Supplementary Material for

Economics of Informed Antibiotic Management and Judicious Use Policies in Animal Agriculture

This PDF file includes:

A Farmer's problem without regulations

In this supplementary material, we present formulated optimization problem without regulations and detailed solutions.

A1 Farmer's optimization problem formulation

Since the standard approach to deriving optimal strategies is backward induction, we also set up optimization problem formulation in temporally reversed order.

A1.1 Antibiotic administrations decisions at information sets ④-⑩

At information set ④, a veterinarian reveals the infection is of type *E*. The farmer compares the payoffs associated with antibiotic use and non-use, $\Phi_E^{NTe,C,Tr}$ and $\Phi_E^{NTe,C,NTr}$, and then treats the infection with antibiotics whenever treatment brings a higher payoff than no treatment. The optimal antibiotic administration decision is $z_{④}^{E}$. Dummy variable z indicates antibiotic treatment actions, i.e., $z = Tr$ or $z = NTr$. The subscript on z denotes the information set under which the decision is made and, as a reminder, the superscript denotes the revealed infection type. Applying similar logic, we can solve for other optimal antibiotic administration decisions where information has been revealed (i.e., information sets ⑤-⑥, ⑧-⑩). For example, at information set ⑩ where a veterinarian reveals *I*, the farmer makes optimal antibiotic administration decision $z_{⑩}^{I}$ by comparing $\Phi_I^{NTe,C,Tr}$ and $\Phi_I^{NTe,C,NTr}$. Since antibiotic treatment does not cure the type *I* infection, the farmer does not use antibiotics at information sets ⑧-⑩.

At information set ⑦, no information is revealed. Under treatment uncertainties, the farmer compares the expected payoffs associated with antibiotic use and non-use, $\beta\Phi_E^{NTe,NC,Tr} + (1-\beta)\Phi_I^{NTe,NC,Tr}$ and $\beta\Phi_E^{NTe,NC,NTr} + (1-\beta)\Phi_I^{NTe,NC,NTr}$, where β is the probability that type E infection occurs. She treats the infection with antibiotics whenever treatment brings a higher expected payoff than no treatment. The optimal antibiotic administration decision is $z_{⑦}$ with no superscript as the infection type is unknown to the farmer.

A1.2 Veterinary service decisions after self-tests at information sets ②-③

To solve for optimal veterinary service decisions when a self-test has revealed information, we take the optimal antibiotic administration decisions in Section A1.1 as given. At information set ②, where a self-test reveals *E*, the farmer compares the payoffs associated with veterinary service and no veterinary service $\Phi_E^{Te,C,z^E_{⑤}}$ and $\Phi_E^{Te,NC,z^E_{⑥}}$. The farmer calls her veterinarian whenever a veterinarian visit brings a higher payoff than no veterinarian visit; otherwise, she does not call her veterinarian. The optimal veterinary service decision is $y^E_{②}$ where dummy variable y indicates veterinary service actions, i.e., $y = C$ or $y = NC$.

Similarly, at information set ③, the farmer makes veterinary service decisions knowing that the infection is of type *I*. Taking the fact that optimal antibiotic administration decisions at subsequent information sets ⑧ and ⑨ are *NTr*, the farmer compares the payoffs associated with veterinary services and no veterinary services $\Phi_I^{Te,C,NTr}$ and $\Phi_I^{Te,NC,NTr}$. The farmer calls a veterinarian whenever a veterinary visit brings a higher payoff than no veterinary visits. The optimal veterinary service decision is $y^I_{③}$.

A1.3 Testing decisions at information set ①

To solve for optimal testing decisions, we take the optimal decisions in sections A1.1 and A1.2 as given. At information set ①, the farmer faces uncertainties about infection type, and so compares expected payoffs associated with self-tests, veterinary services and no tests, as specified below;

$$V^{Te} = \beta\Phi_E^{Te,y^E_{②},\lambda} + (1-\beta)\Phi_I^{Te,y^E_{③},NTr};$$
$$\text{where } \lambda = \begin{cases} z^E_{⑤} & \text{whenever } y^E_{②} = C; \\ z^E_{⑥} & \text{whenever } y^E_{②} = NC; \end{cases} \tag{A.1}$$

$$V^C = \beta\Phi_E^{NTe,C,z^E_{④}} + (1-\beta)\Phi_I^{NTe,C,NTr}; \tag{A.2}$$

$$V^{NTe,NC} = \beta\Phi_E^{NTe,NC,z_{⑦}} + (1-\beta)\Phi_I^{NTe,NC,z_{⑦}}. \tag{A.3}$$

Thus, the farmer's expected payoff maximization problem is

$$V = \max\{V^{Te}, V^{C}, V^{NTe,NC}\}. \tag{A.4}$$

The model setup and backward induction approach seek to characterize the temporal sequence and conditional nature of interactions among self-test, veterinary service and antibiotic decisions.

