Green Payments and Dual Policy Goals

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Abstract

We use a mechanism design framework to analyze the optimal design of green payment policies with the dual goals of conservation and income support for small farms. Each farm is characterized by two dimensions of attributes: farms size and conservation efficiency. Policymakers may not be able to use the attributes as an explicit criterion for payments. We characterize optimal policy when conservation efficiency is unobservable to policy-makers, and when farm size is also unobservable. An income support goal is shown to reduce the conservation distortion caused by asymmetric information. The cost of optimal green payment mechanisms is shown to depend crucially on whether large or small farms have greater conservation efficiency.

Key words: asymmetric information, cost effect, green payments, income support, information rent, mechanism design.

1 Introduction

Green payments are payments a government provides to farms for voluntarily maintaining or adopting conservation practices that enhance the environment. As shown by the debate over the 2002 farm bill, originally referred to as the Conservation Security Act in the U.S. Senate, green payments have moved to the center stage of agri-environmental policies. There are two basic reasons for this interest. First, green payments provide a foundation for farm support by society at large. If agriculture is to continue to receive the billions of dollars it has been receiving in recent years, many analysts believe more substantial justification will be needed. Conservation programs like green payments have become more attractive because of the continued increase in public demand for a better environment (Babcock, Claassen et al.).

Second, green payments can treat agri-environmental problems that have not been adequately addressed. The Conservation Reserve Program (CRP) and the Wetland Reserve Program (WRP) provide conservation services by taking land out of production. Cost-share programs, such as the Environmental Quality Incentive Program (EQIP) and the Wildlife Habitat Incentives Program, pay farms for conservation on land in production. However, when the cost share is less than 100 percent, farms have no incentive to participate unless the targeted practices also provide private benefits. Green payments, such as the Conservation Security Program (CSP) initiated in the 2002 farm bill, cover comprehensive practices and are also more generous, and thus are better positioned to meet conservation needs.

In this paper, we examine the optimal design of green payment programs taking into account some realistic characteristics of the policy environment. First, we recognize that policymakers in general do not know an individual farm's conservation efficiency. For example, how the adoption of conservation tillage affects a farm's profit depends on many factors, such as the natural resource endowments of the farm, weather conditions, the farmer's years of experience, and the equipment the farm already has. It is unlikely that policymakers will have information on all these specifics of a farm. Even when a farm's conservation efficiency is known, it cannot always be used as a basis for payments. For example, the 2002 farm bill stipulates: "If the Secretary determines that the environmental values of 2 or more applications for cost-share payments or incentive payments are comparable, the Secretary shall not assign a higher priority to the application only because it would present the least cost to the program established under the program" (U.S. Congress).

With asymmetry information on conservation efficiency, a mechanism design framework can be used to analyze green payment contracts (e.g., Wu and Babcock 1995, 1996). A standard adverse selection (AS) model for green payments can be described as follows . Policymakers (the principal), given available funds, intend to obtain the maximal conservation services from farms (the agents). However, policymakers do not know each individual farm's conservation efficiency type, although they know the proportion of farms with high (or low) conservation efficiency. In such models, it is well-known that, to induce truthful revelation as implied by the revelation principle, a "bribe" has to be paid to the high efficiency type that is equal to the amount it would obtain by pretending to be the other type.[1] An optimal policy has to take into account the informational cost associated with each additional unit of conservation by the low efficiency type.

In a standard AS model, policymakers' objective is to maximize conservation services. In this paper, we consider green payment policies intended both for income support and conservation. Formally, we broaden the standard AS model on green payments to represent the dual goals. Moreover, our study departs from previous studies on green payments or income support in that heterogeneity is introduced into conservation types, i.e., there are both small family farms and big farms within each conservation type. In other words, each farm is characterized by two dimensions of attributes: farm size and conservation efficiency. However, payments may not be explicitly based on either of the attributes, due to the informational and/or political constraints. Our analysis demonstrates the implications of green payments that attempt to use "one stone to kill two birds." In particular, we show the impacts of the income support objective and the compromises that have to be made in an optimal policy.

When green payments can be designed separately for big and small farms, we demonstrate

[1] Guesnerie and Laffont provide a complete solution to this class of principal-agent problems. The revelation principle basically says that any mechanism is isomorphic to a revelation mechanism, by which the principal elicits truthful answers about the unknown parameter of the agents. For more discussions, see Myerson and Dasgupta, Hammond, and Maskin.

that the income support goal will increase the net payments for all small farms and the income of those with higher conservation efficiency will be increased more. Some previous studies suggested that it might not be feasible to explicitly target small (or high production cost) farms for income transfer due to public relations or strong lobbying from large (low production cost) farms (e.g., Innes, Hueth, Chambers 1992, Bourgeon and Chambers). So, we also examine green payments when farm size is not contractible. In this case, if big farms have higher conservation efficiency, our results indicate that it is optimal for policymakers to pay big farms whatever net payments that are paid to small farms. For a given budget, this means lower income support for small farms and/or less conservation relative to the case without informational or political constraints. In the case of the CSP, almost every farm is entitled to payments according to the 2002 farm bill. However, there is not enough funding for everybody. As a result, the program has only been implemented in a small number of watersheds in the country.

In addition to net payments, the income support goal of green payments will also affect the optimal conservation. This is because the "bribe" in the standard AS model is no longer just a cost. If it goes to small farms, it can act as income support which is now valued by policymakers. Our analysis shows that this will reduce the distortion in conservation that would have occurred in a Standard AS model. In this sense, green payments are more likely to achieve both goals if small farms have higher conservation efficiency than big farms. That is, if small farms are the ones who will be paid the bribe. On the other hand, if big farms are more conservation efficient, then they will get not only the "bribe" but also the income support intended for small farms. Moreover, the "bribe" they obtain will not have any welfare improving effects on the optimal conservation services.

The rest of this paper is organized as follows. We lay out the basic elements of the model in the next section. In section 3, we introduce and analyze the model with dual goals and dual information asymmetries. Specifically, in subsection 3.1, we analyze the case when farm size is contractible to focus on the impacts of the income support objective. In subsection 3.2, to shed light on the implications of the inability to distinguish between big and small farms, green payment policies are examined for the case when farm size is not contractible. We offer some discussions and conclusions in section 4.

