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Agricultural pollution and regulation: How to subsidize agriculture?

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ABSTRACT

Agricultural pollution is extremely serious in China, and agricultural output quantity subsidy makes it even worse. This paper captures the impacts of agricultural subsidy, including quantity subsidy and innovation subsidy, on agricultural pollution. Agriculture output quantity, total pollution or emission, equilibrium price, consumer and producer surplus, government budget, and social welfare are all addressed in this study. The results show that emission-reducing innovation subsidy is better than quantity subsidy because it reduces the pollution from agriculture and profits for the agricultural firm are higher under innovation subsidy than under quantity subsidy. More importantly, output quantity and consumer surplus under innovation subsidy are also larger than those under quantity subsidy if the subsidy rate is not too high. This study finds that the importance of the environment to the consumer, marginal emission, and pollution tax will decrease output quantity, consumer and producer surplus and social welfare; however, agricultural subsidy increases them. Furthermore, this study indicates that innovation subsidy can alleviate the "food quantity safety and quality of environment" dilemma in agriculture.

1. Introduction

Agricultural pollution has become increasingly serious throughout the world, especially in developing countries such as China. Non-point source water pollution is a major source of agricultural pollution because of the excessive amount of fertilizers, herbicides, and insecticides used in agricultural production. Sohu news showed that non-point source water pollution from agriculture has exceeded that from industry and has become the largest source of non-point pollution in China. More seriously, 60% of China's underground water is not fit for human consumption (https://www.rt.com/news/265186-china-water-air-pollution/).

Why is water pollution in agriculture in China so serious? A critical reason is that we focus too much attention on total food quantity for food quantity safety. The central government of China requires that the food self-sufficiency rate should be over 95% in the "National food security and long-term planning framework (2008–2020)," to guarantee our food quantity safety. To increase grain outputs as much as possible, many chemical fertilizers and pesticides are used in agriculture. Data from the World Bank reveal that chemical fertilizer per hectare used in China is 2.8 times as that of the United States and 3.0 times as that of the world average. Different kinds of agricultural subsidies are supported by the governments for peasants, to encourage their enthusiasm for cultivation. As a result, as food outputs increase, the more serious water pollution becomes. On the one hand, water resources are extremely scarce in China and data from the World Bank show that China's per capita renewable freshwater is only one-third of the world's average level: In 2014, China's per capita renewable freshwater was 2062 m^3 and the world's average level was 5925 m^3 (http://data.worldbank.org/). On the other hand, water pollution is extremely serious in China. Those two phenomena show that we should make great efforts to deal with agricultural pollution and to protect our scarce water resource.

How can we deal with agricultural pollution? From the studies of Nie et al. (2016a; 2016b), Chen et al. (2015a) and Sun and Nie (2015), we learn that tax and subsidy are two major regulative methods effective against pollution, based on an economic perspective. Abadie et al. (2016) suggested using taxes and subsidies to reduce emission in food production. Nie et al. (2016a)

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offered three different subsidy policies to stimulate renewable energy production and compared their efficiency difference. Chen et al. (2015a) investigated different impacts of agricultural subsidies, including area subsidy and price subsidy, on total outputs of agriculture, by considering capacity constraints. Subsidy is used to stimulate good behaviors, while tax is employed to inhabit bad actions. So, Nie (2013, 2012) and Chow (2011) highlighted the effect of pollution tax on pollution emissions regulation. Different from these prior studies, this paper will take both tax and subsidy into account to design a more desirable pollution-alleviating regulation mechanism. We use a pollution tax to reduce pollution or emissions, while employing an innovation subsidy to stimulate cleaner production.

Water (Buckley and Carney, 2013), soil (Singh et al., 2015), and greenhouse gas (Reisinger et al., 2013) pollution are three major sources of pollution that involve agriculture. Buckley and Carney (2013) studied water pollution in agriculture and its effect on economic performance of agriculture. Hu and Huang (2014) investigated the water pollution of south China. Llopis-Albert et al. (2014) used a coupled stochastic inverse-management framework to deal with underground water pollution from agriculture. Singh et al. (2015) studied soil metal pollution and found soil arsenic can be used to mitigate soil pollution. Vatn et al. (1997) offered an integrated modelling analysis to regulate non-point source pollution to reduce soil loss from agricultural land. Chhabra et al. (2010) estimated nitrogen losses in Indian agriculture. Reisinger et al. (2013) used the integrated assessment model to measure greenhouse gas emissions from agriculture and its impact on climate change. Vermont and Cara (2010) investigated the cost of non-CO_2 greenhouse gas emissions, such as nitrous oxide, from agriculture. Machines are being increasingly used in modern agriculture; as a result, this sector is among the main users/consumers of fossil fuels in Western countries such as the United States. Nearly 14% of the world greenhouse gas emissions come from the direct use of fossil fuels in the agricultural process (Bardi et al., 2013).

