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Agricultural subsidy with capacity constraints and demand elasticity

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Abstract: Agricultural subsidy has attracted more and more attention. This paper captures the effects of subsidy (including area subsidy and price subsidy) on the total sown areas of crops based on the assumption that subsidy has both stimulating effects and inhibiting effects. Different from the prior studies, this paper considers the impacts of the farmland constraint and demand elasticity and some interesting conclusions are achieved. Firstly, a stimulating effect increases crop sown areas while an inhibiting effect reduces them. Secondly, the output efficiency of farmland as well as the demand elasticity has a major impact on the government subsidy. Besides, the capacity constraint makes thing difference and the government should choose between the areas subsidy and price subsidy under different conditions. Finally, this paper offers an empirical test on the conclusions by adopting the Chinese agricultural statistical data.

Key words: allowance, constrained farmland inputs, inhibiting effect, stimulating effect

Agricultural sector has been subjected to major governmental interventions throughout the world, and almost all governments make great efforts to support agriculture (Anderson et al. 2013). During the development of economic, protection is generally shifting from the industrial sector to agriculture (Swinnen 1994). Furthermore, agricultural supports offered by the governments are much larger in developed countries than in the developing countries (Anderson et al. 2013). However, arguments about the reasons for the governments to support agriculture are never ending. Generally speaking, there are two major viewpoints about agricultural support. One opinion issues that politicians who support farmers are to obtain more political votes (Swinnen 1994; Graff et al. 2009; Anderson and Swinnen 2010; Anderson et al. 2013), while other people declare that the reasons for governments to subsidize agriculture are that agriculture has an intrinsic weakness because the demand for agricultural products are inelastic but the supply of them are elastic (Zhang 1949; Krueger et al. 1988; Zietz and Valdts 1993). Most of the studies which are based on developed countries followed the political support assumption, while other studies which focused on developing countries sustained a weak agriculture assumption.

People who with the political vote assumption will focus their attention on the distortions of agriculture support. Therefore, numerous studies captured the negative effects of agricultural protection, such as the price distortions and welfare losses. Swinnen (1994) explained agricultural protection with the positive political theory. He argued that it is well known to us that agriculture is generally taxed in developing countries but mostly subsidized in developed countries. The reason for that is that the economic development reduces the farmers' organization costs, leading to such government policies that are increasingly beneficial to agriculture. And he noted that there is a negative correlation

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between agricultural protection and agricultural income relative to other income. Anderson et al. (2013) used the Relative Rate of Assistance (RRA) to capture the anti-agricultural bias (positive RRA) or the pro-agricultural bias (negative RRA). Their studies found that high-income countries are more pro-agricultural than the low-income countries and a high RRA results in high welfare losses. Graff et al. (2009) declared that the politicians support agriculture because they can acquire more votes by agricultural subsidy. Another Europe-based study drew by Greenaway and Swinnen (2009) also emphasized the distorting effects of agricultural subsidy.

Agricultural protection is not only confined to industrialized countries, but it also appears in developing countries such as China and Korea in the process of industrialization for the low or decreasing agricultural comparative advantage (Zietz and Valdts 1993). The empirical research of Olper (2001) found that the effects of agricultural protection are different between developed countries and developing countries, which implied that the developing countries should make reforms to protect and enforce property. Many other studies also focused on developing countries for the different effects of agricultural protection (Krueger et al. 1988; Anderson and Will 2009).

China has abolished the agricultural tax, which has been imposed for more than 2000 years, in 2006. Furthermore, the Chinese government adopted rice subsides in 2004 and cotton subsidy in 2008. Then at the same year as the cotton subsidy has been implemented, the Chinese government drafted and announced its longstanding food security policy. As the largest developing country, China attracts more and more attention for its agricultural reform (Huang et al. 2010; Yu and Jensen 2010; Du et al. 2011; Anderson et al. 2013; Tan et al. 2013). Although agricultural subsidies have distortion effects, the evidence shows that subsidies stimulate the agricultural development, too Rizov et al. (2013) issued that after the decoupling reform was implemented, the subsidies have a positive impact on the farm productivity in several EU countries. Tan et al. (2013) declared that subsidies have a negative effect on the total agricultural factor productivity. However, based on the Chinese national household's survey data, Huang et al. (2010) indicated that there is no evidence shown that agricultural subsidies distort the producer decisions.

A great number of studies have been focused on agricultural subsidies. However, few of them take into account those factors which affect the subsidies efficiency, such as the farmland constraints, the product elasticity and the interaction of different products subsidies. Constraints make the difference (Esó et al. 2010; Nie and Chen 2012; Nie 2014), and it is well known that the total farmland is limited. Furthermore, the elasticity of product impacts the demand as well as the subsidies efficiency. For example, Michael and Wolfram (2013)'s empirical research testified the effects of the elasticity of demands and supplies. Besides, the subsidy efficiencies also have something to do with the interrelation between different products. Therefore, different from the original studies, the paper employs all the facts above to study the efficiencies of the primary products subsidies, following the agricultural weakness assumption.

