarly, U_{-i} increases while U_i remains same as Φ_{-i} increases. Therefore, Θ_i decreases as p_{-i} increases by Assumption 1(c).

B.3 Proof of Proposition 1

Proof. Following Lemma 1, as Φ_r is continuous and increases as p_r increases, we can obtain $\tilde{p}_r$ by increasing p_r from 0.

B.4 Proof of Proposition 2

Proof.

$$\mathbf{Tc}_t' = \lambda_t M q_t \{\Theta_t + (p_t - I_t)\Theta_t'\}$$
$$\mathbf{Tc}_t'' = \lambda_t M q_t \{2\Theta_t' + (p_t - I_t)\Theta_t''\} > 0$$

where X_t' and X_t'' denote first and second order differentiation of X with respect to p_t.

B.5 Proof of Proposition 3

Proof. The set Ω obviously is a nonempty, compact and convex subset of $\mathbb{R}^{n+2}$ and both $\mathbf{Gv}$ and $\mathbf{Tc}$ are continuous. Therefore, applying Browder's fixed-point theorem (Browder, 1968), a Nash equilibrium exists. Suppose, (p_r^*, π_j^*, p_t^*) $\forall j = 1, \dots, n$ is such a Nash equilibrium. Since $\mathbf{Tc}$ is convex (Proposition 2), $p_t(p_r^*, \pi_j^*) = \mathrm{argmin}_{p_t} \mathbf{Tc}(p_t, p_r^*, \pi_j^*)$ $\forall j = 1, \dots, n$ is unique. Also, as $\mathbf{Gv}$ is strictly monotone (Assumption 5), by Proposition 3.2 of Harker and Pang (1990), we have $\mathbf{Gv}(p_r^*, \pi_j^*; p_t^*) < \mathbf{Gv}(p_r; \pi_j, p_t^*)$ $\forall p_r \in \Omega_r, \pi_j \in \Omega_j$ $(j = 1, \dots, n)$ and hence (p_r^*, π_j^*) $\forall j = 1, \dots, n$ is unique for $p_t = p_t^*$. Therefore, (p_r^*, π^*, p_t^*) $\forall j = 1, \dots, n$ is unique.