These studies mentioned above and many other researchers have fully investigated the situation and impact of agricultural pollution or supplied some technical method to alleviate agricultural pollution. However, there are more crucial problems: 1) Why don't peasants use cleaner production technologies? 2) How can peasants be stimulated to implement environmentally friendly production methods in agriculture? These are our purposes in this paper.

A full agricultural subsidy system has been set up in China, which includes farmer income subsidies, agricultural production subsidies, agricultural price support subsidies, agricultural insurance subsidies, agricultural financial subsidies, agricultural infrastructure subsidies, and resources and environmental protection subsidies (http://english.agri.gov.cn/). Resources and environmental protection subsidies involve emission-reducing innovation, so that they can be categorized as agricultural innovation subsidies.

We will design an agricultural regulation mechanism by introducing tax and subsidy simultaneously. Output quantity, total emission, consumer and producer surplus, government budget, social welfare, and equilibrium price are all discussed in this study. The results of this study show that all the pollution sensibility, marginal emission and marginal pollution tax decrease the output quantity, consumer surplus, producer surplus, and social welfare. We conclude that marginal pollution tax and subsidy have different effects on equilibrium price, government budget, and social welfare. In this study, emission-reducing innovation increases equilibrium price, consumer surplus, and government budget, but it decreases agricultural emission. More interestingly, this paper shows that output quantity and consumer surplus under emission-reducing innovation subsidy are higher than that under output quantity subsidy if marginal agricultural subsidy is small; those relationships are reversed if marginal subsidy is large. Based on a linear relationship between pollution and production, this study found that quantity subsidy increases total food outputs and agricultural pollution or emission via mathematical analysis. Based on these conclusions, we learn that cleaner technology innovation subsidy and pollution tax are quite efficient in agricultural pollution regulation.

The rest of this paper is as follows. The basic model is outlined in Section 2 and the basic model will consider agricultural pollution, pollution tax, and agricultural subsidies, including quantity subsidy and innovation subsidy. Section 3 contains model analyses, and the main propositions are also offered in this section. The last section has conclusions and discussions.

2. The basic model

The basic model of this study is set up based on a two-stage game and the game timing is as follows. In the first stage, the government declares its subsidy policies or makes a choice between direct quantity subsidy and emission-reducing innovation subsidy. In the second stage, the agricultural firm decides to invest in emission-reducing innovation or not, according to the government's subsidy policies.

Similar to Nie (2012), the analyses of this study are based on a monopoly market, but the conclusions are easy to extend to other market structures by employing product substitutability. The monopoly agricultural firm supplies consumers with grain or food, but it also makes by-products, agricultural pollution, and emission, such as water pollution. If we take the output quality of the firm as the sum of the quality of all the products including by-products, then emission or pollution decreases the total quality and the price. Given the output quantity and pollution, a representative consumer's utility is outlined as follows:

$$U = \left(M - \gamma e - \frac{1}{2}q\right)q - pq. \tag{1}$$

Similar to Nie (2012) and Chow (2011), M is defined as the maximum tolerable amount of emissions. q and e are output quantity and emission. $\gamma \geq 0$ is a constant that describes the sensibility of consumers to emissions or it represents the importance of environment to consumers. The larger γ is, the more important the environment is to consumers, and $\gamma = 0$ means that consumers neglect emissions. Function (1) shows that consumer's utility is impacted by emission and the total quantity of food perchance. Emission increases consumer's utility. The relationship between consumer's utility and quantity is a reverse-U shape because of the law of diminishing marginal utility. This study assumes that the monopoly cannot practice price discrimination; then from function (1), we obtain the linear inverse demand function directly

$$p = M - \gamma e - q. \tag{2}$$

p is the price of the product and all the means of the other letters are the same as function (1). Assume emission is a linear function of quantity and agricultural firm decides to invest in emission-reducing innovation, or not, based on the type of government subsidy. Given the quantity q, innovation I, $0 \leq I \leq q$ and marginal emission rate α, $0 \leq \alpha \leq 1$, we employ the emission function