MODEL AND ANALYSIS

Generally, people classify agricultural products into two kinds: food crop (e.g. rice) and cash crop (e.g. cotton) and we will take both of them into account in our model. Classical economics tell us that the elasticity as well as the product substitutability affects the product price (Michael and Wolfram 2013). Denote products to i, ($i = A, B$) and A represents the food crop while B represents the cash crop. Then similar to Nie and Chen (2012) along with Sacco and Schmutzer (2011), this study takes the following consumer utility function.

$$U(q_i, q_j) = a(q_i + q_j) - \frac{1}{2}[e_i q_i^2 + e_j q_j^2] - \gamma q_i q_j \qquad (1)$$

e_i and γ are the demand elasticity parameter of crop i and the substitute parameter between different products. The purpose of employing the demand elasticity parameter is to capture the effects of demand elasticity on the government's subsidy behaviour. Two kinds of cultivators play with the Cournot competition with a low substitutability. Following, we have the inverse demand function easily.

$$p_i = a - e_i q_i - \gamma q_j \qquad (2)$$

Besides, we assume that there are only two kinds of inputs, labour and farmland. The output of labour satisfies the Cobb-Douglas production function and the total outputs equal to unit outputs of the farmland multiply land area (Tan et al. 2013). Furthermore, the market clearing conditions always hold as a general assumption in other researches. The outputs efficiencies of the labour input (or the unit output of

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farmland) to different crops are the same[1]. Then the outputs function is given by the following:

$$q_i = \theta L^{\alpha} s_i \tag{3}$$

α implies the output elasticity, q means the technical efficiency and θL^a is the unit output of farmland which depends on the inputs of labour, while s_i represents the area of crop i, ($i = A, B$).

We employ a quadratic cost function and S represents the total farmland constraint or $s_i + s_j \le S$. So the input-constrained producer i's profit maximization problem is

$$\underset{s_i}{Max}\,\pi_i = (a - e_i\theta L^{\alpha} s_i - \gamma\theta L^{\alpha} s_j)\theta L^{\alpha} s_i - \frac{(\theta L^{\alpha} s_i)^2}{2} \qquad S.T \quad s_A + s_B \le S \tag{4}$$

The Lagrangian function of the maximization profit problem is

$$L = (a - e_i\theta L^{\alpha} s_i - \gamma\theta L^{\alpha} s_j)\theta L^{\alpha} s_i - \frac{(\theta L^{\alpha} s_i)^2}{2} + \lambda_i(S - s_A - s_B) \tag{5}$$

λ_i represents the Lagrange multiplier or the shadow price of S. In order to increase the cultivation areas or the total crop outputs, the government always offers farmers subsidies including the area subsidy and price subsidy. So following this, this paper will analyse the function (4) with the area subsidy and price subsidy, both under the non-binding constraint and binding constraint conditions.

Non-tight constraint or $s_A + s_B < S$

If the farmland constraint is not tight, then we have $\lambda_A = \lambda_B = 0$. Following, we will analyse the function (5) at the area subsidy as well as price subsidy case.

Area subsidy

The area subsidy means government allowances to farmers based on the cultivation areas. With the area subsidy and $\lambda_A = \lambda_B = 0$, the function (5) can be rewritten as

$$\pi_i = (a - e_i\theta L^{\alpha} s_i - \gamma\theta L^{\alpha} s_j)\theta L^{\alpha} s_i + \tau_i s_i - \frac{(\theta L^{\alpha} s_i)^2}{2} \tag{6}$$

τ_i, ($i = A, B$) is the sown area subsidy ratios of crop i. Easy knows that $\frac{\partial \pi_i}{\partial s_i} \ge 0$ and $\frac{\partial^2 \pi_i}{\partial s_i^2} < 0$ from (6), which means the profit function is concave and it has the only optimal solution. Solving the function (6), we get the equilibrium cultivation areas

$$s_A = \frac{a\theta L^{\alpha} - \gamma a\theta L^{\alpha} + 2e_B a\theta L^{\alpha} + (1+2e_B)\tau_A - \gamma\tau_B}{(1-\gamma^2 + 2e_A + 2e_B + 4e_A e_B)\theta^2 L^{2\alpha}}, \quad s_B = \frac{a\theta L^{\alpha} - \gamma a\theta L^{\alpha} + 2e_A a\theta L^{\alpha} + (1+2e_A)\tau_B - \gamma\tau_A}{(1-\gamma^2 + 2e_A + 2e_B + 4e_A e_B)\theta^2 L^{2\alpha}} \tag{7}$$

Price subsidy

If the government supports farmers with the price subsidy, then the income that the farmers obtain per the sold product is higher than the market equilibrium price, which implies that the government allowances distort the equilibrium price. If the subsidy ratio of crop i, ($i = A, B$) is also τ_i, then the price the farmers acquire is $p_i = a + \tau_i - e_i q_i - \gamma q_i$ and the cultivators' profits functions are

$$\pi_i = (a + \tau_i - e_i\theta L^{\alpha} s_i - \gamma\theta L^{\alpha} s_j)\theta L^{\alpha} s_i - \frac{(\theta L^{\alpha} s_i)^2}{2} \tag{8}$$

From the function (8), we have

$$s_A^* = \frac{a(1-\gamma+2e_B) + (1+2e_B)\tau_A - \gamma\tau_B}{(1-\gamma^2 + 2e_A + 2e_B + 4e_A e_B)\theta L^{\alpha}}, \quad s_B^* = \frac{a(1-\gamma+2e_A) + (1+2e_A)\tau_B - \gamma\tau_A}{(1-\gamma^2 + 2e_A + 2e_B + 4e_A e_B)\theta L^{\alpha}} \tag{9}$$

Based on the analyses above, this paper achieves the following propositions:

Proposition 1 $\frac{\partial s_A}{\partial \tau_A} > 0$, $\frac{\partial s_A}{\partial \tau_B} < 0$; $\frac{\partial \tau_A}{\partial e_A} > 0$, $\frac{\partial \tau_A}{\partial \theta} > 0$

Proof See in Appendix.

