Optimal subsidies for conservation: a real options approach

Abstract

We build a real options model to investigate the optimal level of payments to landowners for conservation and the optimal timing of their introduction. Such subsidy contracts, which require landowners to conserve land and preclude development, can be used to increase ecosystem services (ESS) provided by the land and/or preserve existing ESS, which would be lost if development occurs. They enhance ESS provision both directly, once the contract has been accepted by the landowner, and also indirectly, by delaying development.

Governments and other public bodies trade off the value of the flow of ESS benefits generated by the land with the costs of providing the subsidy. Increasing the (permanent) level of subsidy increases the government's cost and hence reduces value once the landowner accepts the conservation contract, but increases the present value of the ESS benefits by increasing the expected time until development occurs. The level of subsidy that maximises expected ESS value net of subsidy costs thus varies with the relative proximities of the development threshold and conservation contract acceptance threshold. Assuming that the announcement of a subsidy level is irreversible, we determine the optimal subsidy level and threshold at which the announcement is made. We plan to investigate the impacts on landowner thresholds and optimal subsidies of different expected conservation contract durations and political risk, whereby such subsidised conservation contracts are available only temporarily.

Extended abstract

1 Introduction

The benefits of preserving and enhancing ecosystems, because of the services they provide, is now widely recognised. These can be in the form of provisioning services, such as flood alleviation, air quality enhancement or carbon sequestration, biodiversity or amenity value. However, owners of land on which ecosystems occur which either already provide or have the potential to generate substantial levels of ecosystem services (ESS), often face conflicting pressures. They may not obtain much if any benefit from the ecosystem services their land provides, whereas there may be significant monetary benefits available if the land is converted to other uses. In this situation, conservation or easement contracts, by which a governmental or other body provides payments to the land-owner in return for a commitment that the land is not developed (and possibly also that ESS are enhanced), can reduce the likelihood of conversion by altering the trade-offs faced by the land owner.(Fackler *et al* (2007)).[1] However, the implications of this for the level and timing of subsidies has not yet been studied.

In this paper we use a real options setting to investigate the value to a governmental or other public body of offering such a conservation or easement contract to a landowner. This commits the public body to the payment of an ongoing subsidy to land-owners who accept the contract. During the lifetime of the contract, the land-owner is not permitted to develop the land or more generally to reduce the current level of ESS. The land-owner may also be required to implement additional measures which enhance ESS but incur costs and may also reduce any revenue the land-owner can obtain from the land. Examples include the U.S. Conservation Reserve Program and EU Agri-Environmental Schemes, and the recently introduced Sustainable Farming Incentive in the UK.

We assume the public body values the flow of ESS provided by the land and trades

[1]Other papers that have investigated the timing of payments for conservation include Shah and Ando (2016) and Iacona *et al* (2017).

off the benefit from increased ESS with the cost of the subsidy. However, the benefits of the subsidy arise not only once the contract is accepted. The existence of the option to accept the conservation contract increases the effective cost of developing the land to the land-owner (because conservation is no longer possible once development has occurred) and thus delays development. This increases value for the public body because of the delay to the cessation of the flow of ESS benefits. Indeed, whilst the land-owner has signed neither the conservation nor the development contract, the public body enjoys the benefits of offering the conservation contract (due to the delay in development) without making any subsidy payments. Only once it is worthwhile for the land-owner to commit to conservation (and to give up the development option) are subsidy amounts payable to the landowner.

Increases in the level of subsidy thus have two opposing effects: once payments have started, a higher subsidy level reduces the net benefit to the public body. However, before the land-owner has accepted the conservation contract, the increased value of the subsidy increases the payoff required for development and thus delays development further, extending the time over which any partial ESS benefits are received and retaining the option for the land to be conserved in the future. The net effect on the value to the public body of increasing the subsidy level can either be positive, particularly close to the development threshold, or negative, for example close to the conservation threshold. We thus find there is an optimum level of subsidy, which maximises the value to the public body (ESS value net of subsidy), but the optimum level varies depending on the relative distance to the conservation and development thresholds. The greater the current payoff to development, the greater the optimal subsidy.

This raises the question as to what level of subsidy the public body should announce and when. In practice, changing subsidy levels and regimes is time-consuming and costly, and changes are infrequent. We assume the subsidy level, once announced, cannot be varied[2] and investigate at what level (and at what threshold) a subsidy will be announced.