2 Model setup

Farms are characterized by two variables: farm size ϕ and conservation efficiency θ. For simplicity, we assume that ϕ and θ have two levels: $\phi \in \Phi \equiv \{b, s\}$ and $\theta \in \Theta \equiv \{h, l\}$, where the English letters represent *b*ig, *s*mall, *h*igh, and *l*ow, respectively.[2] We denote their joint and marginal distributions as $P_{\phi\theta}$, P_{ϕ}, and P_{θ}, respectively. The two variables may be correlated. For example, positive correlation may occur if big farms are able to adopt conservation practices more efficiently because they have more efficient management. Negative correlation may occur if small farms can provide conservation services at a relatively low cost because their land is environmentally sensitive.

Farmers can provide conservation services, denoted as E, by adopting conservation practices such as leaving more residue in the field and reducing the use of nitrogen. We normalize E to zero in the absence of any external incentives. To provide a positive level of E, a farm incurs costs which include profit loss and/or expenditures related to adopting conservation practices, Denote the cost function of providing E as $C_{\phi\theta}(E)$ with[3]

$$C_{\phi h}(E) - C_{\phi l}(E) \leq 0, \qquad C'_{\phi h}(E) - C'_{\phi l}(E) \leq 0, \tag{1}$$

that is, $\theta = h$ is assumed to be associated with lower total and marginal costs than $\theta = l$. We

[2] Despite the fact that farm size and conservation efficiency are distributed in a continuous fashion, we believe our analyses based on dual characterization of types can have direct relevance for policy discussions. This is because, continuous distributions may be divided into discrete categories for practical reasons. In fact, discrete tiers have also been used in conservation programs (e.g. the CSP). There are also definitions of small farms and large farms—according to the Economic and Research Services at USDA (ERS/USDA), small family farms are farms with sales less than \$250,000. Moreover, to what degree small farms, as opposed to large farms, can benefit from government payments is often an issue of great interest to both the public and policymakers. (e.g., Claassen et al.).

[3] We could start the analysis from a yield function as in Wu and Babcock (1996), although here we would have two parameters, farm size (ϕ) and conservation efficiency (θ). That is, we could have a yield function like $f_{\phi\theta}(\mathbf{x})$, where $\mathbf{x}$ is a vector of input variables. Let the net return function before and after the adoption of conservation measures be $\pi_{\phi\theta}(\mathbf{x}^*)$ and $\pi_{\phi\theta}(\mathbf{x}^0)$, respectively, where $\mathbf{x}^*$ and $\mathbf{x}^0$ are the corresponding profit maximizing input choices. Conservation services (E) can be defined as the change from $\mathbf{x}^*$ to $\mathbf{x}^0$. That is, $E \equiv d(\mathbf{x}^*, \mathbf{x}^0)$, which can be as simple as input use reduction or some environmental consequences of input use changes. Then the cost of providing E would be the difference between the two net return functions, that is, $C_{\phi\theta}(E) = \pi_{\phi\theta}(\mathbf{x}^*) - \pi_{\phi\theta}(\mathbf{x}^0)$.

make the standard assumption that $C(\cdot)$ is convex in E.

Policymakers intend to make payments to farms as incentives for conservation and as a way of supporting farm income. We refer to such payments as green payments, denoted as $G_{\phi\theta}$. The benefit policymakers derive from income support is represented as $\tilde{W}(\cdot)$, with

$$\tilde{W}(T_{\phi\theta}) = \begin{cases} W(T_{\phi\theta}), \text{ if } \phi = s, \\ 0, \text{ if } \phi = b, \end{cases} \tag{2}$$

where $T_{\phi\theta}$ is the *net payments* to farms, that is, $T_{\phi\theta} \equiv G_{\phi\theta} - C_{\phi\theta}(E)$. We also refer to $T_{\phi\theta}$ as the income support that type $\phi\theta$ farms obtain from the government. The function W is assumed to be increasing and concave with $W'(\cdot) \geq 0$, $W''(\cdot) \leq 0$. Thus, (2) indicates that policymakers only derive benefit from supporting small farms' income, and as their income increases the marginal benefit from supporting them decreases.

The social benefit of conservation is denoted as $V(E)$, which is assumed to be increasing and concave. Funds for green payments are usually financed with some sort of distortionary tax whose unit deadweight loss we denote as $\lambda > 0$.[4] To make the problem interesting, we assume that $W'(0) > \lambda$, i.e., the marginal benefit from increasing small farms' initial income by a small amount is greater than the cost of transferring funds.

3 An adverse selection model with dual goals

Just as in standard AS models, we will model a green payment program as a truthful direct revelation mechanism, where the government offers farms a menu of conservation levels and green payments, $(E_{\phi\theta}, G_{\phi\theta})$, and farms can pick any one choice from the menu. Specifically, the policymakers' problem is to choose $E_{\phi\theta}$ and $G_{\phi\theta}$ to maximize the sum of benefits from

[4] An alternative interpretation of λ is that it is the multiplier of policymakers' budget constraint.

conservation and income support, minus the cost of conservation and funding, i.e.,

$$\max_{E,G} \quad \sum_{\phi} \sum_{\theta} \left[V(E_{\phi\theta}) - C_{\phi\theta}(E_{\phi\theta}) + \tilde{W}\,(T_{\phi\theta}) - \lambda G_{\phi\theta} \right] P_{\phi\theta}, \tag{3a}$$

$$s.t. \qquad T_{\phi\theta} = G_{\phi\theta} - C_{\phi\theta}(E_{\phi\theta}) \geq 0, \tag{3b}$$

$$G_{\phi\theta} - C_{\phi\theta}(E_{\phi\theta}) \geq G_{\phi'\theta'} - C_{\phi\theta}(E_{\phi'\theta'}), \tag{3c}$$

where $\phi, \phi' \in \Phi$, $\theta, \theta' \in \Theta$. In addition to the benefit from income support in the objective function, the above problem differs from a standard AS model in the heterogeneity introduced within each conservation efficiency type. Here, for each conservation type, there are small and big farms both of whom may receive income support if policymakers cannot or do not explicitly distinguish between them. The expression in (3b), denoted as $IR_{\phi\theta}$, contains the individual rationality constraints, which require voluntary participation. It is in general politically infeasible to require farms to provide conservation without compensation because of long-standing concerns for farm income support. In fact, most agri-environmental programs are voluntary mechanisms, for example, CRP, WRP, EQIP, and CSP. The expression in (3c), denoted as $IC_{\phi\theta,\phi'\theta'}$, contains the incentive compatibility constraints: revealing her true type gives a farm a higher income than pretending to be other types.