Remark*:* The conclusions of Proposition 1 show that the agricultural subsidy has both the stimulating effects and the inhibiting effects. The stimulating effects increase the farmers' cultivation areas, while the inhibiting effects decrease the areas. Most of the existing studies ignore the inhibiting effects of the agricultural subsidy. The elasticity parameter as well as the technical efficiency increase the subsidy ratio of the government. Most of agricultural products lack in demand elasticity, so the governments all over the world supply farmers with subsidies to protect the development of agriculture. As the technical efficiency increases, the governments should also give the cultivators more allowances. If not, the paradox

[1]Labor inputs are not a key factor in the study, so we turn the analysis about the output efficiency of labor to the output efficiency of farmland.

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that the farmers' incomes reduce as the output of crops increases will happen time again and again.

Proposition 2.

If $\theta L^{\alpha} > 1$,

it has $s_A - s_A^* < 0$, $\frac{\partial s_A}{\partial \tau_A} - \frac{\partial s_A^*}{\partial \tau_A} < 0$ and $\left|\frac{\partial s_A}{\partial \tau_B}\right| - \left|\frac{\partial s_A^*}{\partial \tau_B}\right| < 0$;

if $\theta L^{\alpha} < 1$,

it has $s_A - s_A^* > 0$, $\frac{\partial s_A}{\partial \tau_A} - \frac{\partial s_A^*}{\partial \tau_A} > 0$ and $\left|\frac{\partial s_A}{\partial \tau_B}\right| - \left|\frac{\partial s_A^*}{\partial \tau_B}\right| > 0$.

Proof See in Appendix.

Remark: Proposition 2 implies that the output efficiency of farmland or θL^{α} is an important factor which impacts all the total area, the stimulating effects and the inhibiting effects of subsidy. If the output efficiency of farmland is high or $\theta L^{\alpha} > 1$, the total cultivation areas, the effects as well as the inhibiting effects of the subsidy are higher at price subsidy case. If the output efficiency of farmland is low or $\theta L^{\alpha} < 1$, then the total cultivation areas, the stimulating effects as well as the inhibiting effects of the subsidy are higher at the area subsidy case. The policy implication of Proposition 2 is that the governments should consider the output efficiency of farmland when they make the subsidy decisions.

Many industries are facing the capacity constraints. And agriculture is no exception, for the total areas are limited. So next we will take the tight constraint into consideration.

Tight constraint or $s_A + s_B = S$

Again, we will analyse the base model under the area subsidy and price subsidy conditions. Then compare the results of the tight constraint case with the non-tight constraint status. The non-tight constraint means $\lambda_i > 0$. The same as Nie and Chen (2012), we further assume that $\lambda_A = \lambda_B$, which means the shadow prices of the cultivating lands of different crops are the same. Without losing the general, we denote A to the food crop and B to the cash crop. Furthermore, we assume that the food crop is more important than the cash crop, which means the farmers will plant enough food crops at first if they face the farmland constraint and that the assumption is acceptable.

Area subsidy

Substituting $s_A + s_B = S$ or $s_B = S - s_A$ to the function (3), we have

$$\pi_A = [a - e_A\theta L^{\alpha} s_A - (S - s_A)]\theta L^{\alpha} s_A + \tau_A s_A - \frac{(\theta L^{\alpha} s_A)^2}{2} \quad (10)$$

Solving the function (10) we obtain the following equilibrium solutions

$$s_A^C = \frac{a\theta L^{\alpha} - \gamma S\theta^2 L^{2\alpha} + \tau_A}{(1-2\gamma+2e_A)\theta^2 L^{2\alpha}}, \quad s_B^C = \frac{-a\theta L\alpha + (1-\gamma)S\theta^2 L^{2\alpha} + 2Se_A\theta^2 L^{2\alpha} - \tau_A}{(1-2\gamma+2e_A)\theta^2 L^{2\alpha}} \quad (11)$$

Price subsidy

Replacing the area subsidy with price subsidy, we acquire the alternative expression of (10) as follows

$$\pi_A = [a + \tau_A - e_A\theta L^{\alpha} s_A - \gamma\theta L^{\alpha}(S - s_A)]\theta L^{\alpha} s_A - \frac{(\theta L^{\alpha} s_A)^2}{2} \quad (12)$$

Then we have

$$s_A^{C*} = \frac{a - \gamma S\theta L^{\alpha} + \tau_A}{(1-2\gamma+2e_A)\theta L^{\alpha}}, \quad s_B^{C*} = \frac{-a + (1+2e_A)S\theta L^{\alpha} - \gamma S\theta L^{\alpha} - \tau_A}{(1-2\gamma+2e_A)\theta L^{\alpha}} \quad (13)$$

Now, we achieve other two propositions of this study.

Proposition 3. The conclusions of Proposition 1 and Proposition 2 are holed under the farmland constraint.
Proof See in Appendix.

Remark: Proposition 3 illustrates that no matter whether the farmland constraint is tight or not, we can get the same conclusions that the stimulating effects increase the cultivating areas while the inhibiting effect decrease them and the output efficiency of farmland is a major factor in the process of the subsidy policy implementation. In other words, our conclusions are robust.

Proposition 4. If $\theta L^a > 1$, then $s_A^C - s_B^C < s_A^{C*} - s_B^{C*}$; If $\theta L^a < 1$, then $s_A^C - s_B^C > s_A^{C*} - s_B^{C*}$.