A2 Possible payoffs for unregulated farmers

Possible payoffs for unregulated farmers which depend on nature's and the farmer's actions can be written as

$$\Phi_E^{NTe,C,Tr} = \Phi_E\left(x_{①}=0, y_{①}=1, z_{④}^{E}=1\right) = a - l_1 - b - v; \tag{A.5}$$

$$\Phi_E^{NTe,C,NTr} = \Phi_E\left(x_{①}=0, y_{①}=1, z_{④}^{E}=0\right) = a - l_2 - v; \tag{A.6}$$

$$\Phi_E^{Te,C,Tr} = \Phi_E\left(x_{①}=1, y_{①}=0, y_{②}^{E}=1, z_{⑤}^{E}=1\right) = a - l_1 - b - d - v; \tag{A.7}$$

$$\Phi_E^{Te,C,NTr} = \Phi_E\left(x_{①}=1, y_{①}=0, y_{②}^{E}=1, z_{⑤}^{E}=0\right) = a - l_2 - d - v; \tag{A.8}$$

$$\Phi_E^{Te,NC,Tr} = \Phi_E\left(x_{①}=1, y_{①}=0, y_{②}^{E}=0, z_{⑥}^{E}=1\right) = a - l_1 - b - d; \tag{A.9}$$

$$\Phi_E^{Te,NC,NTr} = \Phi_E\left(x_{①}=1, y_{①}=0, y_{②}^{E}=0, z_{⑥}^{E}=0\right) = a - l_3 - d; \tag{A.10}$$

$$\Phi_E^{NTe,NC,Tr} = \Phi_E\left(x_{①}=0, y_{①}=0, z_{⑦}=1\right) = a - l_1 - b; \tag{A.11}$$

$$\Phi_E^{NTe,NC,NTr} = \Phi_E\left(x_{①}=0, y_{①}=0, z_{⑦}=0\right) = a - l_3; \tag{A.12}$$

$$\Phi_I^{NTe,NC,Tr} = \Phi_I\left(x_{①}=0, y_{①}=0, z_{⑦}=1\right) = a - l_3 - b; \tag{A.13}$$

$$\Phi_I^{NTe,NC,NTr} = \Phi_I\left(x_{①}=0, y_{①}=0, z_{⑦}=0\right) = a - l_3; \tag{A.14}$$

$$\Phi_I^{Te,C,Tr} = \Phi_I\left(x_{①}=1, y_{①}=0, y_{③}^{I}=1, z_{⑧}^{I}=1\right) = a - l_2 - b - d - v; \tag{A.15}$$

$$\Phi_I^{Te,C,NTr} = \Phi_I\left(x_{①}=1, y_{①}=0, y_{③}^{I}=1, z_{⑧}^{I}=0\right) = a - l_2 - d - v; \tag{A.16}$$

$$\Phi_I^{Te,NC,Tr} = \Phi_I\left(x_{①}=1, y_{①}=0, y_{③}^{I}=0, z_{⑨}^{I}=1\right) = a - l_3 - b - d; \tag{A.17}$$

$$\Phi_I^{Te,NC,NTr} = \Phi_I\left(x_{①}=1, y_{①}=0, y_{③}^{I}=0, z_{⑨}^{I}=0\right) = a - l_3 - d; \tag{A.18}$$

$$\Phi_I^{NTe,C,Tr} = \Phi_I\left(x_{①} = 0, y_{①} = 1, z_{⑩}^I = 1\right) = a - l_2 - v - b; \tag{A.19}$$

$$\Phi_I^{NTe,C,NTr} = \Phi_I\left(x_{①} = 0, y_{①} = 1, z_{⑩}^I = 0\right) = a - l_2 - v. \tag{A.20}$$

A3 Solutions to farmer's optimization problem

The standard approach to deriving optimal strategies is backward induction. Hence we first solve antibiotic administration decisions, then veterinary service decisions after self-tests, and finally testing decisions.

A3.1 Antibiotic administration decisions

Antibiotics are not used in revealed type I infection cases since they come at some cost but are not beneficial for type I infections. That is, the farmer does not use antibiotics at information sets ⑧-⑩. Our analysis focuses on antibiotic administration decisions when no information is purchased and when information reveals E.