$$e = \alpha(q - I). \tag{3}$$

Function (3) illustrates that product quantity increases emission, while innovation investment reduces it. For the agricultural firm, whether to invest in emission-reducing innovation, or not, is dependent on innovation subsidy because this kind of innovation is quite costly. Therefore, the firm will make different innovation choices based on different government subsidy policies. Under the condition of monopoly or some other imperfect competition market, if the government subsidizes agriculture with marginal quantity subsidy $0 \le s \le 1$ and levies marginal emission tax $0 \le \tau \le 1$, the firm will invest nothing, or $I = 0$, and firm's objective function is

$$\pi = (M - \gamma\alpha q - q)q - c_1 q^2 - \tau\alpha q + sq, \tag{4}$$

c_1 is production cost parameter. The result may change under a perfect competitive market, but nearly all markets, in reality, are imperfect. If the government subsidizes the agricultural firm with emission-reducing investment subsidy, then the firm will invest in innovation. This means that during the two-stage game, if the government pronounces emission-reducing subsidy policy in the first stage, then the firm will choose emission-reducing investment in the following stage. Firm's corresponding profit function is rewritten as

$$\pi = [M - \gamma\alpha(q - I) - q]q - c_1 q^2 - c_2 I^2 - \tau\alpha(q - I) + sI. \tag{5}$$

$c_2 > c_1$ is the innovation cost parameter. $c_2 > c_1$ means emission-reducing innovation is more costly than the costs of production, and hence, firm generally has little willingness to make innovation without subsidy. We can find reality support for this assumption because most of the firms have little motivation to practice innovation investment behavior due to high cost and risk. Therefore, the government should subsidize firms to increase innovation. This assumption is reasonable because few agriculture firms implement emission-reducing innovation in reality without government subsidy. Data from the World Bank show that the proportion of research and development expenditure on GDP in China is a little more than 2%, while the same index in agriculture is less than 1%. Additionally, $c_2 > c_1$ also guarantees $q \ge I$ or $e = \alpha(q - I) \ge 0$. Obviously, subsidy increases firm's profit, while tax decreases it. Furthermore, we assume the marginal innovation subsidy rate is the same as the quantity subsidy parameter s.

3. Model analyses

The base model will be analyzed under two different cases: output quantity subsidy and innovation subsidy.

3.1. Quantity subsidy

$\alpha \ge 0$ indicates the marginal emission of outputs. τ and s represent tax rate of emissions and subsidy rate of quality of the government, respectively. Following Chen et al. (2015b) and Chen and Nie (2016) and Chen et al. (2016), we assume $c_1 = \frac{1}{2}$; then, function (4) is rewritten as

$$\pi = [M - \gamma\alpha q - q]q - \frac{1}{2}q^2 - \tau\alpha q + sq. \tag{6}$$

Function (6) is concave in q. Based on the following first-order optimal condition

$$\frac{\partial\pi}{\partial q} = M + s - (3 + 2\gamma\alpha)q - \tau\alpha = 0, \tag{7}$$

we have equilibrium solutions as

$$q = \frac{M + s - \alpha\tau}{3 + 2\gamma\alpha}, \tag{8}$$

$$e = \frac{(M + s - \alpha\tau)\alpha}{3 + 2\gamma\alpha}. \tag{9}$$

Then we obtain the following proposition.

Proposition 1. $\frac{dq}{d\gamma} < 0, \frac{dq}{d\alpha} < 0, \frac{dq}{d\tau} < 0, \frac{dq}{ds} > 0; \frac{de}{d\gamma} < 0, \frac{de}{d\alpha} > 0, \frac{de}{d\tau} < 0, \frac{de}{ds} > 0.$

Proof. *From function* (7), *we have* $\frac{dq}{d\gamma} = -\frac{M+s-\alpha\tau}{(3+2\gamma\alpha)^2} < 0$, $\frac{dq}{d\alpha} = -\frac{2\alpha^2(M+s-\alpha\tau)}{(3+2\gamma\alpha)^2} < 0$, $\frac{dq}{d\tau} = -\frac{\alpha}{3+2\gamma\alpha} < 0$ *and* $\frac{dq}{ds} = \frac{1}{3+2\gamma\alpha} > 0$. *Similarly, from function* (8), *we get* $\frac{de}{d\gamma} = -\frac{2\alpha^2(M+s-\alpha\upsilon)}{(3+2\gamma\alpha)} < 0$, $\frac{de}{d\alpha} = \frac{3M+3s-2\alpha(3+\gamma\alpha)\tau}{(3+2\gamma\alpha)^2} > 0$, $\frac{de}{d\tau} = -\frac{\alpha^2}{3+2\gamma\alpha} < 0$ *and* $\frac{de}{ds} = \frac{\alpha}{3+2\gamma\alpha} > 0$ *easily.*

Conclusions are therefore achieved and the proof is complete.