But $\frac{d\left[\left(s_A^C - s_B^C\right) - \left(s_A^{C*} - s_B^{C*}\right)\right]}{d\tau_A} > 0$ always holds.

Proof See in Appendix.

Remark: Once again, the conclusions of Proposition 4 show that the output efficiency of farmland has critical impacts on the results of the agricultural subsidy. The cultivating areas difference between crops is lager under the price subsidy than under the area subsidy if the output efficiency of farmland is high

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and vice versa, while the subsidy of the advantage crop always enlarges the gap of the cultivating areas difference between different crops under a different subsidy status.

Proposition 5. $\left|s_A - s_A^*\right| - \left|s_A^C - s_A^{C*}\right| = \left|s_B - s_B^*\right| - \left|s_B^C - s_B^{C*}\right| < 0$,

$$\left|\left|\frac{\partial s_A}{\partial \tau_A}\right| - \left|\frac{\partial s_A^*}{\partial \tau_A}\right|\right| < \left|\left|\frac{\partial s_A^C}{\partial \tau_A}\right| - \left|\frac{\partial s_A^{C*}}{\partial \tau_A}\right|\right| \text{ and } \left|\left|\frac{\partial s_A}{\partial \tau_B}\right| - \left|\frac{\partial s_A^*}{\partial \tau_B}\right|\right| < \left|\left|\frac{\partial s_A^C}{\partial \tau_B}\right| - \left|\frac{\partial s_A^{C*}}{\partial \tau_B}\right|\right|.$$

Proof See in Appendix.

Remark: Proposition 2 and Proposition 3 illustrate that the relationships of the cultivating areas, the stimulating effects and the inhibiting effects between different subsidy cases are ambiguous, because they depend on the output efficiency of farmland (θL^α). However, the Proposition 5 shows that the gaps of the cultivating areas, as well as the gaps of the stimulating effects and inhibiting effects, among different subsidy conditions are larger at the tight constraint state than the non-tight constraint status, which means the farmland constraint enlarges the effects difference of different subsidy policies. And those differences have nothing to do with the output efficiency of farmland.

Welfare analysis

Another significant issue is the welfare of different cases, so we compare the welfare differences between the area subsidy and price subsidy both at the non-tight constraint condition and the tight constraint condition. As we all know, the total social welfare (SW) includes the consumer surplus (CS) and the producer surplus (PS) or $SW = CS + PS$. Denoting the total social welfare, consumer surplus and the producer surplus at the area subsidy case to SW, CS and PS, while at the price subsidy case to SW^*, CS^* and PS^* under the non-tight constraint condition. Based on the analyses above, we have the following conclusions:

Proposition 6. $CS > CS^*$, $PS > PS^*$ and $SW > SW^*$ if $\theta L^\alpha < 1$; $CS < CS^*$, $PS < PS^*$ and $SW < SW^*$ if $\theta L^\alpha > 1$. Proof See in the Appendix.

Remark: The conclusions of Proposition 6 indicate that the relationships of the consumer surplus, producer surplus as well as the total social welfare between different subsidy cases depend on the output efficiency of farmland (θL^α). If the output efficiency of farmland is efficient or $\theta L^\alpha > 1$, then the price subsidy results in high welfares. However, if the output efficiency of farmland is inefficient or $\theta L^\alpha < 1$, then the government should carry out the area subsidy. The policy implication of Proposition 6 illustrates that the politician should take the output efficiency of farmland into consideration if they make choice between the area subsidy and price subsidy. However, unfortunately the relationships of the consumer surplus, the producer surplus and the total social welfare under different subsidy cases are ambiguous if the farmland constraint is tight. The reason for it is that the sown areas increase of one kind of crops will reduce the sown areas of the other, so the total social welfare is ambiguous.

EMPIRICAL ANALYSIS: EVIDENCE FROM CHINA

China is the biggest developing country which has more than 1.3 billion people, but only 1.827 billion cultivated lands. In other word, it has to cultivate 20% people with less than 8% farmland of the world. Furthermore, one negative effect of the process of industrialization is that our farmlands are becoming less and less. That is why the food security and food safety are so serious in China. So in order to heighten the output efficiency of agriculture and to enhance the total food supplies, on the one hand, the Chinese government abolishes the agricultural tax and on the other hand, it has begun to subsidize farmers since the beginning of 21 century. Rice is the most important product of the food crops while

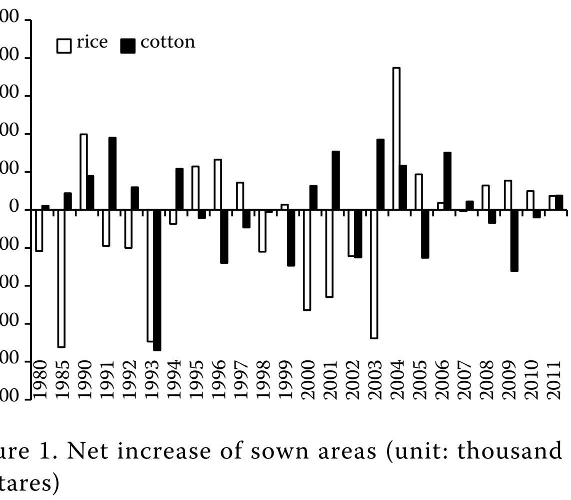

Figure 1. Net increase of sown areas (unit: thousand hectares)