A3.1.1 Antibiotic administration decisions at information sets ④ and ⑤

At information sets ④ and ⑤, a test reveals antibiotics to be an effective treatment for the infection at hand. The farmer administers antibiotics under veterinarian oversight whenever

$$\Phi_E^{NTe,C,Tr} > \Phi_E^{NTe,C,NTr}, \tag{A.21}$$

or

$$\Phi_E^{Te,C,Tr} > \Phi_E^{Te,C,NTr}. \tag{A.22}$$

These two inequalities are equivalent and can be simplified to

$$b < l_2 - l_1. \tag{A.23}$$

The farmer administers antibiotics at information sets ④ and ⑤ whenever antibiotic cost satisfies inequality (A.23), otherwise she does not administer antibiotics.

A3.1.2 Antibiotic administration decisions at information set ⑥

At information set ⑥, the farmer makes the antibiotic decision, having concluded from self-test results that antibiotics are effective. The farmer administers antibiotics whenever

$$\Phi_E^{Te,NC,Tr} > \Phi_E^{Te,NC,NTr}. \qquad (A.24)$$

We can rewrite inequality (A.24) as

$$b < l_3 - l_1. \qquad (A.25)$$

The farmer administers antibiotics at information set ⑥ whenever antibiotic cost satisfies inequality (A.25), but not otherwise.

A3.1.3 Antibiotic administration decisions at information set ⑦

At information set ⑦, the farmer has no information about the antibiotic effectiveness in the infection case at hand and makes antibiotic administration decisions based on the expected value of payoffs across infection types. The farmer administers antibiotics whenever

$$\beta\Phi_E^{NTe,NC,Tr} + (1-\beta)\Phi_I^{NTe,NC,Tr} > \beta\Phi_E^{NTe,NC,NTr} + (1-\beta)\Phi_I^{NTe,NC,NTr}, \qquad (A.26)$$

which may be written as

$$b < \beta(l_3 - l_1). \qquad (A.27)$$

The farmer administers antibiotics at information set ⑦ whenever antibiotic cost satisfies inequality (A.27), but not otherwise.

Three reservation values of antibiotic cost from above antibiotic decision analysis are

$$b_1 = l_2 - l_1; \qquad (A.28)$$

$$b_2 = \beta(l_3 - l_1); \qquad (A.29)$$

$$b_3 = l_3 - l_1. \qquad (A.30)$$

Reservation value b_1 is the antibiotic cost that makes the farmer indifferent between Tr and NTr in type E infection cases under veterinarian oversight (i.e., at information sets ④ and ⑤). Value b_2 is the antibiotic cost that makes the farmer indifferent between Tr and NTr when antibiotic effectiveness is uncertain (i.e., at information set ⑦). Value b_3 is the cost that makes the farmer indifferent between Tr and NTr in type E infection cases without veterinarian oversight (i.e., at information set ⑥). The right-hand side of these reservation values is the expected loss avoided by antibiotic administrations given different information sets. Note that $b_2 < b_3$ since $\beta \in (0,1)$. Note also that $b_1 < b_3$ since $l_2 < l_3$. We also assume $b_1 < b_2$ in the following analysis because it simplifies the analysis and is not a restrictive assumption since b_1 will be less than b_2 whenever l_3 is relatively large. Therefore we can categorize antibiotic cost into four levels using three reservation values: *i)* low antibiotic cost $b \le b_1$, *ii)* lower medium antibiotic cost $b_1 < b \le b_2$, *iii)* upper medium antibiotic cost $b_2 < b \le b_3$, and *iv)* high antibiotic cost $b > b_3$.

A3.2 Veterinary service decisions after self-tests

When the farmer self-tests to obtain information, a series of follow-up decisions are: 1) whether to call a veterinarian when a self-test has revealed *E* at information set ②; or 2) whether to call a veterinarian when a self-test has revealed *I* at information set ③. When solving for this decision at information set ② or ③, according to the backward induction approach we take optimal antibiotic administration decisions at subsequent information sets as given.

A3.2.1 Veterinary service decisions after self-tests at information set ②

At information set ②, the farmer decides whether to call a veterinarian knowing that antibiotic treatment is effective for the infection at hand, taking optimal antibiotic decisions at information sets ⑤ and ⑥ as given. This decision is discussed given three levels of antibiotic cost.