Remarks *Based on the signs of derivatives of* Proposition 1, *we learn that total agricultural pollution/emission decreases with the importance of environment to consumers and marginal pollution tax, while it increases with marginal emission and subsidy rate. These conclusions are reasonable because the importance of environment and marginal pollution tax can be seen as restrictive factors for agricultural pollution. However, at the same time, these factors also limited the total quantity of outputs. Therefore, the government will be confronted with a paradox between food quantity safety and environment quality. On the other hand, quantity subsidy increases output quantity and agricultural pollution, which means quantity subsidy will force the government into the dilemma again. Take the situations of China and the United States as an example. It is known that environmental pollution in China is much more serious than that in the United States. A suitable reason is that people in developed countries, such as the United States care more about the environment and the governments in those countries have heavier pollution tax policies than those in developing countries. On the other hand, technologies used in the agricultural production of developing countries such as China are less developed than in the developed countries and developing countries offer less investment subsidy to agriculture.*

$$p = \frac{(2 + \gamma\alpha) - (1 + \gamma\alpha)(s - \alpha\tau)}{3 + 2\gamma\alpha}. \tag{10}$$

Proposition 2. $\frac{dp}{d\gamma} < 0, \frac{dp}{d\alpha} < 0, \frac{dp}{d\tau} > 0, \frac{dp}{ds} < 0.$

Proof. *The proof is almost the same as that of* Proposition 1, *and we omit it here.*

Remarks *The more consumers value the quality of environment, the lower price they prefer to pay for the agricultural products produced with pollution/emission; hence, both increase in the importance of environment to consumers and the marginal emission will reduce the price. Note that quantity subsidy increases total emission and that emission increase is equated to the decrease of output quality, because emission is a by-product and it is bad for the consumers. The conclusions of* Proposition 2 *imply that quantity subsidy decreases price. On the one hand, more subsidies mean more emission and lower output quality, which will decrease the price. On the other hand, conclusions of* Proposition 1 *show that quantity subsidy increases total outputs. From the function of price, we know that both the decrease of quality and the increase of quantity will lower the price. Organic agricultural productions are more expensive that non-organic ones. The reason is that organic food is higher quality and more environmentally friendly, except the costs of organic food are higher. Interestingly, emission tax increases the price, while quantity subsidy decreases it. This means that part of the tax and subsidy effects will be transferred to consumers by price.*

Next, we will make some analyses about producer surplus (*PS*), consumer surplus (*CS*), government budget (*GB*) and social welfare (*SW*). *PS* equates to its profit and *CS* is given by function (1). *GB* equates to total taxes minus total subsidies. Both $GB > 0$ (revenues) and $GB < 0$ (costs) can occur. By function (1), we have the equilibrium CS as follows:

$$CS = \frac{q^2}{2} = \frac{(M + s - \alpha\tau)^2}{2(3 + 2\gamma\alpha)^2}. \tag{11}$$

Then from function (6)–(10), we obtain PS and GB as

$$PS = \pi = \frac{(M + s - \alpha\tau)^2}{6 + 4\gamma\alpha}, \tag{12}$$

$$GB = \frac{(M + s - \alpha\tau)(\alpha\tau - s)}{3 + 2\gamma\alpha}. \tag{13}$$

For $0 \le \alpha, \tau, s \le 1$, we further define $s > \alpha\tau$, which means $GB < 0$ or net budget (total taxes minus total subsidies) of the government is negative under quantity subsidy. Both $s > \alpha\tau$, if or marginal tax or τ is not to high, and,$s < \alpha\tau$ if the government imposes high environment tax, can occur. But generally, τ is not high enough to lead $s < \alpha\tau$ for $0 \le \alpha, \tau, s \le 1$. Hence, we assume $s > \alpha\tau$ and, $GB < 0$ accordingly. Finally, we obtain $SW = CS + PS + GB$ as follows:

$$SW = \frac{(M + s - \alpha\tau)[(2 + \gamma\alpha)M - (1 + \gamma\alpha)(s - \alpha\tau)]}{(3 + 2\gamma\alpha)^2}. \tag{14}$$

Based on equation (11)–(14), we get Proposition 3.