Source: China Rural Statistical Yearbook. National Bureau of Statistics of China

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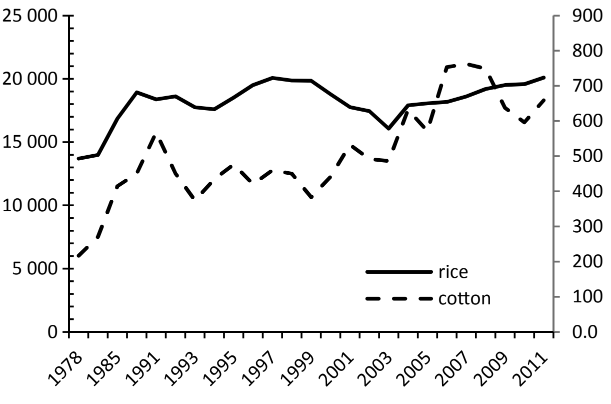

Figure 2. Total outputs (Unit: ten thousand tons)

Notes: The left ordinate represents rice and the right ordinate represents cotton

Source: China Rural Statistical Yearbook. National Bureau of Statistics of China

cotton is one of the major cash crops. Following, we will employ the Chinese statistical data of rice and cotton to test the Propositions about the results of subsidy of China.

The results of Figure 1 show that the total sown area of rice decreases for most of the years before 2004, while it increases in all the years after 2004. One significant reason is that the Chinese government started to subsidise rice farmers at 2004. However, the thing that confuses us is that although the Chinese government also supplies the cotton farmers with the allowance since 2008, the same change of the total sown areas has not happen for cotton, or the total sown areas of cotton are not increasing.

The same phenomenon happens again for the total outputs of rice and cotton (Figure 2). From Figure 2, we know that the total outputs of rice increase year by year since 2004 but to the contrary, the total outputs of cotton even decrease after 2008. Why did this happen? It is possible that the reasons for that are the output efficiency increase or the demands for cotton decrease.

So in the following, we will employ the output efficiency and the demands data of China. Figure 3 tells us that the yields per area unit of rice and cotton were not changing significantly since 1997, which means that the farmland output efficiency of rice as well as cotton was almost the same from 1997 to 2011. Combining Figures 1, 2 and 3, we get the conclusions that the major reason for the increase (decrease) of rice (cotton) is the increase (decrease) of the cultivating areas.

It is possible that the reasons for the decrease of the total outputs and sown areas of cotton are that the Chinese people reduced their demand for cotton. However, Figure 4 illustrates that the net imports of cotton are increasing as the total outputs of cotton decrease. So we can exclude the demand decrease out of the reasons for the reducing of the total outputs and sown areas of cotton.

The total cultivable areas of China are near 1.83 billion and they are decreasing year by year because of the urbanization and industrialization of China, which means that the Chinese agricultural products are produced under the inputs constraint. The inputs constraint combined with the dual-effects of subsidies leads to the results of increasing the production of rice and decreasing that of cotton.

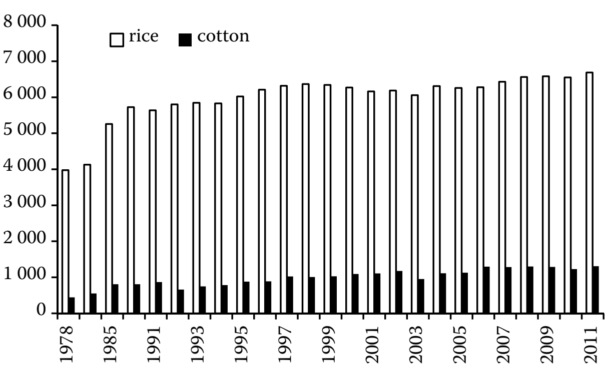

Figure 3. Yields per unit of area (unit: kilogram/hectare)

Source: China Rural Statistical Yearbook. National Bureau of Statistics of China

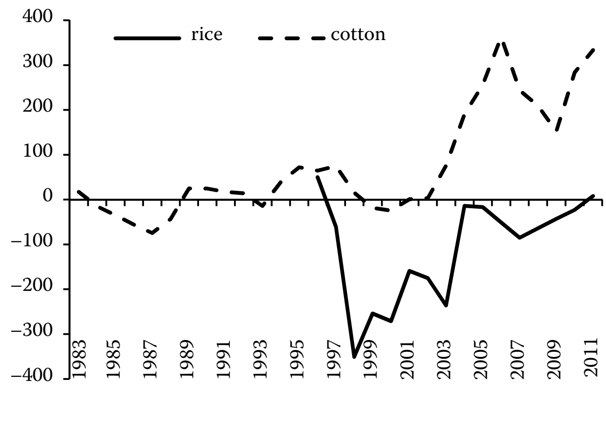

Figure 4. Net imports (Unit: million tons)

Source: China Rural Statistical Yearbook. National Bureau of Statistics of China

Note: Because the data of imports of rice before the year of 1996 are missing, the net imports data of rice begin at 1996

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DISCUSSION AND CONCLUSIONS

Employing two major kinds of crops, the food crop and the cash crop, this paper captures the agricultural subsidy with the farmland constraint and the demand elasticity. Taking the area subsidy and price subsidy into consideration, this study analyses the base model both at the non-tight farmland constraint and the tight constraint status. Then we adopted the Chinese rice (food crop) and cotton (cash crop) statistical data to carry out the empirical research.