If ϕ and θ are contractible, then (3c) does not apply and we derive the perfect information optimum:

$$V'(\hat{E}_{\phi\theta}) - (1+\lambda)C'_{\phi\theta}(\hat{E}_{\phi\theta}) = 0;\ \hat{T}_{b\theta} = 0;\ \text{and}\ \ W'(\hat{T}_{s\theta}) = \lambda;\ \ \text{for}\ \phi \in \Phi,\ \theta \in \Theta. \tag{4}$$

That is, the optimal conservation services for both small and big farms are set to equalize the marginal benefit and marginal cost of conservation. It is easy to see that $\hat{T}_{sh} = \hat{T}_{sl} > \hat{T}_{bh} = \hat{T}_{bl} = 0$. In other words, for big farms, there is no benefit from income support, so their net payments are equal to zero—their green payments are just equal to their conservation costs. For small farms, their net payments will be positive and are determined by setting the marginal benefit of income support equal to the marginal cost. Thus, income transfers are made to small farms without any distortion in conservation. As to conservation levels, from (1) and (4), we know that $\hat{E}_{\phi h} \geq \hat{E}_{\phi l}$ for $\phi = b$ and s. When we discuss the impacts of the dual goals and information asymmetry in the rest of the paper, $\hat{T}_{\phi\theta}$ and $\hat{E}_{\phi\theta}$ will be used as benchmarks.

3.1 When farm size is contractible

The introduction of dual goals into the standard AS model does not have to involve dual information asymmetries. In this section, we investigate the implication of introducing only dual goals, but not dual information asymmetries. By limiting to one dimension of information asymmetry, we can isolate the effects of dual goals. Specifically, suppose farm size (ϕ) is contractible, but conservation efficiency (θ) is not. Then, we can solve the problem separately for small and big farms. Without benefit from income support, the problem for big farms is just a standard AS model described in the introduction section.

For small farms, the problem becomes more complicated with dual goals and still one dimension of information asymmetry. More specifically, the problem can be written in a two-stage form as follows:

$$\max_{E_{sh},E_{sl}} \left\{ \sum_{\theta} \left[V(E_{s\theta}) - C_{s\theta}(E_{s\theta})\right] \tfrac{P_{s\theta}}{P_s} + \max_{G} \left\{ Z^s : \text{(3b)-(3c) with } \phi, \phi' = s \right\} \right\} \tag{5a}$$

$$\text{where} \quad Z^s \left(E_{sl}, E_{sh}, G_{sl}, G_{sh}\right) \equiv \textstyle\sum_{\theta} \left[W(T_{s\theta}) - \lambda G_{s\theta}\right] \tfrac{P_{s\theta}}{P_s}. \tag{5b}$$

In the Appendix, we show the details of solving (5). Here we present the major characteristics of the solutions indicated by "*". Define $I_{\phi\theta,\phi'\theta'}(E) \equiv C_{\phi'\theta'}(E) - C_{\phi\theta}(E)$, then we have

Lemma 1 *For the problem in (5), given any conservation $\boldsymbol{E}$ with $E_{sh} \geq E_{sl}$, the optimal net payments to farms are such that*[5]

$$T^*_{sh} = T^*_{sl} + I_{sh,sl}(E_{sl}), \tag{6a}$$

$$\lambda = W'(T^*_{sl})\tfrac{P_{sl}}{P_s} + W'(T^*_{sh})\tfrac{P_{sh}}{P_s}. \tag{6b}$$

[5] Bold letters indicate vectors throughout the paper. With a slight abuse of notation, we use $\boldsymbol{E}$ to indicate the conservation services of all types in all cases, even though the number of relevant types may differ in different cases. Similar usage applies to $\boldsymbol{G}$.

The first equation indicates that the optimal net payment to type sh exceeds the optimal net payment to type sl by $I_{sh,sl}(E_{sl})$, which is the information rent type sh would earn by misrepresenting itself. Just as (4) in the case with perfect information, (6b) requires that the marginal cost and the (expected) marginal benefit of income support are equalized, even though marginal benefits take different forms in the two equations. Specifically, no expectation is taken in (4) while an expectation is taken in (6b) with respect to all small farms since green payments cannot be explicitly directed at a subgroup of them. From (6), we have $W'(T_{sl}^*) \geq \lambda \geq W'(T_{sh}^*)$. Then, given the concavity of $W'(\cdot)$, we know from (4),

Remark 1 *Under perfect information, all small farms receive the same net payments. With asymmetric information, small farms with high conservation efficiency receive more net payments than small farms with low conservation efficiency.*

The gap between the net payments is equal to the information rent. In addition to payments, information rent will also affect the optimal conservation for some farm types. In particular,

Lemma 2 *For the problem in (5), E_{sh}^* is given by (4), and E_{sl}^* is given by*

$$V'(E_{sl}^*) - (1+\lambda)C'_{sl}(E_{sl}^*) = \left[\lambda - W'(T_{sh}^*)\right] I'_{sh,sl}(E_{sl}^*)\tfrac{P_{sh}}{P_{sl}}. \tag{7}$$

In the standard AS model information rent arises from the bribe that has to be paid to high conservation efficiency type for its truthful revelation. This effect, which we refer to as the cost effect of information rent, also exists in the dual goal model as reflected by $\lambda I'_{sh,sl}(E_{sl}^*)$ in (7). Since $I'_{sh,sl}(E_{sl}^*) > 0$, the cost effect in this case makes the optimal conservation for type sl (E_{sl}^*) smaller than the perfect information optimum, making it harder for the types to misrepresent themselves. Such "spreading effect" has also been observed in some other works (e.g., Innes).

Information rent increases the income of those farms who obtain it. In the standard AS model, since income support is not a policy goal, this "unnecessary" income increase has no value (beyond inducing truthful revelation). Therefore, a cost effect is the only role of information rent. However, in our dual-goal model, an increase in small farms' income generates a benefit for policymakers. Consequently, information rent has another effect, which we will refer to as the *income effect*, since it is related to income support. In (7), the income effect is $W'(T^*_{sh})I'_{sh,sl}(E^*_{sl})$, which is just the marginal effect of the extra income support due to information rent. The two effects enter the optimal conditions with opposite signs, i.e.,

Remark 2 *In the dual goal model, asymmetric information has two effects on optimal conservation: a cost effect and an income effect. The cost effect distorts the "low efficiency" farms' conservation level below its perfect information level ($E^*_{sl} < \hat{E}_{sl}$); the income effect partially offsets this distortion.*

The effects of the income support goal is illustrated in Figure 1(a) for small farms. The optimal conservation and net payments under complete information, $\hat{T}_{\phi\theta}$ and $\hat{E}_{\phi\theta}$, are marked on the axes for the case where type *bl* has lower marginal conservation costs than type *sh*.[6] The optimal solutions with and without income support are indicated by the small circles and squares, respectively. For either big or small farms, the deviation of the squares from the corresponding ($\hat{E}_{\phi\theta}$, $\hat{T}_{\phi\theta}$) results from asymmetric information, as predicted by the standard AS model. The difference between the squares and the corresponding circles shows the impacts of income support. For big farms, the circles and squares coincide with each other since their income support does not generate social benefit. For small farms, three differences can be observed. First, the net payments for both type *sh* and *sl* increase with income support. Second, for type *sh* farms, while their conservation stays the same as $\hat{E}_{sh}$, their net payments are higher than $\hat{T}_{sh}$. Third, for type *sl* farms, both their net payments and conservation are lower than the complete information optimum although their conservation level is closer to $\hat{E}_{sl}$ relative to the case without income support.