[2]In further work, we plan to incorporate political uncertainty, where the subsidy is only in place under certain political conditions (for example under some but not all political parties), which will enable us to consider the impact of time-varying subsidy levels in a simplified setting.

In our base case model we assume that conservation, like development, is permanent, i.e. the conservation contract lasts indefinitely. However, in practice contracts are not necessarily permanent. We thus investigate the impact of different expected contract lengths on land-owners' decision thresholds. In preliminary results we find that decreasing the expected length of the contract increases both the development threshold and the acceptance threshold for the conservation contract but has much greater effect on the contract acceptance threshold, thus narrowing the region in which neither development nor conservation occurs. For contracts with short expected lengths and high subsidy levels, landowners will optimally accept a temporary conservation contract even if the payoff to immediate development is higher than the value of permanent conservation. In practice, public bodies therefore have another dimension to consider when deciding on the optimal conservation contract: its expected duration. We leave the consideration of this more complex problem for future work.

In future work we also plan to incorporate political risk and in doing so relax the assumption that the announcement of a particular subsidy level is irreversible. Different governments may have spending priorities which either include or do not include subsidising the environmental benefits (ESS) produced by land. We will investigate the impact of suspension of the availability of the subsidised conservation contract to landowners resulting from a change in government.

2 Base Case Model

2.1 No subsidy base case

A landowner owns a plot of land which is currently undeveloped but which can be developed at a cost I to generate a value V, which represents the value of developed land, which follows Geometric Brownian Motion:

$$dV = \mu V dt + \sigma V dW \tag{1}$$

In the absence of any alternative uses for the land, the landowner has an option to develop the land, $F_0(V)$, which satisfies

$$\frac{\sigma^2}{2}V^2\frac{\partial^2 F_0}{\partial V^2} + \mu V\frac{\partial F_0}{\partial V} - \rho F_0 \quad = \quad 0$$

subject to $F_0(0) = 0$, $F_0(V_{D_0}) = V_{D0} - I$ and $F_{0V}(V_{D0}) = 1$. This has standard solution

$$F_0 \quad = \quad (V_0^* - I)\left(\frac{V}{V_0^*}\right)^{\beta_1}$$

where $\beta_1 > 1$ is the positive root of the characteristic equation $\frac{\sigma^2}{2}\beta(\beta - 1) + \mu\beta - \rho = 0$ and the optimal development threshold

$$V_{D0} = \frac{\beta_1}{\beta_1 - 1}I \tag{2}$$

In its undeveloped state, the land generates a stream of ecosystem service (ESS) benefits with value $\phi\gamma$ per period, where γ represents the maximum potential level of ESS benefits for this land and $0 \geq \phi \geq 1$ represents the proportion of the maximum level of ESS benefits the land provides in its current state, i.e. the environmental state of the land. High values of ϕ represent relatively pristine ecosystems, whereas low values of ϕ reflect land which is relatively degraded.

The flow of ESS continues only as long as the land is not developed. The present value of ESS flows in the absence of any conservation contract, N_0, thus depends on the value of developed land and satisfies

$$\frac{\sigma^2}{2}V^2\frac{\partial^2 N_0}{\partial V^2} + \mu V\frac{\partial N_0}{\partial V} - \rho N_0 + \phi\gamma \quad = \quad 0$$

subject to $N_0(0) = \frac{\phi\gamma}{\rho}$, $N_0(V_{D_0}) = 0$ which has solution

$$N_0(V) \quad = \quad \begin{cases} \left(\frac{\phi\gamma}{\rho}\right)\left(1 - \left(\frac{V}{V_{D_0}}\right)^{\beta_1}\right) & V \leq V_{D_0} \\ 0 & V_{D_0} \leq V \end{cases}$$

where V_{D_0} is the landowner's optimal development threshold given by (2)

2.2 Fixed subsidy level

Now suppose a government or other public body, which aims to preserve and enhance the ESS provided by the land, offers a land conservation agreement to the landowner. Under the conservation agreement the landowner gets a flow of subsidy payments at rate s in return for giving up the right to develop the land.[3] We initially assume the contract lasts indefinitely, but consider temporary contracts with varying expected duration as an extension. We initially consider an arbitrary subsidy rate s, and then allow the subsidy provider to optimise over the choice of s, assuming that, once announced, the conservation contract with subsidy rate s is available indefinitely.