(1) Low antibiotic cost: $b \le b_1$

The farmer chooses *Tr* under both information sets ⑤ and ⑥. Then she makes the veterinary service decision by comparing payoffs $\Phi_E^{Te,C,Tr}$ and $\Phi_E^{Te,NC,Tr}$. Thus, the farmer calls a veterinarian whenever

$$\Phi_E^{Te,C,Tr} > \Phi_E^{Te,NC,Tr}. \quad \text{(A.31)}$$

Since inequality (A.31) never holds under our assumptions, the farmer prefers *NC* in this situation.

(2) Medium antibiotic cost: $b_1 < b \le b_3$

The farmer chooses *NTr* at information set ⑤ and *Tr* at information set ⑥. She makes the veterinary service decision by comparing $\Phi_E^{Te,C,NTr}$ with $\Phi_E^{Te,NC,Tr}$. Thus, the farmer calls a veterinarian whenever

$$\Phi_E^{Te,C,NTr} > \Phi_E^{Te,NC,Tr}, \tag{A.32}$$

which can be written as

$$v < b + l_1 - l_2. \tag{A.33}$$

That is, the farmer prefers to call a veterinarian if and only if inequality (A.33) holds.

(3) High antibiotic cost: $b > b_3$

The farmer chooses *NTr* under both information sets ⑤ and ⑥. She makes the veterinary service decision by comparing $\Phi_E^{Te,C,NTr}$ with $\Phi_E^{Te,NC,NTr}$. Thus, the farmer calls a veterinarian whenever

$$\Phi_E^{Te,C,NTr} > \Phi_E^{Te,NC,NTr}, \tag{A.34}$$

which can be written as

$$v < l_3 - l_2. \tag{A.35}$$

That is, the farmer prefers to call a veterinarian if and only if inequality (A.35) holds.

A3.2.2 Veterinary service decisions after self-tests at information set ③

At information set ③, the farmer decides whether to call a veterinarian when a self-test has revealed *I*, taking optimal antibiotic administrations at information sets ⑧ and ⑨ as given. She makes this veterinary service decision by comparing $\Phi_I^{Te,C,NTr}$ with $\Phi_I^{Te,NC,NTr}$. The farmer calls a veterinarian whenever the payoff from ⑧ exceeds that from ⑨, i.e., whenever

$$\Phi_I^{Te,C,NTr} > \Phi_I^{Te,NC,NTr}. \tag{A.36}$$

We can rewrite inequality (A.36) as (A.35). Thus, the farmer calls a veterinarian if and only if the cost is sufficiently low that inequality (A.35) holds.

A3.3 Testing decision

At information set ①, the farmer makes testing decisions whenever an infection is suspected. She can purchase information through a self-test or purchase both information and other services through a veterinarian call. Or she can choose not to purchase any information. At the time point when testing decisions are made the farmer is uncertain about infection types. She therefore compares the expected payoffs associated with self-tests, veterinary services and no tests. The expected payoffs are weighted averages of payoffs in different infection cases. In the following analysis, we first calculate expected payoffs from three testing choices, taking subsequent optimal decisions derived in sections A3.1 and A3.2 as given. Then we compare these expected payoffs to solve for optimal testing decisions.

A3.3.1 Calling a veterinarian

The expected payoff from calling a veterinarian is an average of payoffs at information sets ④ and ⑩ weighted by the probabilities of infection type. Since optimal antibiotic administration decisions at information set ④ vary with antibiotic cost, so too do the corresponding payoffs. Thus the expected payoff from calling a veterinarian can be written as

$$V^C = \begin{cases} \beta\Phi_E^{NTe,C,Tr} + (1-\beta)\Phi_I^{NTe,C,NTr} & \text{whenever } 0 < b \le b_1; \\ \beta\Phi_E^{NTe,C,NTr} + (1-\beta)\Phi_I^{NTe,C,NTr} & \text{whenever } b > b_1. \end{cases} \quad \text{(A.37)}$$

Explicitly, we can rewrite equation (A.37) as a function of cost parameters;

$$V^C = \begin{cases} a - \beta(l_1 + b) - (1-\beta)l_2 - v & \text{whenever } 0 < b \le b_1; \\ a - l_2 - v & \text{whenever } b > b_1. \end{cases} \quad \text{(A.38)}$$

A3.3.2 Performing a self-test

As with calling a veterinarian, the expected payoff from performing a self-test equals an average of payoffs at information sets ② and ③ weighted by the probabilities of infection type. Since optimal decisions at information sets ② and ③ vary with cost parameters so too do the corresponding payoffs. Therefore, the expected payoff from performing a self-test is a function of cost parameters.