Remark 3 *With dual goals and one-dimensional asymmetric information, "high efficiency" small farms obtain a higher net payment, and "low efficiency" small farms obtain a lower net payment, than under perfect information ($T^*_{sh} > \hat{T}_{sh}, T^*_{sl} < \hat{T}_{sl}$).*

[6] This condition on the marginal costs enables us to have a complete ordering of $\hat{E}_{\phi\theta}$ to facilitate illustration, given that (1) only implies that $E_{\phi h} \geq E_{\phi l}$.

3.2 When farm size is not contractible

When both dual goals and dual information asymmetries are introduced, the problem becomes a multi-dimensional (specifically, two-dimensional) AS model, which is recognized to be very complicated to solve (e.g., Laffont, Maskin and Rochet, Armstrong, Armstrong and Rochet, McAfee and McMillan, and Basov). Thus, in this section, we examine the model in (3) by focusing on some interesting cases. It is well-known that the "single-crossing" property, such as $C'_{\phi h}(E) \leq C'_{\phi l}(E)$ in (1), helps us derive the sorting of the types (see Guesnerie and Laffont for more related discussion). Thus, we start by introducing the following assumption.

Assumption 1. *Conservation cost satisfies (1),* $C_{bl}(E) \leq C_{sh}(E)$, *and* $C'_{bl}(E) \leq C'_{sh}(E)$.

Given the same conservation efficiency, $C'_{b\theta}(E) \leq C'_{s\theta}(E)$ implies that big farms have lower marginal cost than small farms. Whether $C'_{bl}(E)$ is greater than $C'_{sh}(E)$ depends on whether farm size or conservation efficiency is relatively more important in determining the marginal cost of conservation. If farm size is more important, then $C'_{bl}(E) \leq C'_{sh}(E)$.[7] Assumption 1 implies a ranking of the types based on their marginal cost of conservation:

$$bh \succcurlyeq bl \succcurlyeq sh \succcurlyeq sl. \tag{8}$$

Based on Assumption 1, it is straightforward to show that incentive compatibility requires $E_{bh} \geq E_{bl} \geq E_{sh} \geq E_{sl}$.[8] In other words, under any incentive compatible green payment policy, a type with lower marginal conservation cost will have a higher conservation level. Of course, the ranking of the types and conservation levels will differ under a different assumption. However, our analysis below will primarily be based on Assumption 1. As will be clear later, this case

[7] It is an empirical question as to what the ranking of the types looks like. Larger farms may have lower cost because they may have economies of scale and lower management costs on a per unit basis. Such reasonings are supported by the findings of Caswell et al. They find that larger farmers are more likely to adopt such conservation practices as biological controls, conservation tillage, and N-testing. However, they also find that, in some regions, farm size does not seem to have an effect on the cost of conservation practices. They suggest that when farm size is beyond a certain threshold, the effect of a further increase in size on conservation cost becomes less clear.

[8] For example, for $\text{IC}_{bh,bl}$ and $\text{IC}_{bl,bh}$ to hold, we must have $C_{bl}(E_{bh}) - C_{bl}(E_{bl}) \geq C_{bh}(E_{bh}) - C_{bh}(E_{bl})$. This implies that $\int_{E_{bl}}^{E_{bh}} [C'_{bl}(E) - C'_{bh}(E)]dE \geq 0$. Then, by (1), we must have $E_{bh} \geq E_{bl}$. Other pairs of inequality can be shown similarly.

reveals some of the key compromises that will be involved in a dual goal green payment policy. The possible implications of different assumptions will be discussed at the end of this section.

In general, there are 4 individual rationality constraints (one for each type) represented in (3b) and 12 incentive compatibility constraints represented in (3c)—each type can pretend to be one of the other three types. Thus, it is useful to know first which constraints bind. However, as suggested by Armstrong, we have little alternative but to depend on an educated guess at the relevant constraints. A natural guess is that all incentive constraints will be satisfied if each type is just indifferent between the package intended for itself and the package intended for the type one level below it in the order given by (8). We verify this is the case in the Appendix.

Lemma 3 *For the problem in (3), under Assumption 1, for any given* $\mathbf{E}$*, all constraints are satisfied if* $IC_{bh,bl}$*,* $IC_{bl,sh}$*, and* $IC_{sh,sl}$ *bind, and the net payment to type sl is non-negative, i.e.,* $T_{sl} \geq 0$.

Since the net payment to type sl can be less than zero under the binding incentive constraints, $T_{sl} \geq 0$ is required so that IR_{sl} will be satisfied. For green payments with an income support component, it is reasonable that we will have $T_{sl} \geq 0$ any way. However, without the income support objective, $T_{sl} \geq 0$ will be an important condition. The binding constrains in Lemma 3 imply that the net payment to each type is equal to what it would get by pretending to be the type one level below it. That is,

$$T_{sh} = T_{sl} + I_{sh,sl}(E_{sl}), \quad T_{bl} = T_{sh} + I_{bl,sh}(E_{sh}), \quad T_{bh} = T_{bl} + I_{bh,bl}(E_{bl}). \tag{9}$$

The equations in (9) suggest that the dual goal model in this case is a straightforward extension of the standard AS model. Since (9) is based on Assumption 1 for the case when farm size is not contractible, we can make the following remark,

Remark 4 *When green payment policies do not explicitly differentiate farm sizes and when big farms have higher conservation efficiency than small farms, big farms will obtain greater income support than small farms.*

Based on Lemma 3, we can solve for the optimal payments and conservation.