2.2.1 Landowner

We first consider the landowner's reaction to the availability of such a conservation contract with subsidy rate s. The landowner now has two options: to develop the land or to sign the conservation contract. Exercising either of the options eliminates the possibility of exercising the other option in the future. Before either option has been exercised, the value of the land to the landowner, $F(V)$, now satisfies

$$\frac{\sigma^2}{2}V^2\frac{\partial^2 F}{\partial V^2} + \mu V\frac{\partial F}{\partial V} - \rho F = 0$$

subject to $F(V_C) = \frac{s}{\rho}$, $F_V(V_C) = 0$, $F(V_D) = V_D - I$ and $F_V(V_D) = 1$. This has solution (See Fackler *et al* (2007))

$$\begin{aligned} F &= A_F V^{\beta_1} + B_F V^{\beta_2} \\ A_F &= ((1-\beta_2)V_D + \beta_2 I)\frac{1}{\beta_1 - \beta_2}V_D^{-\beta_1}, \\ B_F &= ((\beta_1 - 1)V_D - \beta_1 I)\frac{1}{\beta_1 - \beta_2}V_D^{-\beta_2} \end{aligned}$$

where $\beta_1 > 1$ and $\beta_2 < 0$ are the positive and negative roots respectively of the characteristic equation $\frac{\sigma^2}{2}\beta(\beta-1)+\mu\beta-\rho = 0$, and the optimal development threshold V_D and conservation

[3]We later extend the model to incorporate compulsory ESS enhancement under the contract for restoration which incurs a flow cost of c to the landowner.

contract acceptance threshold V_C satisfy:

$$
\begin{aligned}
V_C &= \xi V_D && (1)\\
V_D &= \left(\frac{\beta_1}{\beta_1 - 1}\right)\left(1 + \left(\frac{s}{\rho I}\right)\xi^{-\beta_2}\right) = \left(\frac{\beta_2}{\beta_2 - 1}\right)\left(1 + \left(\frac{s}{\rho I}\right)\xi^{-\beta_1}\right) && (2)
\end{aligned}
$$

2.2.2 Subsidy provider

We assume the government values the flows of ESS net of the costs of subsidy payment once the landowner accepts the conservation contract ($V \leq V_C$). Recall that before the landowner has accepted the conservation contract, there are no subsidy payments but the flow of ESS is lower than its full potential by a factor $\phi < 1$. Once the conservation contract has been accepted, the government is committed to pay subsidies at a rate s in perpetuity. The restoration or ecosystem enhancement measures dictated by the conservation contract are then assumed to increase the level of ecosystem services to their maximum potential level, but to do so only gradually. We thus allow for the possibility that, even under a newly signed conservation contract, the present value of future ESS benefits may be lower than the theoretical maximum. We represent this in reduced form by assuming the capitalised value of ESS for land at the start of a conservation contract equals $\frac{\nu\gamma}{\rho}$ where $\nu < 1$ is the discount due to the gradual nature of the restoration of ESS and will be site-specific.

The government's value before the landowner has signed the conservation contract with subsidy level s, $N(V; s)$, thus satisfies

$$
\frac{\sigma^2}{2}V^2\frac{\partial^2 N}{\partial V^2} + \mu V\frac{\partial N}{\partial V} - \rho N + \phi\gamma = 0
$$

subject to $N(V_C) = \frac{\nu\gamma - s}{\rho}$, $N(V_D) = 0$. This has solution

$$
N(V; s) = \begin{cases} \frac{\nu\gamma - s}{\rho} & V \leq V_C \\ \left(\frac{\phi\gamma}{\rho}\right) + A_N V^{\beta_1} + B_N V^{\beta_2} & V_C \leq V \leq V_D \\ 0 & V_D \leq V \end{cases} \qquad (3)
$$

where V_C, V_D are the landowner's optimal conservation contract acceptance and development thresholds respectively given by (2), and the arbitrary constants A_N, B_N are given by:

$$A_N = \frac{\gamma}{\rho}\left(\nu - \frac{s}{\gamma} - \phi(1-\xi^{\beta_2})\right)\xi^{-\beta_1}V_D^{-\beta_1} \tag{4}$$

$$B_N = \frac{\gamma}{\rho}\left(\frac{s}{\gamma} - \nu\xi - \phi(1-\xi^{\beta_2})\right)V_D^{-\beta_2} \tag{5}$$

The government's value function for a given level of subsidy, s, has three regions. Once the landowner has accepted the conservation contract, the ecosystem is preserved with an initial capitalised value of ESS flows of $\frac{\nu\gamma}{\rho}$, but the government is committed to a stream of subsidy payments with capitalised value $-\frac{s}{\rho}$. Depending on the subsidy level chosen the overall value may be greater than or less than the capitalised value of the flow of ESS at their unconserved level $\frac{\phi\gamma}{\rho}$. This is relevant when the value of developed land is relatively low (for $V < V_C(s)$).