The theoretical and empirical study show that the agricultural subsidy has positive (stimulating) effects on increasing the total sown areas of the allowanced crop itself, but it also has negative (inhibiting) effects on reducing the total cultivating areas of others. Those conclusions imply that the studies about subsidies should take different crops into consideration at the same time. If not (it means considering one kind of crop such as rice or cotton singly), the study will overestimate or underestimate the effects of the subsidy or even get absurd conclusions. Furthermore, this study illustrates that the output efficiency of farmland as well as the demand elasticity have a significant impact on the subsidy and the relationships of welfare among different subsidy cases depending on the output efficiency of the farmland. Therefore, the governments should take those factors into account when they make the area subsidy or price subsidy decisions.

This study also offers a reasonable explanation to the phenomenon that the total sown areas of cotton are decreasing after the cotton subsidy. Because the food crops are more important than the cash crops, then if agriculture faces the farmland constraint, the people will meet their need for the food cultivation first. The result of that is that the total sown areas of the cash crops are not necessarily increasing even when the governments subsidise farmers with allowances. And the government should take notice of the interaction between different crops subsidies. Agricultural subsidy is important for the agriculture development, especially for the developing country such as China, so more researches should be taken to help the government to formulate an efficient subsidy policy.

APPENDIX

Proof of proposition 1

From (7), we have the following conclusions by the comparative static analysis,

$$\frac{\partial s_A}{\partial \tau_A} = \frac{1+2e_j}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2L^{2\alpha}} > 0 \qquad (1a)$$

$$\frac{\partial s_A}{\partial \tau_B} = -\frac{\gamma}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2L^{2\alpha}} < 0 \qquad (1b)$$

Then we get the following conclusions by the comparative static analysis, we achieve

$$\frac{\partial \tau_A}{\partial e_A} = -\frac{\dfrac{\partial s_A}{\partial \tau_A}}{\dfrac{\partial s_A}{\partial e_A}} = \frac{2[a\theta L^{\alpha}(1-\gamma)+2e_Ba\theta L^{\alpha}+(1+2e_B)\tau_A-\lambda\tau_B]}{1-\gamma^2+2e_A+2e_B+4e_Ae_B} > 0 \qquad (2a)$$

and

$$\frac{\partial \tau_A}{\partial \theta} = -\frac{\dfrac{\partial s_A}{\partial \tau_A}}{\dfrac{\partial s_A}{\partial \theta}} = \frac{a(1-\gamma)\theta L^{\alpha}+2ae_B\theta L^{\alpha}+(2+2e_B)\tau_A-2\gamma\tau_B}{(1+2e_i)\theta} > 0 \qquad (2b)$$

For the same reasons, from (9) we have the following results,

$$\frac{\partial s_A^*}{\partial \tau_A} = \frac{1+2e_B}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta L^{\alpha}} > 0 \qquad (3a)$$

$$\frac{\partial s_A^*}{\partial \tau_B} = -\frac{\gamma}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta L^{\alpha}} < 0 \qquad (3b)$$

and

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$$\frac{\partial \tau_A^*}{\partial e_A} = -\frac{\frac{\partial s_A}{\partial \tau_A}}{\frac{\partial s_A}{\partial e_A}} = \frac{(1-\gamma+2e_B)a+(1+2e_B)\tau_A-\gamma e_B}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2L^\alpha} > 0 \quad (4a)$$

$$\frac{\partial \theta}{\partial \tau_A} = -\frac{\frac{\partial s_A}{\partial \tau_A}}{\frac{\partial s_A}{\partial \theta}} = \frac{(1-\gamma+2e_B)a+(1+2e_B)\tau_A-\gamma e_B}{(1+e_B)\theta} > 0 \quad (4b)$$

The conclusions are therefore achieved and the proof is complete.

Proof of proposition 2

Subtracting (7) by (9), it is easy to know that

$$s_A - s_A^* = \frac{(1-\theta L^\alpha)[(1+2e_B)\tau_A-\gamma\tau_B]}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2L^{2\alpha}}\bigg|_{\theta L^\alpha>1} < 0, \bigg|_{\theta L^\alpha<1} > 0 \quad (5a)$$

(1a) minus (3a) results in

$$\frac{\partial s_A}{\partial \tau_A} - \frac{\partial s_A^*}{\partial \tau_A} = \frac{(1-\theta L^\alpha)(1+2e_B)}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2L^{2\alpha}}\bigg|_{\theta L^\alpha>1} < 0, \bigg|_{\theta L^\alpha<1} > 0 \quad (5b)$$

And subtracting (1b) by (3b), we have

$$\left|\frac{\partial s_A}{\partial \tau_B}\right| - \left|\frac{\partial s_A^*}{\partial \tau_B}\right| = \frac{\gamma(1-\theta L^\alpha)}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2L^{2\alpha}}\bigg|_{\theta L^\alpha>1} < 0, \bigg|_{\theta L^\alpha<1} > 0 \quad (5c)$$

The conclusions are therefore achieved and the proof is complete.