(1) Low antibiotic cost: $b \le b_1$

With low antibiotic cost $b \le b_1$, the farmer prefers not to call a veterinarian at information set ② and receives payoff $\Phi_E^{Te,NC,Tr}$, while the optimal decision at information set ③ varies. When veterinary service cost is low such that inequality (A.35) applies, the farmer chooses C and receives payoff $\Phi_I^{Te,C,NTr}$ at information set ③. Thus, the expected payoff from performing a self-test is

$$V^{Te} = \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,C,NTr}. \quad \text{(A.39)}$$

Explicitly, we can rewrite equation (A.39) as the following function of cost parameters;

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)(l_2 + v) - d. \quad \text{(A.40)}$$

Conversely, when veterinary service cost is sufficiently high that inequality (A.35) is violated, the farmer changes decision from C to NC at information set ③, and receives payoff $\Phi_I^{Te,NC,NTr}$. The expected payoff from performing a self-test is

$$V^{Te} = \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,NC,NTr}; \quad \text{(A.41)}$$

which reduces to

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)l_3 - d. \quad \text{(A.42)}$$

(2) Medium antibiotic cost: $b_1 < b \le b_3$

With medium antibiotic cost $b_1 < b \le b_3$, the optimal decisions at information sets ② and ③ vary. When veterinary service cost is sufficiently low that it satisfies both inequalities (A.35) and (A.33), the farmer prefers C at both information sets ② and ③, and receives respective payoffs $\Phi_E^{Te,C,NTr}$ and $\Phi_I^{Te,C,NTr}$. The expected payoff from performing a self-test is

$$V^{Te} = \beta\Phi_E^{Te,C,NTr} + (1-\beta)\Phi_I^{Te,C,NTr}, \quad \text{(A.43)}$$

which can also be re-stated as

$$V^{Te} = a - l_2 - v - d. \quad \text{(A.44)}$$

When veterinary service cost is at some medium level such that inequality (A.35) holds but

(A.33) is violated[1], then the farmer prefers NC at information set ② but C at information set ③, and receives respective payoffs $\Phi_E^{Te,NC,Tr}$ and $\Phi_I^{Te,C,NTr}$. The expected payoff from performing a self-test is

$$V^{Te} = \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,C,NTr}; \qquad (A.39)$$

which abbreviates to

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)(l_2 + v) - d. \qquad (A.40)$$

When veterinary service cost is sufficiently high that inequalities (A.35) and (A.33) are both violated, the farmer prefers NC at both information sets ② and ③, receives payoffs $\Phi_E^{Te,NC,Tr}$ and $\Phi_I^{Te,NC,NTr}$. The expected payoff from performing a self-test is

$$V^{Te} = \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,NC,NTr}. \qquad (A.41)$$

The equation may be re-written as

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)l_3 - d. \qquad (A.42)$$

(3) High antibiotic cost: $b > b_3$

With high antibiotic cost $b > b_3$, the optimal decisions at information sets ② and ③ vary. When veterinary service cost is low such that inequality (A.35) holds, the farmer prefers C at both information sets ② and ③, and receives payoffs $\Phi_E^{Te,C,NTr}$ and $\Phi_I^{Te,C,NTr}$. Therefore, the expected payoff from performing a self-test is written as

$$V^{Te} = \beta\Phi_E^{Te,C,NTr} + (1-\beta)\Phi_I^{Te,C,NTr}, \qquad (A.43)$$

and cancellations then lead to the equivalent expression

$$V^{Te} = a - l_2 - v - d. \qquad (A.44)$$

Conversely, when veterinary service cost is sufficiently high that inequality (A.35) is violated,

[1] When $b < b_3$, then (A.33) is a sufficient condition for (A.35).

the farmer prefers *NC* at both information sets ② and ③, and receive respective payoffs $\Phi_E^{Te,NC,NTr}$ and $\Phi_I^{Te,NC,NTr}$. Therefore, the expected payoff from performing a self-test can be stated as