Lemma 4 *For the problem in (3), under Assumption 1 and the conditions in Lemma 3, the optimal income support satisfies*

$$\lambda = W'(T_{sh}^{**})P_{sh} + W'(T_{sl}^{**})P_{sl}; \tag{10}$$

E_{bh}^{**} *is set at the perfect information optimum, and conservation for other types satisfies*

$$V'(E_{sl}^{**}) - (1+\lambda)C'_{sl}(E_{sl}^{**}) = \left[\lambda - \tfrac{P_{sh}}{1-P_{sl}} W'\left(T_{sh}^{**}\right)\right] I'_{sh,sl}(E_{sl}^{**})\tfrac{1-P_{sl}}{P_{sl}}; \tag{11a}$$

$$V'(E_{sh}^{**}) - (1+\lambda)C'_{sh}(E_{sh}^{**}) = \lambda I'_{bl,sh}(E_{sh}^{**})\tfrac{P_{bh}+P_{bl}}{P_{sh}}; \tag{11b}$$

$$V'(E_{bl}^{**}) - (1+\lambda)C'_{bl}(E_{bl}^{**}) = \lambda I'_{bh,bl}(E_{bl}^{**})\tfrac{P_{bh}}{P_{bl}}. \tag{11c}$$

The proof is straightforward. With (9), we can rewrite (3a) in terms of T_{sl} and then optimize with respect to T_{sl} for given $\boldsymbol{E}$ to obtain (10); and optimize with respect to $\boldsymbol{E}$ to obtain (11).

As in the case when farm size is contractible, the optimal income support for small farms will equalize the expected marginal benefit and marginal cost; and setting $V'(E_{\phi\theta}^{**}) - (1+\lambda)C'_{\phi\theta}(E_{\phi\theta}^{**}) = 0$ (the condition for the perfect information optimum) is not necessarily optimal. Which $E_{\phi\theta}^{**}$ should be modified and how the modification should be made depend on several factors including the information rent and the distribution of farms. In the above lemma, the role of information rent is similar to that in Lemma 2. However, since information rent derived by big farms does not generate income support benefit, income effect does not appear in (11b) and (11c). We show in the Appendix:

Remark 5 *With dual goals and dual information asymmetries (and Assumption 1), conservation levels are distorted below perfect information levels for all but large "high efficiency" (bh) farms. However, the income support goal reduces the extent of these distortions.*

The solutions characterized by Lemmas 3 and 4 are illustrated by the circles in Figures 1(b). This is the same as Figure 1(a) except that it demonstrates the case when farm size is not contractible. Again, the differences between the circles and the corresponding squares indicate the impacts of income support.[9] There are two notable differences. First, the net payments for all types increase when income support becomes a policy goal. Further, the net payments for big farms are higher.[10] Under the conditions in Remark 4, big farms will take the conservation and payment packages intended only for small farms if they find it more profitable to do so. The extra compensations to big farms are often necessary to make the packages incentive compatible. Second, the conservation for type sl is moved closer to the complete information optimum relative to the case without income support. For all other types, their conservation is the same with or without income support since, as explained earlier, they are not affected by the income effect of information rent. However, income effect will not completely eliminate the inefficiencies of information asymmetry. In other words, even though there is some beneficial welfare effect by introducing the income support goal into green payments, the extent of such effect is limited.

In the cases analyzed in this section and the previous section, the same incentive constraint binds with or without the income support goal. However, positive net payments intended for some farms can also change a farm's decision on which package of conservation and payments to accept. Thus, different net payments can lead to different sets of incentive constraints to bind, which in turn will affect optimal conservation levels. Instead of Assumption 1, suppose we have *(1),* $C'_{b\theta}(E) \geq C'_{s\theta}(E)$*, and* $C'_{bh}(E) \geq C'_{sl}(E)$. Then, the ranking of the types is: $sh \succcurlyeq sl \succcurlyeq bh \succcurlyeq bl$, based on their marginal conservation costs. Further, suppose the desired income support is high enough that small farms will not be tempted to pretend in order to gain information rent but also low enough that big farms will not be tempted to pretend in order to receive income support. Then, green payment policies can be designed as if farm size were contractible. Alternatively, suppose net payments to small farms are so large that big farms have the incentive to pretend. In such a situation, it is possible for every other type to obtain the income support type sl receives.[11]

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[9] When income support is not a goal, the optimal solutions, represented by squares, can be obtained from (9) and (11) by setting $T_{sl} = 0$ and $W'(\cdot) = 0$.

[10] In the figure, all small farms receive net payments that are lower than what they would get under complete information. From (10), we know this can happen.

[11] When big and small farmers have identical conservation cost function, it can happen that only the incentive constraint for the high (or low) efficiency type binds or neither constraint binds. In the latter case, the complete

3.2.1 Implementation mechanisms

In addition to the direct mechanism that specifies a menu of conservation levels and green payments, the optimal solutions characterized in Lemmas 2 and 4 can be implemented by non-linear payment schedules similar to those proposed in Hueth and Chambers (2002). The schedules are essentially deficiency payment schemes with a total cap on subsidy payments and incentive-compatible side payments. When farm size is contractible, such non-linear schedules can be applied with little modification. When farm size is not contractible, an extension of these schemes can be used. Suppose the marginal benefit of conservation $V'(E)$ is a constant denoted as $\hat{p}$, and let $p = \frac{1}{1+\lambda}\hat{p}$ to take into account the cost of funding. Under certain conditions,[12] we can verify that the following mechanism can implement the solutions implied in Lemma 4:

$$G = \begin{cases} (p+d)E, & \text{if } E \leq E^{**}_{sl}; \\ (p+d)E^{**}_{sl} + p(E - E^{**}_{sl}) - M_1 & \text{if } E^{**}_{sl} < E \leq E^{**}_{sh}; \\ (p+d)E^{**}_{sl} + p(E - E^{**}_{sl}) - M_2 & \text{if } E^{**}_{sh} < E \leq E^{**}_{bl}; \\ (p+d)E^{**}_{sl} + p(E - E^{**}_{sl}) - M_3 & \text{if } E^{**}_{bl} < E \leq E^{**}_{bh}; \end{cases} \tag{12}$$

where $M_1 = u_{sh,sl}$, $M2 = u_{sh,sl} + u_{bl,sh}$, $M3 = u_{sh,sl} + u_{bl,sh} + u_{bh,bl}$, and $u_{\phi\theta,\phi'\theta'}$ is the profit difference for type $\phi\theta$ when it provides $E^{**}_{\phi\theta}$ versus $E^{**}_{\phi'\theta'}$. For example, $u_{sh,sl} = [pE^{**}_{sh} - C_{sh}(E^{**}_{sh})] - [pE^{**}_{sl} - C_{sh}(E^{**}_{sl})]$.[13]

Basically, a subsidy (d) per unit of conservation services can be used at a low level of conservation. After that, conservation services are paid at a fixed price supplemented by a lump sum payment with different tiers: the higher the conservation level, the lower the lump sum

information optimum will be achieved for all types. Which case actually occurs depends on the level of income support and the distribution of farm types. Complete solutions are available upon request.