Proof of proposition 3

Combining (11) and (13) and using the static analysis and comparative statistics, we have

$$\frac{\partial s_B^C}{\partial \tau_A} = \frac{1}{(1-2\gamma+2e_A)\theta^2L^{2\alpha}} > 0 \quad (6a)$$

$$\frac{\partial s_B^C}{\partial \tau_A} = -\frac{1}{(1-2\gamma+2e_A)\theta^2L^{2\alpha}} < 0 \quad (6b)$$

$$\frac{\partial \tau_A}{\partial e_A} = -\frac{\frac{\partial s_A}{\partial e_A}}{\frac{\partial s_A}{\partial \tau_A}} = \frac{2[\theta L^\alpha(a-\gamma S\theta L^\alpha)+\tau_A]}{1-2\gamma+2e_A} > 0 \quad (6c)$$

$$\frac{\partial \tau_A}{\partial \theta_A} = -\frac{\frac{\partial s_A}{\partial \theta}}{\frac{\partial s_A}{\partial \tau_A}} = aL^\alpha + \frac{2\tau_A}{\theta} > 0 \quad (6d)$$

as well as

$$\frac{\partial s_A^{C*}}{\partial \tau_A} = \frac{1}{(1-2\gamma+2e_A)\theta L^\alpha} > 0 \quad (7a)$$

$$\frac{\partial s_B^{C*}}{\partial \tau_A} = -\frac{1}{(1-2\gamma+2e_A)\theta L^\alpha} < 0 \quad (7b)$$

and

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$$\frac{\partial \tau_A}{\partial e_A} = -\frac{\frac{\partial s_A}{\partial e_A}}{\frac{\partial s_A}{\partial \tau_A}} = \frac{2[\ a - \gamma S\theta L^{\alpha}) + \tau_A]}{1-2\gamma+2e_A} > 0 \qquad (7c)$$

$$\frac{\partial \tau_A}{\partial \theta_A} = -\frac{\frac{\partial s_A}{\partial \theta_A^{C'}}}{\frac{\partial s_A}{\partial \tau_A}} = \frac{a+\tau_A}{\theta} > 0 \qquad (7d)$$

Then similar to the proof of Proposition 2, we have

$$s_A^C - s_A^{C*} = \frac{(1-\theta L^{\alpha})\tau_A}{(1-2\gamma+2e_A)\theta^2 L^{2\alpha}}\Big|_{\theta L^{\alpha}>1} < 0, \Big|_{\theta L^{\alpha}<1} > 0 \qquad (8a)$$

$$\frac{\partial s_A}{\partial \tau_A} - \frac{\partial s_A^*}{\partial \tau_A} = \frac{1-\theta L^{\alpha}}{(1-2\gamma+2e_A)\theta^2 L^{2\alpha}}\Big|_{\theta L^{\alpha}>1} < 0, \Big|_{\theta L^{\alpha}<1} > 0 \qquad (8b)$$

and

$$\left|\frac{\partial s_A}{\partial \tau_B}\right| - \left|\frac{\partial s_A^*}{\partial \tau_B}\right| = \frac{1-\theta L^{\alpha}}{(1-2\gamma+2e_A)\theta^2 L^{2\alpha}}\Big|_{\theta L^{\alpha}>1} < 0, \Big|_{\theta L^{\alpha}<1} > 0 \qquad (8c)$$

The conclusions are therefore achieved and the proof is complete.

Proof of proposition 4

Subtracting the equilibrium sown areas of crop A by B both at the non-tight case and the tight case, we have

$$s_A^C - s_B^C = \frac{2a\theta L^{\alpha} - S\theta^2 L^{2\alpha} - 2Se_A\theta^2 L^{2\alpha} + 2\tau_A}{\theta^2 L^{2\alpha}(1-2\gamma+2e_A)} \qquad (9a)$$

and

$$s_A^{C*} - s_B^{C*} = \frac{2a - S\theta L^{\alpha} - 2e_A S\theta L^{\alpha} + 2\tau_A}{\theta L^{\alpha}(1-2\gamma+2e_A)} \qquad (9b)$$

Then we have the following conclusions,

$$\left(s_A^C - s_B^C\right) - \left(s_A^{C*} - s_B^{C*}\right) = -\frac{2(\theta L^{\alpha}-1)\tau_A}{\theta^2 L^{2\alpha}(1-2\gamma+2e_A)}\Big|_{\theta L^{\alpha}>1} < 0, \Big|_{\theta L^{\alpha}<1} > 0 \qquad (10a)$$

$$\frac{d\left|\left(s_A^C - s_B^C\right) - \left(s_A^{C*} - s_B^{C*}\right)\right|}{d\tau_A} = \left|\frac{2(\theta L^{\alpha}-1)}{\theta^2 L^{2\alpha}(1-2\gamma+2e_A)}\right| > 0 \qquad (10b)$$

The conclusions are therefore achieved and the proof is complete.

Proof of proposition 5

From (7), (9), (11) and (13), we get

$$\left|s_A - s_A^*\right| - \left|s_A^C - s_A^{C*}\right| = \left|s_B - s_B^*\right| - \left|s_B^C - s_B^{C*}\right| = -\left|\frac{\gamma(\theta L^{\alpha}-1)[(2-\gamma+4e_B)\tau_A + (1-2\gamma+2e_A)\tau_B]}{(1-2\gamma+2e_A)(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2 L^{2\alpha}}\right| < 0 \qquad (11a)$$

and by the comparative static analysis, we obtain the following relationships,

$$\left|\left|\frac{\partial s_A}{\partial \tau_A}\right| - \left|\frac{\partial s_A^*}{\partial \tau_A}\right|\right| - \left|\left|\frac{\partial s_A^C}{\partial \tau_A}\right| - \left|\frac{\partial s_A^{C*}}{\partial \tau_A}\right|\right| = -\left|\frac{\gamma(\theta L^{\alpha}-1)(2-\gamma+4e_B)}{(1-2\gamma+2e_A)(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2 L^{2\alpha}}\right| < 0 \qquad (11b)$$

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and

$$\left\| \frac{\partial s_A}{\partial \tau_B} \right| - \left| \frac{\partial s_A^*}{\partial \tau_B} \right\| - \left\| \frac{\partial s_A}{\partial \tau_B} \right| - \left| \frac{\partial s_A^*}{\partial \tau_B} \right\| = -\left| \frac{(\theta L^\alpha - 1)[1-\gamma+\gamma^2+2(1-\gamma+e_B)e_A+2(1+e_A)e_B]}{(1-2\gamma+2e_A)(1-\gamma^2+2e_A+2e_B+4e_Ae_B)\theta^2 L^{2\alpha}} \right| < 0 \quad (11c)$$

The conclusions are therefore achieved and the proof is complete.