$$V^{Te} = \beta\Phi_E^{Te,NC,NTr} + (1-\beta)\Phi_I^{Te,NC,NTr}, \tag{A.45}$$

and so, upon simplification,

$$V^{Te} = a - l_3 - d. \tag{A.46}$$

In summary, the expected payoff from performing a self-test is

$$V^{Te} = \begin{cases} \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,C,NTr} & \text{whenever } b \le b_1 \text{ and (A.35) holds} \\ \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,NC,NTr} & \text{whenever } b \le b_1 \text{ and (A.35) is violated} \\ \beta\Phi_E^{Te,C,NTr} + (1-\beta)\Phi_I^{Te,C,NTr} & \text{whenever } b_1 < b \le b_3\text{, (A.33) and (A.35) holds} \\ \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,C,NTr} & \text{whenever } b_1 < b \le b_3\text{, (A.33) is violated but (A.35) holds} \\ \beta\Phi_E^{Te,NC,Tr} + (1-\beta)\Phi_I^{Te,NC,NTr} & \text{whenever } b_1 < b \le b_3\text{, (A.33) and (A.35) are violated} \\ \beta\Phi_E^{Te,C,NTr} + (1-\beta)\Phi_I^{Te,C,NTr} & \text{whenever } b > b_3 \text{ and (A.35) holds} \\ \beta\Phi_E^{Te,NC,NTr} + (1-\beta)\Phi_I^{Te,NC,NTr} & \text{wWhenever } b > b_3 \text{ and (A.35) is violated} \end{cases} \tag{A.47}$$

This branched function resolves to

$$V^{Te} = \begin{cases} a - \beta(l_1 + b) - (1-\beta)(l_2 + v) - d & \text{whenever } b \le b_1 \text{ and (A.35) holds} \\ a - \beta(l_1 + b) - (1-\beta)l_3 - d & \text{whenever } b \le b_1 \text{ and (A.35) is violated} \\ a - l_2 - v - d & \text{whenever } b_1 < b \le b_3\text{, (A.33) and (A.35) holds} \\ a - \beta(l_1 + b) - (1-\beta)(l_2 + v) - d & \text{whenever } b_1 < b \le b_3\text{, (A.33) is violated but (A.35) holds} \\ a - \beta(l_1 + b) - (1-\beta)l_3 - d & \text{whenever } b_1 < b \le b_3\text{, (A.33) and (A.35) are violated} \\ a - l_2 - v - d & \text{whenever } b > b_3 \text{ and (A.35) holds} \\ a - l_3 - d & \text{whenever } b > b_3 \text{ and (A.35) is violated} \end{cases} \tag{A.48}$$

A3.3.3 No information purchases

The expected payoff from purchasing no information is the payoff at information set ⑦ which is the weighted average of payoffs from making homogeneous antibiotic administration decisions regardless of infection type. The optimal antibiotic decision at information set ⑦ depends on antibiotic cost and so does the expected payoff. Therefore, the expected payoff from purchasing no information can be written as

$$V^{NTe,NC} = \begin{cases} \beta\Phi_E^{NTe,NC,Tr} + (1-\beta)\Phi_I^{NTe,NC,Tr} & \text{whenever } 0 < b < b_2; \\ \beta\Phi_E^{NTe,NC,NTr} + (1-\beta)\Phi_I^{NTe,NC,NTr} & \text{whenever } b > b_2. \end{cases} \quad (A.49)$$

This branched function resolves to

$$V^{NTe,NC} = \begin{cases} a - \beta l_1 - (1-\beta) l_3 - b & \text{whenever } 0 < b < b_2; \\ a - l_3 & \text{whenever } b > b_2. \end{cases} \quad (A.50)$$

A3.3.4 Compare the expected payoffs from the testing choices

Having calculated the expected payoffs associated with self-tests, veterinary services and no tests, we compare them. The farmer prefers the one resulting in the largest expected payoff.

(1) Low antibiotic cost ($b < b_1$)

(1-1) When the veterinary service cost is low such that inequality (A.35) holds, then the respective expected payoffs associated with self-tests, veterinary services and no tests are

$$V^C = a - \beta(l_1 + b) - (1-\beta)l_2 - v; \quad (A.37)\text{-}1$$

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)(l_2 + v) - d; \quad (A.48)\text{-}1$$

$$V^{NTe,NC} = a - \beta l_1 - (1-\beta)l_3 - b. \quad (A.50)\text{-}1$$

The optimal testing decision is C whenever cost parameters satisfy the condition pair

$$\begin{cases} d > \beta v; \\ b > l_2 - l_3 + \dfrac{v}{1-\beta}. \end{cases} \quad (A.51)$$

The optimal testing decision is Te whenever

$$d < \min[(1-\beta)(l_3 + b - l_2 - v), \beta v]. \quad (A.52)$$

Finally, the optimal testing decision is NTe, NC whenever

$$\begin{cases} d > (1-\beta)(l_3 + b - l_2 - v); \\ b < l_2 - l_3 + \dfrac{v}{1-\beta}. \end{cases} \quad (A.53)$$