Proposition 3. $\frac{dPS}{d\gamma} < 0$, $\frac{dPS}{d\alpha} < 0$, $\frac{dPS}{d\tau} < 0$, $\frac{dPS}{ds} > 0$; $\frac{dCS}{d\gamma} < 0$, $\frac{dCS}{d\alpha} < 0$, $\frac{dCS}{d\tau} < 0$, $\frac{dCS}{ds} > 0$; $\frac{d|GB|}{d\gamma} < 0$, $\frac{d|GB|}{d\alpha} < 0$, $\frac{d|GB|}{d\tau} < 0$, $\frac{d|GB|}{ds} > 0$; $\frac{dSW}{d\gamma} < 0$, $\frac{dSW}{d\alpha} < 0$, $\frac{dSW}{d\tau} < 0$, $\frac{dSW}{ds} > 0$.

Proof. *The proof of* Proposition 3 *is almost the same as that of* Proposition 1 *so we omit it here.*

Remarks *The conclusions of* Proposition 3 *indicate that producer surplus, consumer surplus, government budget (costs), and social welfare all decrease with the importance of environment to consumer, marginal emission, and marginal tax but increase with agricultural subsidy. Although emission tax inhibits agricultural pollution, it also decreases consumer surplus, producer surplus, and total social welfare. Therefore, the government should make a trade-off between the negative effects and positive effects of pollution tax by carrying out a suitable tax rate. The effects of agricultural subsidy are just contrary to the pollution, and that means the government should also choose a moderate subsidy rate.*

3.2. Emission-reducing innovation subsidy

The analyses above show that quantity subsidy will aggravate agricultural pollution. That is what the Chinese government has recently done. What will happen if the government implements other agricultural subsidies, such an innovation subsidy? Innovation subsidy may be more helpful for environmental improvement. Hence, in this section, we consider the condition that the government changes quantity subsidy into emission-reducing innovation subsidy. If the government offers innovation subsidy and $I \neq 0$, then function (5) can be rewritten as

$$\pi = [M - \gamma\alpha(q - I) - q]q - \frac{1}{2}q^2 - \frac{3}{2}I^2 - \tau\alpha(q - I) + sI. \tag{15}$$

Based on $c_2 > c_1$ and to simplify our analyses, we denote $c_2 = \frac{3}{2}$. Because the above profit function is globally concave in q and I, unique solutions exist. The first-order optimal conditions are outlined as

$$\begin{aligned} \frac{\partial\pi}{\partial q} &= M - (3 + 2\gamma\alpha)q + \gamma\alpha I - \alpha\tau = 0, \\ \frac{\partial\pi}{\partial I} &= s + \gamma\alpha q + \alpha\tau - 3I = 0. \end{aligned} \tag{16}$$

Equation (16) implies the following solutions in equilibrium

$$q^* = \frac{3M + [\gamma s - (3 - \gamma\alpha)\tau]\alpha}{9 + 6\gamma\alpha - \gamma^2\alpha^2}, \tag{17}$$

$$I^* = \frac{(3 + 2\gamma\alpha)s + [\gamma M + (3 + \gamma\alpha)\tau]\alpha}{9 + 6\gamma\alpha - \gamma^2\alpha^2}, \tag{18}$$

$$e^* = \frac{(3 - \gamma\alpha)M - (3 + \gamma\alpha)s - 6\alpha\tau}{9 + 6\gamma\alpha - \gamma^2\alpha^2}\alpha. \tag{19}$$

$$p^* = \frac{3(2 + \gamma\alpha)M + [(2 + \gamma\alpha)\gamma s + (3 + 5\gamma\alpha)\tau]\alpha}{9 + 6\gamma\alpha - \gamma^2\alpha^2}. \tag{20}$$

Proposition 4. $\frac{dI}{d\gamma} > 0$, $\frac{dI}{d\alpha} > 0$, $\frac{dI}{d\tau} > 0$, $\frac{dI}{ds} > 0$.