Proof of proposition 6 ($i, j = A, B$)

From (1), we know that $\frac{\partial U(q_i,q_j)}{\partial q_i} = p_i > 0$ and $\frac{\partial U(q_i,q_j)}{\partial q_j} = p_j > 0$, ($i, j = A, B$). If $s_i > s_i^*$, then $q_i = e_i\theta L^\alpha s_i > q_i^* = e_i\theta L^\alpha s_i^*$ and $U(q_i,q_j) > U(q_i^*,q_j^*)$; If $s_i < s_i^*$, then $q_i = e_i\theta L^\alpha s_i < q_i^* = e_i\theta L^\alpha s_i^*$ and $U(q_i,q_j) < U(q_i^*,q_j^*)$. So from Proposition 2, we have $CS > CS^*$ if $qL^a < 1$ while $CS < CS^*$ if $qL^a > 1$.

Denoting the total profits of producers at the non-tight constraint and the tight constraint cases are Π and Π^*, from (10) and (12) we have

$$\Pi - \Pi^* = \frac{(1-\theta L^\alpha)(1+2e_A)[(1+2e_B)\tau_A - \gamma\tau_B][2a(1-\gamma+2e_B)\theta L^\alpha + (1+2e_B)(1+\theta L^\alpha)\tau_A - (1+\theta L^\alpha)\gamma\tau_B]}{(1-\gamma^2+2e_A+2e_B+4e_Ae_B)^2\theta^2 L^{2\alpha}} \quad (12)$$

Then, it gets $\Pi - \Pi^*\big|_{\theta L^\alpha > 1} < 0, \big|_{\theta L^\alpha < 1} > 0$ or $CS - CS^*\big|_{\theta L^\alpha > 1} < 0, \big|_{\theta L^\alpha < 1} > 0$.

So it is easy to obtain $SW - SW^*\big|_{\theta L^\alpha > 1} < 0, \big|_{\theta L^\alpha < 1} > 0$ for $SW = CS + PS$.

The conclusions are therefore achieved and the proof is complete.

Table 1. Main statistical data about rice and cotton in China (1978–2011)

Year	Sown areas		Total yields		Yields per unit area		Imports		Exports	
	rice	cotton	rice	cotton	rice	cotton	rice	cotton	rice	cotton
	thousand ha		ten thousand tons		kg/ha		ten thousand tons		ten thousand tons	
1978	34 421	4 866	13 693	217	3 978	445				
1980	33 878	4 920	13 991	271	4 130	550		89	109	1.0
1985	32 070	5 140	16 857	415	5 256	807			101	35.0
1990	33 064	5 588	18 933	451	5 726	807		42	33	17.0
1991	32 590	6 538	18 381	568	5 640	868		37	69	20.0
1992	32 090	6 835	18 622	451	5 803	660		28	95	14.0
1993	30 355	4 985	17 751	374	5 848	750		1	143	15.0
1994	30 171	5 528	17 593	434	5 831	785		50	152	11.0
1995	30 744	5 422	18 523	477	6 025	879		74	5	2.0
1996	31 406	4 722	19 510	420	6 212	890	76	65	26	0.4
1997	31 765	4 491	20 073	460	6 319	1 025	33	75	94	0.1
1998	31 214	4 459	19 871	450	6 366	1 009	24	20	375	4.5
1999	31 283	3 726	19 849	383	6 345	1 028	17	5	271	23.6
2000	29 962	4 041	18 791	442	6 272	1 093	24	5	295	29.2
2001	28 812	4 810	17 758	532	6 163	1 107	27	6	186	5.2
2002	28 202	4 184	17 454	492	6 189	1 175	24	18	199	15.0
2003	26 508	5 111	16 066	486	6 061	951	26	87	262	11.2
2004	28 379	5 693	17 909	632	6 311	1 111	77	191	91	0.9
2005	28 847	5 062	18 059	571	6 260	1 129	52	257	69	0.5
2006	28 938	5 816	18 172	753	6 280	1 295	73	364	124	1.3
2007	28 919	5 926	18 603	762	6 433	1 286	49	246	134	2.1
2008	29 241	5 754	19 190	749	6 563	1 302	33	211	97	1.6
2009	29 627	4 949	19 510	638	6 585	1 289	36	153	79	0.8

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Year	Sown areas		Total yields		Yields per unit area		Imports		Exports	
	rice	cotton	rice	cotton	rice	cotton	rice	cotton	rice	cotton
	thousand ha		ten thousand tons		kg/ha		ten thousand tons		ten thousand tons	
2010	29 873	4 849	19 576	596	6 553	1 229	39	284	62	0.6
2011	30 057	5 038	20 100	659	6 687	1 308	60	336	52	2.6

Source: China Rural Statistical Yearbook, National Bureau of Statistics of China; China Statistical Yearbook, National Bureau of Statistics of China

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