(1-2) Whenever the veterinary service cost violates the bound in inequality (A.35), while payoffs associated with veterinary services and no tests do not change compared with (1-1), then the expected payoff from performing a self-test changes to

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)l_3 - d \qquad \text{(A.48)-2}$$

as previously presented. The optimal testing decision is *C* whenever

$$\begin{cases} d > v - (1-\beta)(l_3 - l_2); & (1) \\ b > l_2 - l_3 + \dfrac{v}{1-\beta}. & (2) \end{cases} \qquad \text{(A.54)}$$

However, since inequality (A.35) does not hold and $b < b_1$ $(b_1 < b_2)$, condition (A.54)-(2) does not hold. Therefore, choosing *C* is not optimal in this case.

The optimal testing decision is *Te* whenever

$$\begin{cases} d < v - (1-\beta)(l_3 - l_2); & (1) \\ d < (1-\beta)b. & (2) \end{cases} \qquad \text{(A.55)}$$

When inequality (A.35) does not hold and $b_1 < b_2$, then (A.55)-(2) is sufficient condition for (A.55)-(1) to apply.

The optimal testing decision is *NTe, NC* whenever

$$\begin{cases} b < l_2 - l_3 + \dfrac{v}{1-\beta}; & (1) \\ d > (1-\beta)b. & (2) \end{cases} \qquad \text{(A.56)}$$

When inequality (A.35) does not hold and $b < b_1$ $(b_1 < b_2)$, then condition (A.56)-(1) holds.

(2) Lower medium antibiotic cost ($b_1 < b < b_2$)

(2-1) When veterinary service cost is sufficiently low that inequalities (A.35) and (A.33) hold, then the expected payoffs associated with self-tests, veterinary services and no tests are

$$V^{C} = a - l_2 - v; \qquad \text{(A.37)-2}$$

$$V^{Te} = a - l_2 - v - d; \qquad \text{(A.48)-3}$$

$$V^{NTe,NC} = a - \beta l_1 - (1-\beta)l_3 - b. \qquad \text{(A.50)-1}$$

Te is dominated by *C* and so we only need to compare the expected payoff from choosing *C* with that from *NTe, NC*. When inequality (A.33) holds, the payoff from calling a veterinarian is the greatest among the three choices.

(2-2) When the veterinary service cost is intermediate such that inequality (A.35) holds but (A.33) does not, while the payoffs from choosing *C* and *NTe, NC* are unchanged compared with (2-1), then the expected payoff from choosing *Te* changes to

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)(l_2 + v) - d. \tag{A.48)-4}$$

The optimal testing decision is *C* whenever

$$\begin{cases} d > \beta(l_2 - l_1 - b + v); \\ b > v - \beta l_1 - (1-\beta) l_3 + l_2. \end{cases} \tag{A.57}$$

The optimal testing decision is *Te* when

$$d < \min[(1-\beta)(l_3 + b - l_2 - v), \beta(l_2 - l_1 - b + v)]. \tag{A.58}$$

The optimal testing decision is *NTe, NC* whenever

$$\begin{cases} d > (1-\beta)(l_3 + b - l_2 - v); \\ b < v - \beta l_1 - (1-\beta) l_3 + l_2. \end{cases} \tag{A.59}$$

(2-3) When the veterinary service cost breaches the value set satisfying inequality (A.35) then (A.33) does not hold either. While the payoffs from choosing *C* and *NTe, NC* are unchanged compared with (2-1), the expected payoff from choosing *Te* changes to

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta) l_3 - d. \tag{A.48)-5}$$

The optimal testing decision is *C* when the following condition pair is satisfied:

$$\begin{cases} b > v - \beta l_1 - (1-\beta) l_3 + l_2; & (1) \\ d > v - \beta(l_1 + b) - (1-\beta) l_3 + l_2. & (2) \end{cases} \tag{A.60}$$

However, when inequality (A.35) is violated and $b < b_2$, then (A.60)-(1) does not hold. Thus, choosing *C* is not optimal in this case.

The optimal testing decision is *Te* when both of the following conditions are satisfied:

$$\begin{cases} d < v - \beta(l_1 + b) - (1-\beta) l_3 + l_2; & (1) \\ d < (1-\beta) b. & (2) \end{cases} \tag{A.61}$$

When inequality (A.35) does not hold, then (A.61)-(2) is a sufficient condition for (A.61)-(1).