Proof. *The proof is almost the same as that of* Proposition 1, *and we omit it here.*

Remarks *Interestingly, the importance of environment to consumer, marginal emission, tax rate, and innovation subsidy rate increase emission-reducing innovation. Hence, it is good for the government to implement innovation subsidy. This is because firm's innovation investment will be insufficient without innovation subsidy and environment effect of innovation subsidy will be enhanced by other factors, such as pollution tax, importance of the environment to consumer, and marginal emission.*

From functions (17)–(20), we have

$$CS^* = \frac{1}{2}\left\{\frac{3M + [\gamma s - (3 - \gamma\alpha)\tau]\alpha}{9 + 6\gamma\alpha - \gamma^2\alpha^2}\right\}^2, \tag{21}$$

$$PS^* = \frac{3M^2 + (3 + 2\gamma\alpha)s^2 + 2(3 + \gamma\alpha)\alpha s + 2\alpha[\gamma s - (3 - \gamma\alpha)\tau]M + 6\gamma^2\alpha^2}{2(9 + 6\gamma\alpha - \gamma^2\alpha^2)}, \tag{22}$$

$$GB^* = \frac{[3M - (3 - \gamma\alpha)\tau]\alpha\tau - [\gamma M + 3\tau]\alpha s - (3 + 2\gamma\alpha)s^2}{9 + 6\gamma\alpha - \gamma^2\alpha^2}, \tag{23}$$

$$SW^* = \frac{2[3\gamma s-(9-12\gamma\alpha-6\gamma^2\alpha^2+\gamma^2\alpha^2)\tau]\alpha M+(9+12\gamma\alpha+13\gamma^2\alpha^2-2\gamma^3\alpha^3)\alpha^2\tau^2}{2(9+6\gamma\alpha+\gamma^2\alpha^2)^2} + \frac{(36+18\gamma\alpha-3\gamma^2\alpha^2)M^2-(27+36\gamma\alpha+8\gamma^2\alpha^2-2\gamma^3\alpha^3)s^2+2(6+7\gamma\alpha-\gamma^2\alpha^2)\gamma\alpha^2\tau s}{2(9+6\gamma\alpha-\gamma^2\alpha^2)^2}. \tag{24}$$

Notice that $GB^*>0$. This is good news for the government, because if the government changes quantity subsidy to innovation subsidy, its net budget will change from negative to positive, or total taxes will exceed total subsidies. Then, we achieve the following Proposition.

Proposition 5. $\frac{dp^*}{ds}>0$, $\frac{dGB^*}{d\tau}>0$, $\frac{dGB^*}{ds}<0$ *and all other relationships under quantity subsidy are held here.*

Proof. *The proof is almost the same as that of Proposition 1, and we omit it here.*

Remarks *Different form quantity subsidy, innovation subsidy increases equilibrium price. A suitable explanation is that the increase of emission has a similar effect as the decrease of output quality on price and, conversely, the decrease of emission has the same impact as the increase of output quality on price. Hence, innovation subsidy will raise price by decreasing emission. Actually* $\frac{dGB^*}{d\tau}>0$ *and* $\frac{dGB^*}{ds}<0$ *is consistent with* $\frac{d|GB|}{d\tau}<0$ *and* $\frac{d|GB|}{ds}>0$, *because* $|GB|$ *are the total costs of the government, while* GB^* *are the total incomes of the government. So, the decrease of* $|GB|$ *is the same as the increase of* GB^*, *or a decrease in costs equates to an increase in income.*

3.3. Comparing analyses

The next important question is as follows: What are the differences between the two cases? Here, we will make some comparison analyses about the results of the two different subsidy policies. To measure the difference we subtract the same one under innovation subsidy from the variable under quantity subsidy. For example, given the quantity q of quantity subsidy and q^* of innovation subsidy, the quantity difference is defined as $\Delta q = q - q^*$. All the differences are outlined as follows.

$$\Delta q = q - q^* = \frac{3(3+\gamma\alpha-\gamma^2\alpha^2)s-[\gamma M-(3+\gamma\alpha)\tau]\gamma\alpha^2}{(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)}, \tag{25}$$

$$\Delta e = e - e^* = \frac{(18+15\gamma\alpha+\gamma^2\alpha^2)s+(3+\gamma\alpha)[\gamma M+(3+\gamma\alpha)\tau]\alpha}{(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)}, \tag{26}$$

$$\Delta p = p - p^* = -\frac{(9+21\gamma\alpha+12\gamma^2\alpha^2+\gamma^3\alpha^3)s+\gamma\alpha^2(2+\gamma\alpha)[M\gamma+(3+\gamma\alpha)\tau]}{(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)}, \tag{27}$$