[12] One set of conditions needed is: $pE^{**}_{\phi'\theta'} - C_{\phi'\theta'}(E^{**}_{\phi'\theta'}) \geq p\hat{E}_{\phi'\theta'} - C_{\phi'\theta'}(\hat{E}_{\phi'\theta'}) - u_{\phi\theta,\phi'\theta'}$, for $(\phi\theta, \phi'\theta') = (bh, bl)$, (bl, sh), and (sh, sl), where $\hat{E}_{\phi'\theta'}$ is the optimal conservation under complete information as determined by (4). These conditions ensure that type $\phi'\theta'$ will not be tempted to take the package intended for types above it by the ranking in (8).

[13] When farm size is not contractible, we show in Appendix D that bunching is possible. In other words, it is optimal for different types of farmers to provide the same level of conservation and receive the same amount of payment. If bunching occurs among a large proportion of farmers, then the optimal policy can be implemented with a flexible environmental standard capable of handling specific cases. That is, farmers may have to receive more (less) payment than specified in the standard if they provide more (less) conservation services. We thank an anonymous reviewer for drawing our attention to this point.

payment. Among the conservation programs in the U.S. agriculture, the CSP seems to resemble a green payment policy with dual goals the most. While other programs undoubtedly help improve environmental quality, their income support component is not clear. For example, the CRP, by far the largest agri-environmental program of the nation, actually uses a competitive bidding system to select applications. The payments under the CSP consist of several components including an annual stewardship payment for the existing base level conservation treatment and a one-time new practice payment for additional needed practices. A farm can participate in the CSP at one of three tiers for different levels of conservation services and payments. The maximum annual payments for the tiers are as follows: $20000 for tier I, $35000 for tier II, and $45000 for tier III (NRCS/USDA 2005). Such a tiered mechanism is an example of the non-linear schedule proposed in (12). However, careful empirical investigation is needed to determine whether the actual amount of conservation services and payment limits used in the CSP were set close to the socially optimal levels.

4 Conclusions

Green payments have been considered as a potential substitute for traditional farm income support in addition to providing conservation services. One critical question surrounding green payments is whether they will be effective in achieving both goals. If they are not effective, then alternatives may have to be considered such as “greening” the current income support program by making conservation a condition for transfer payments (Claassen and Morehart). When there were no informational and political constraints, that is, when policymakers knew farms’ conservation efficiency and farm size could be used as an explicit criterion for payments, we show that green payment contracts could be used to achieve both goals efficiently. In this case, the decisions on optimal conservation and income support are essentially separate—green payments are just used as a conveyor of what is effectively a lump sum transfer.

However, like many current agri-environmental programs, green payment policies will likely be implemented under informational and/or political constraints. Under such circumstances, compromises may have to be made. If large farms are more conservation efficient then our results suggest that the two goals compete in the sense that large farms will obtain net payments which generate no income support benefits. On the other hand, if small farms have higher conservation efficiency, the two policy goals work in tandem since the possible gains of these farms from their informational advantage will also act as income support for them. This effect will partly correct the distortions in their conservation levels due to information asymmetry. Of course, not all small (or big) farms have the same conservation efficiency which implies that different small farms may receive different levels of income support. If the income support for some small farms is very low, then green payments may be deemed ineffective as an income support tool. Thus, it is important to understand which types of farms have lower costs for different activities when judging the efficacy of green payment mechanisms.

Like any policy tool, some practical issues can arise. Given a conservation practice, actual measurement of environmental change can be very difficult and/or prohibitively expensive. However, reasonable estimates can be made by using sophisticated biophysical models or simple biophysical relationships. The environmental benefit index used in the CRP is an example of how environmental performance can be estimated based on simple procedures and a variety of factors including soil and land characteristics, weather conditions, geographical location, and the land use history of a field. Different practices may pose different degrees of challenge for verification and monitoring. For example, while it is easy to verify the use of conservation tillage, it is almost impossible to monitor fertilizer use on a field. The burden of verification can be shifted to farms. In the implementation of CSP, which pays farms for maintaining conservation practices on working land, farms are explicitly asked record related questions (NRCS/USDA 2004). If they have written documents as a proof that they have adopted certain practices, then it is more likely that they will be eligible to participate in the program.

Appendix

A. Proof of Lemmas 1 and 2. As a reference point, maximizing Z^s without any constraint, we get $W'(T^s_{s\theta}) = \lambda$,[14] which implies $G^s_{sl} - C_{sl}(E_{sl}) = G^s_{sh} - C_{sh}(E_{sh})$, or

$$G^s_{sh} - G^s_{sl} = C_{sh}(E_{sh}) - C_{sl}(E_{sl}). \tag{A1}$$

However, the incentive constraints require that

$$C_{sh}(E_{sh}) - C_{sh}(E_{sl}) \leq G_{sh} - G_{sl} \leq C_{sl}(E_{sh}) - C_{sl}(E_{sl}), \tag{A2}$$

Along with (1), the above equations imply $E_{sh} \geq E_{sl}$, the feasible set of problem (5) is as illustrated by the shaded area in Figure 2, and that $\boldsymbol{G}^s$ is below the feasible set. Totally differentiating both sides of (5b) with respect to Z^s, G_{sl}, and G_{sh}, setting $dZ^s = 0$, and rearranging, we get

$$\frac{dG_{sh}}{dG_{sl}} = -\frac{\lambda - W'(T_{sl})}{\lambda - W'(T_{sh})} \frac{P_{sl}}{P_{sh}}. \tag{A3}$$

Differentiating $\frac{dG_{sh}}{dG_{sl}}$ with respect to G_{sl}, we have

$$\frac{d^2 G_{sh}}{dG^2_{sl}} = \frac{P_{sl}}{P_{sh}} \frac{W''(T_{sl})}{\lambda - W'(T_{sh})} + \left(\frac{dG_{sh}}{dG_{sl}}\right)^2 \frac{W''(T_{sh})}{\lambda - W'(T_{sh})}. \tag{A4}$$

$\boldsymbol{G}^*$ must lie in the feasible set. Given that $\boldsymbol{G}^s$ is below the feasible set, then the optimal green payments $\boldsymbol{G}^*$ lie to the northwest of $\boldsymbol{G}^s$, that is,[15]

$$G^*_{sh} > G^s_{sh} \quad \text{and} \qquad G^*_{sl} < G^s_{sl}.$$

Since $\boldsymbol{G}^s$ is determined by setting $W'(T^s_{s\theta}) = \lambda$, from the concavity of $W(\cdot)$, we know for any

[14] The superscript “s” on the decision variables indicates solutions which maximize Z^s without constraint.