At the other extreme, when the value of developed land is sufficiently high, it will be optimal for the landowner to develop the land, even though that destroys the option to conserve and receive the conservation subsidy. Development destroys the ecosystem and thus any benefits from it, so the government's value $N = 0$ above the landowner's development threshold $V_D(s)$. Note both the conservation threshold and the development threshold depend on the level of subsidy offered by the government, s.

In the intermediate region, before either conservation or development has occurred, the government's value of having offered a conservation contract with subsidy level s reflects the relative likelihood of each possibility (conservation or development) occurring. When the likelihood of development dominates (sufficiently close to the development threshold), the government's value function decreases with increases in the value of developed land and hence the likelihood of ecosystem destruction due to development occurring before conservation. On the other hand, when the likelihood of conservation dominates (sufficiently close to the conservation threshold), decreases in the value of developed land, which increase the likelihood of conservation contract acceptance, can also decrease the government's value function because acceptance of the conservation contract forces the government to start paying the subsidy, and for subsidy levels higher than the increase in the flow of ESS benefits the government's value may decrease. Before acceptance of the conservation contract, there is a partial flow of ESS benefits without subsidy payments. Acceptance of the contract locks in a higher level of ESS benefits but requires ongoing subsidy payments.

The overall impact is that, particularly for pieces of land with relatively pristine ecosystems, for which the current environmental state ϕ is high, and for higher subsidy levels, the government's value function once they have announced a given subsidy level s can have an inverted U-shape between V_C and V_D.

There are thus several effects of increasing the subsidy level on the government's value in such a subsidy regime. Paying a higher subsidy decreases the net benefits of conservation to the government once the landowner has accepted the conservation contract (for low values of developed land, $V < V_C$). In addition, recall that both the conservation threshold and the development threshold depend on the level of subsidy offered by the government, s. A higher subsidy brings forward[4] the conservation decision, *i.e.* V_C increases. This extends the range of V for which the conservation contract will be accepted and these higher subsidy rates need to be paid by the government. It also increases the magnitude of the government's expected present value of subsidy costs before acceptance of the conservation contract, reducing the overall value of the subsidy regime to the government. However it also increases and thus delays the development decision, *i.e.* $V_D(s)$ increases, and this extends the range of V and time for which partial ESS benefits continue to be generated, and also for which the possibility of permanent conservation (via later acceptance of the conservation contract by the landowner) is retained. Both these effects increase the overall value of the subsidy regime to the government.

The magnitude of the impact of each effect varies depending on the relative importance of delaying development (which favours higher subsidy rates) and reducing the expected present value of subsidy costs (which favours lower subsidy rates). The former dominates for higher values of developed land, when the threat of development and loss of ecosystem benefits is more imminent, whereas for lower values of V when the threat of development is more remote, the cost saving from choosing a lower subsidy level becomes increasingly important.

[4] Assuming $V \geq V_C(s)$

The subsidy provider (government) needs to determine the optimal level of subsidy to offer to the landowner. We assume the government chooses the subsidy to maximise the present value of the benefits of the flow of future ESS arising from the land, net of any subsidy payments made. However, the government's subsidy offer, s, once made, cannot be changed, whereas the subsidy level which maximises the government's value varies with the current value of the developed land, V. We thus view the government as having an option to announce a subsidy level, and determine the optimal subsidy level jointly with the optimal timing of the announcement.

References

Fackler P, Brimlow JN and Mercer E (2007) Real Option Approaches to Conservation Easements. Working Paper, North Carolina State University

Iacona GD, Possingham HP and Bode M (2017) Waiting can be an optimal conservation strategy, even in a crisis discipline. Proceedings of the National Academy of Sciences of the United States of america 114 (39) pp 10497 - 10502

Shah P and Ando AW (2016) Permanent and Temporary Policy Incentives for Conservation under Stochastic Returns from Competing Land Uses. American Journal of Agricultural Economics 98(4) pp 1074 - 1094