$$\Delta CS = CS - CS^* = \frac{(18+12\gamma\alpha-\gamma^2\alpha^2)M+(9+9\gamma\alpha+\gamma^2\alpha^2)s-3(6+3\gamma\alpha-\gamma^2\alpha^2)\alpha\tau}{2(3+2\gamma\alpha)^2} \times \frac{3(3+\gamma\alpha-\gamma^2\alpha^2)s-\gamma\alpha^2[\gamma M+(3+\gamma\alpha)\tau]}{(9+6\gamma\alpha-\gamma^2\alpha^2)^2}, \tag{28}$$

$$\Delta PS = PS - PS^* = \frac{[3(3+\gamma\alpha-\gamma^2\alpha^2)s-\gamma\alpha^2(3+\gamma\alpha)\tau]2M-M^2\gamma^2\alpha^2}{2(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)} - \frac{\left[(6+5\gamma\alpha)\gamma s^2+2(18+15\gamma\alpha+\gamma^2\alpha^2)\tau s+(3+\gamma\alpha)^2\alpha\tau^2\right]\alpha}{2(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)}, \tag{29}$$

$$\Delta GB = |GB| - GB^* \frac{[(9+9\gamma\alpha+\gamma^2\alpha^2)s-(18+12\gamma\alpha-\gamma^2\alpha^2)\alpha\tau]M+(6+6\gamma\alpha-\gamma^2\alpha^2)}{(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)} + \frac{3(6+3\gamma\alpha-\gamma^2\alpha^2)\alpha^2-(9+6\gamma\alpha-2\gamma^2\alpha^2)}{(3+2\gamma\alpha)(9+6\gamma\alpha-\gamma^2\alpha^2)}, \tag{30}$$

$$\begin{aligned}\Delta SW &= SW - SW^{*}\\ &= \frac{2(162+324\gamma\alpha+117\gamma^2\alpha^2-87\gamma^3\alpha^3-38\gamma^4\alpha^4+6\gamma^5\alpha^5)\alpha\tau s}{2(3+2\gamma\alpha)^2(9+6\gamma\alpha-\gamma^2\alpha^2)^2}+\frac{(81+270\gamma\alpha+360\gamma^2\alpha^2+210\gamma^3\alpha^3+30\gamma^4\alpha^4-10\gamma^5\alpha^5)s^2}{2(3+2\gamma\alpha)^2(9+6\gamma\alpha-\gamma^2\alpha^2)^2}\\ &\quad+\frac{2[(81+81\gamma\alpha-18\gamma^2\alpha^2-24\gamma^3\alpha^3+\gamma^4\alpha^4)s}{2(3+2\gamma\alpha)^2(9+6\gamma\alpha-\gamma^2\alpha^2)^2}-\frac{(45+48\gamma\alpha+8\gamma^2\alpha^2-2\gamma^3\alpha^3)M^2\gamma^2\alpha^2}{2(3+2\gamma\alpha)^2(9+6\gamma\alpha-\gamma^2\alpha^2)^2}\\ &\quad-\frac{3(81+198\gamma\alpha+183\gamma^2\alpha^2+66\gamma^3\alpha^3+2\gamma^4\alpha^4-2\gamma^5\alpha^5)\alpha^2\tau^2}{2(3+2\gamma\alpha)^2(9+6\gamma\alpha-\gamma^2\alpha^2)^2}-\frac{(108+180\gamma\alpha+99\gamma^2\alpha^2+13\gamma^3\alpha^3-4\gamma^4\alpha^4)\gamma\alpha^3\tau]M}{2(3+2\gamma\alpha)^2(9+6\gamma\alpha-\gamma^2\alpha^2)^2},\end{aligned} \tag{31}$$

Denote $\hat{s}=\frac{[\gamma M-(3+\gamma\alpha)\tau]\gamma\alpha^2}{3(3+\gamma\alpha-\gamma^2\alpha^2)}$ the threshold of subsidy rate and from equations (25)–(31), we have Proposition 6.

Proposition 6. *$\Delta p<0$, $\Delta e>0$, $\Delta PS<0$, $\Delta GB>0$; $\Delta q>0$, $\Delta CS>0$, if $s>\hat{s}$ while $\Delta q<0$, $\Delta CS<0$, if $s<\hat{s}$; sign$\{\Delta SW\}$ is ambiguous.*