[15] Moving due north or due west is not optimal, i.e., the following holds as strict inequality because of the concavity of $W(\cdot)$. For example, if $G^*_{sh} > G^0_{sh}$ but $G^*_{sl} = G^0_{sl}$, then we can increase the value of Z^s by decreasing both G^*_{sh} and G^*_{sl} a little. By the concavity of $W(\cdot)$, the reduction of Z^s through the decrease of G^*_{sl} will be offset by the increase of Z^s through the decrease of G^*_{sh}. In addition, total green payments are reduced.

green payments to the northwest of $\boldsymbol{G}^s$,

$$\frac{dG_{sh}}{dG_{sl}} > 0, \quad \text{and} \quad \frac{d^2G_{sh}}{dG_{sl}^2} < 0,$$

i.e., the isoquant of $Z^s(\cdot)$ is concave to the northwest of $\boldsymbol{G}^s$, as shown by the curve z^s in Figure 2. As green payments move further away from $\boldsymbol{G}^s$ in the northwest direction, the value of $Z^s(\cdot)$ decreases: type sh would get excessive payment which generates less benefit than the extra cost of transfer, and type sl would get too little transfer which reduces benefit more than the saved cost of transfer. Therefore, we conclude that $\boldsymbol{G}^*$ is the tangent point of $Z^s(\cdot)$ on $\text{IC}_{sh,sl}$ as indicated by the point G^* in Figure 2. This implies $\text{IC}_{sh,sl}$ binds but not $\text{IC}_{sl,sh}$ to maximize the value of Z^s. By rewriting the binding $\text{IC}_{sh,sl}$, we obtain (6a).

With (6a), rewriting Z^s in terms of T_{sl}, we get,

$$\begin{aligned} Z^s\left(E_{sl}, E_{sh}\right) &= W(T_{sl})\tfrac{P_{sl}}{P_s} - \lambda\left[C_{sl}\left(E_{sl}\right) + T_{sl}\right]\tfrac{P_{sl}}{P_s} \\ &\quad + W[I_{sh,sl}(E_{sl}) + T_{sl}]\tfrac{P_{sh}}{P_s} - \lambda\left[C_{sh}\left(E_{sh}\right) + I_{sh,sl}(E_{sl}) + T_{sl}\right]\tfrac{P_{sh}}{P_s} \end{aligned}$$

and then optimizing with respect to T_{sl} for given $\boldsymbol{E}$, we get (6b). Plugging into (5) the optimized value of Z^s, and optimizing with respect to $\boldsymbol{E}$, we obtain Lemma 2. ■

B. Proof of Lemma 3. First, as mentioned earlier, the incentive constraints require: $E_{bh} \geq E_{bl} \geq E_{sh} \geq E_{sl}$. Then, given (1), $\text{IC}_{bh,bl}$ binding implies: $G_{bh} - G_{bl} = C_{bh}\left(E_{bh}\right) - C_{bh}\left(E_{bl}\right) \leq C_{bl}\left(E_{bh}\right) - C_{bl}\left(E_{bl}\right)$, i.e., $\text{IC}_{bl,bh}$ holds. From binding $\text{IC}_{bh,bl}$ and $\text{IC}_{bl,sh}$, we get $G_{sh} - C_{bh}\left(E_{sh}\right) - \left[G_{bh} - C_{bh}\left(E_{bh}\right)\right] = \left[C_{bh}\left(E_{bl}\right) - C_{bl}\left(E_{bl}\right)\right] - \left[C_{bh}\left(E_{sh}\right) - C_{bl}\left(E_{sh}\right)\right] \leq 0$, i.e., $\text{IC}_{bh,sh}$ holds. The inequality again comes from (1). Similarly, we can verify that all other incentive constraints are satisfied. Then, we need to show that the individual rationality constraints are satisfied. Rearranging the three binding incentive constraints, we obtain (9). From (1), Assumption 1, and the definition of $I_{\phi\theta,\phi'\theta'}(E)$, we have $I_{sh,sl}(E_{sl}) \geq 0$, $I_{bl,sh}(E_{sh}) \geq 0$, and $I_{bh,bl}(E_{bl}) \geq 0$. Thus, all individual rationality constraints will be satisfied if $T_{sl} \geq 0$. ■

C. Proof of Remark 5. For the proof, all we need to show is that the right hand side of (11a)-

(11c) is nonnegative. From Assumption 1, and the definition of $I_{\phi\theta,\phi'\theta'}(E)$, we know $I'_{sh,sl}(E_{sl}) \geq 0$, $I'_{bl,sh}(E_{sh}) \geq 0$, and $I'_{bh,bl}(E_{bl}) \geq 0$. Thus, the task is to prove $\lambda - \frac{P_{sh}}{1-P_{sl}} W'(T^{**}_{sh}) \geq 0$ for (11a). When farm size is not contractible, suppose green payments could separately target two groups: farms of type sl and farms of all other types. Without incentive constraints, the optimal net payments (denoted with superscript '00') would equalize marginal cost and marginal benefit of income support for each group, i.e.,

$$W'(T^{00}_{sl}) = \lambda = \tfrac{P_{sh}}{1-P_{sl}} W'[T^{00}_{sh}], \tag{A5}$$

which implies

$$T^{00}_{sh} \leq T^{00}_{sl} \quad \text{and} \quad \lambda = W'(T^{00}_{sh})P_{sh} + W'(T^{00}_{sl})P_{sl}. \tag{A6}$$

However, from Lemma 3, the optimal net payments satisfy

$$T^{**}_{sh} \geq T^{**}_{sl} \quad \text{and} \quad \lambda = W'(T^{**}_{sh})P_{sh} + W'(T^{**}_{sl})P_{sl}. \tag{A7}$$

Then, we must have $T^{**}_{sh} \geq T^{00}_{sh}$. Otherwise, there will be contradictions. For example, suppose $T^{**}_{sh} < T^{00}_{sh}$, then the second equations in (A6) and (A7) imply: $T^{**}_{sl} \geq T^{00}_{sl}$. This means $T^{**}_{sl} \geq T^{00}_{sh} > T^{**}_{sh}$, which contradicts the inequality in (A7). From (A5) and the concavity of $W(\cdot)$, we obtain $\lambda \geq \frac{P_{sh}}{1-P_{sl}} W'(T^{**}_{sh})$. ■

D. Bunching may occur when farm size is not contractible. For example, E^{**}_{sh} and E^{**}_{sl} have to be set equal, if the right hand side (RHS) of (11a) is sufficient smaller than the RHS of (11b). This may happen if P_{sh} is small. Graphically speaking, in Figure 3, if the RHS of (11a) is equal to distance b and the RHS of (11b) is equal to (or greater than) distance c, then bunching of type sh and sl occurs. ■

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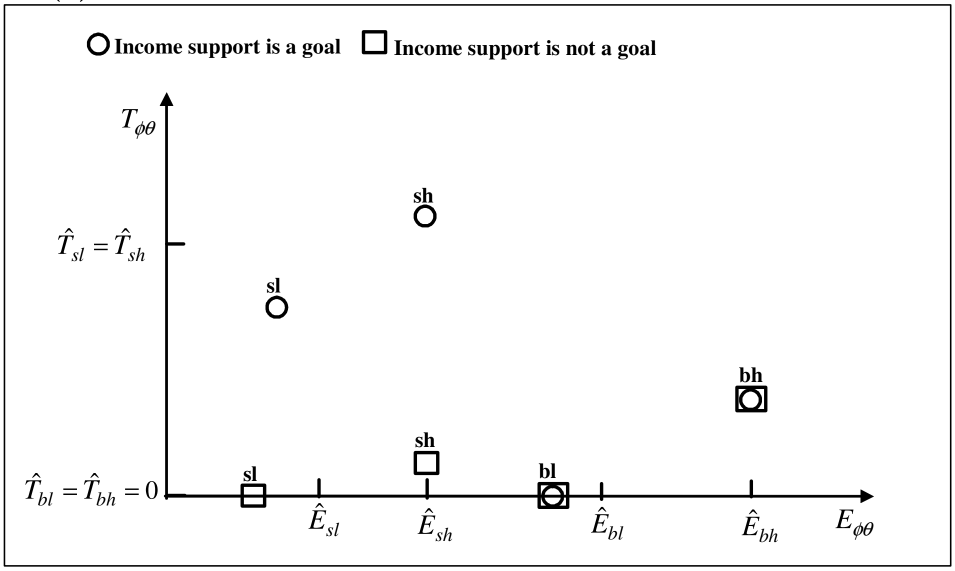
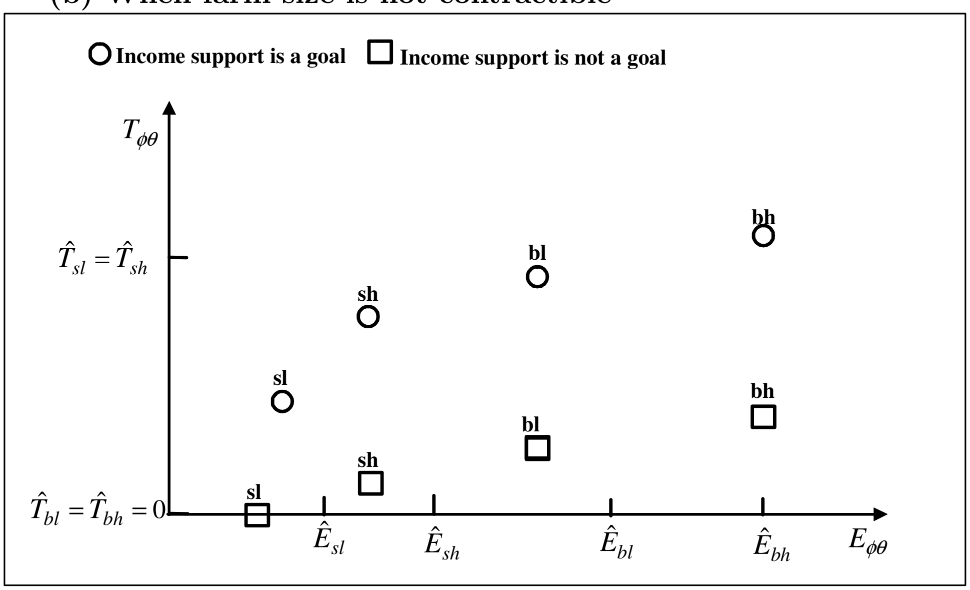
Figure 1. An illustration of optimal conservation and net payments

(a)When farm size is contractible



(b) When farm size is not contractible



Note: In both (a) and (b), $\hat{T}_{\phi\theta}$ and $\hat{E}_{\phi\theta}$ are the complete information optimum when income support for small farms is a policy goal.

Figure 2. The optimal green payments for small farms (for given $E_{sh} \geq E_{sl}$)

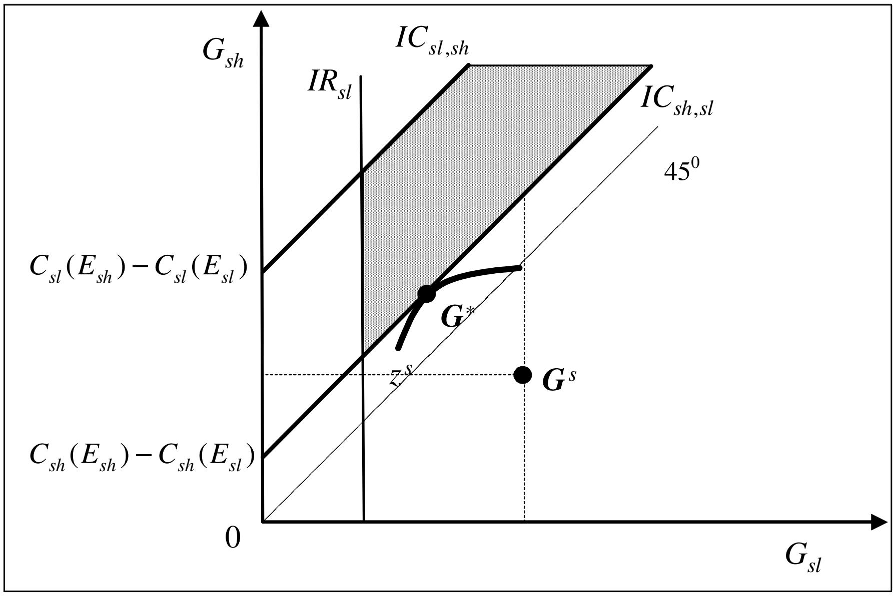


Figure 3. When bunching occurs—an illustration for E_{sh} and E_{sl}