Proof. *From* (25) *and* (28), *we know that the sign of Δq and ΔCS are dependent on the sign of $3(3+\gamma\alpha-\gamma^2\alpha^2)s-\gamma\alpha^2[\gamma M+(3+\gamma\alpha)\tau]$. $\Delta q>0$ and $\Delta CS>0$ if $3(3+\gamma\alpha-\gamma^2\alpha^2)s-\gamma\alpha^2[\gamma M+(3+\gamma\alpha)\tau]$ or $s>\hat{s}=\frac{[\gamma M-(3+\gamma\alpha)\tau]\gamma\alpha^2}{3(3+\gamma\alpha-\gamma^2\alpha^2)}$, while $\Delta q<0$ and $\Delta CS<0$ if $s<\hat{s}=\frac{[\gamma M-(3+\gamma\alpha)\tau]\gamma\alpha^2}{3(3+\gamma\alpha-\gamma^2\alpha^2)}$. The sign of ΔSW is ambiguous because it is dependent on all the parameters. All other conclusions of Proposition 6 can be obtained by* equations (25)–(31) *by direct calculation.*

Conclusions are therefore achieved and the proof is complete.

Remarks *Obviously, emission-reducing innovation reduces total agricultural emission. Based on the terrible impact of agriculture on the environment and the importance of environment to residents, the government of China should adjust quantity subsidy to innovation subsidy. Furthermore, innovation subsidy increases firm's profits and that is good news for grain producers, undoubtedly, and they will prefer innovation subsidy to quantity subsidy. Although innovation subsidy raises equilibrium price, output quantity and consumer surplus under innovation subsidy are also higher than those under quantity subsidy if the density of subsidy is less than a certain value. Besides, innovation subsidy alleviates the government's financial burden. However, the relationship between total social welfare is ambiguous. More importantly,* Proposition 6 *gives the threshold of subsidy rate to relieve the dilemma of agriculture.*

4. Discussions and conclusions

Agriculture in China is confronted with a dilemma. On the one hand, it needs to cultivate enough grains to feed its people. On the other, its environment is becoming increasingly worse because of agriculture, and output quantity subsidy makes thing even worse. Fortunately, this study finds emission-reducing innovation subsidy is an ideal way to relieve the dilemma. In practice, agricultural subsidy system reform based on green ecological agriculture is being implementing by China's Ministry of Agriculture, and resources and environmental protection subsidy is a major type of agricultural subsidy.

This study assumes that marginal subsidies of different agricultural subsidy policies are the same. If subsidy rates are different under different subsidy conditions, some interesting conclusions may be achieved; thus, further study can try to abandon the same subsidy rate assumption and to capture the optimal subsidy rates under different conditions. We consider quantity subsidy and innovation subsidy separately, but the government may practice them simultaneously under some conditions. Thus, employing different subsidy policies with a more complex framework is a valuable prolongation. Besides, further study could take competition effect or competition structure into consideration.

By taking the importance of environment into account, this study captures the impact of agricultural pollution tax and agricultural subsidy, including quantity subsidy and innovation subsidy, on firm decision and the environment. Output quantity subsidy is a major agricultural subsidy in China and based on the food quantity safety perspective. The results of this study illustrate that quantity subsidy increases food quantity, but it also increases agricultural pollution. In other words, we offer a reasonable explanation for China's serious agricultural pollution and some suggestions about how to alleviate it. This paper finds that quantity subsidy in agriculture is not environmentally friendly, while innovation subsidy is helpful for agricultural pollution relief. The results of this paper show as the importance of environment to consumers increases, marginal emission/pollution, and tax rate decrease all the output quantity, consumer surplus, producer surplus and social welfare, but the increase of subsidy rate increases all of them. These conclusions are held under both quantity subsidy and innovation subsidy. Interestingly, quantity subsidy lowers equilibrium price by increasing equilibrium quantity, but innovation subsidy raises it because it increases total quality. We can obtain these conclusions under any imperfect competition market, and almost all markets are imperfect competition in reality. More importantly, compared with quantity subsidy, innovation subsidy decreases total emission and increases producer surplus. Further, innovation subsidy even increases total output quantity and consumer surplus if subsidy rate of agriculture is less than some value. This means that innovation subsidy can alleviate the dilemma of food quantity and environment pollution. All these conclusions imply that emission-reducing innovation subsidy is better than quantity subsidy.

The novel contribution of this study is that it combines pollution tax and agricultural subsidy with study agricultural pollution and makes a deep analysis based on microeconomic theory. We obtain the conclusion that innovation subsidy is better than quantity subsidy, by comparing the different effects of the two agricultural subsidy policies. Furthermore, we design a feasible regulation mechanism to regulate agricultural pollution and find a threshold of agricultural subsidy rate to alleviate the dilemma of agriculture in China.

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