The optimal testing decision is *NTe, NC* whenever

$$\begin{cases} b < v - \beta l_1 - (1-\beta) l_3 + l_2; & (1) \\ d > (1-\beta) b. & (2) \end{cases} \tag{A.62}$$

When inequality (A.35) is violated and $b < b_2$, then (A.62)-(1) is not binding.

(3) Upper medium antibiotic cost: $b_2 < b < b_3$

When antibiotic cost rise from the level of lower medium to upper-medium level, the only change arises at information set ⑦ and therefore the expected payoff from choosing *NTe, NC* changes.

(3-1) When the veterinary service cost is low such that inequalities (A.35) and (A.33) both hold, while the payoffs from choosing C and Te are unchanged compared with (2-1), the expected payoff from choosing *NTe, NC* changes to

$$V^{NTe,NC} = a - l_3. \qquad \text{(A.50)-2}$$

It can be seen that Te is dominated by C and so we only need to compare the expected payoffs from choosing C with *NTe, NC*. Given inequality (A.35), the payoff from calling a veterinarian is the greatest among the three choices.

(3-2) When the veterinary service cost is sufficiently low that inequality (A.35) holds but (A.33) does not, while the payoffs from choosing C and Te are unchanged compared with (2-2), then the expected payoff from choosing *NTe, NC* changes to

$$V^{NTe,NC} = a - l_3. \qquad \text{(A.50)-2}$$

The optimal testing decision is C whenever

$$d > \beta(l_2 - l_1 - b + v). \tag{A.63}$$

The optimal testing decision is Te when condition (A.63) is violated. Note that *NTe, NC* is dominated by C given inequality (A.35).

(3-3) When the veterinary service cost is high such that inequality (A.35) does not hold then neither does (A.33), while the payoffs from choosing C and Te are unchanged compared with (2-

3), the expected payoff from choosing *NTe, NC* changes to

$$V^{NTe,NC} = a - l_3. \tag{A.50)-2}$$

When inequality (A.35) does not hold, then *C* is dominated by *NTe, NC*. Therefore, we only compare the payoffs from choosing *Te* with *NTe, NC*. The optimal testing decision is *Te* whenever

$$d < \beta(l_3 - l_1 - b). \quad \text{(A.64)}$$

Otherwise the optimal testing decision is *NTe, NC*.

(4) High antibiotic cost: $b > b_3$

(4-1) When the veterinary service cost is low such that inequality (A.35) holds, then the expected payoffs from choosing *C*, *Te* and *NTe, NC* are

$$V^C = a - l_2 - v; \quad \text{(A.37)-2}$$

$$V^{Te} = a - l_2 - v - d; \quad \text{(A.48)-6}$$

$$V^{NTe,NC} = a - l_3. \quad \text{(A.50)-2}$$

When inequality (A.35) applies, the optimal testing approach is *C*.

(4-2) When the veterinary service cost is high such that inequality (A.35) does not hold, while the payoffs from choosing *C* and *NTe*, *NC* are unchanged, the expected payoff from choosing *Te* changes to

$$V^{Te} = a - l_3 - d. \quad \text{(A.48)-7}$$

Te is dominated by *NTe, NC*. Given that inequality (A.35) does not hold, the expected payoff from choosing *NTe, NC* exceeds that from choosing *C*. Therefore purchasing no information is the optimal testing choice in this situation.

A4 Summary of optimal strategies in basic model

There are six possible optimal strategies:

S1: Neither call a veterinarian nor perform a self-test at information set ①, always treat with antibiotics at information set ⑦

S2: Perform a self-test at information set ①, in type E infection cases do not call a veterinarian (at information set ②) but treat with antibiotics (at information set ⑥), in type I infection cases neither call a veterinarian (at information set ③) nor treat with antibiotics (at information set ⑨)

S3: Neither call a veterinarian nor perform a self-test at information set ①, never treat with antibiotics at information set ⑦

S4: Call a veterinarian at information set ①, in type E infection cases treat with antibiotics (at information set ④), in type I infection cases do not treat with antibiotics (at information set ⑩)

S5: Call a veterinarian at information set ①, do not treat with antibiotics at information sets ④ and ⑩

S6: Self-test at information set ①, in type E infection cases do not call a veterinarian (at information set ②) but treat with antibiotics (at information set ⑥), in type I infection cases call a veterinarian (at information set ③) but do not treat with antibiotics (at information set ⑧)

We summarize and organize the conditions on cost parameters under which each strategy is optimal. The respective conditions under which S1-S6 are optimal are as

$$\text{(S1)} \quad \begin{cases} b > l_2 - l_1 \\ b < \beta\left(l_3 - l_1\right) \\ v < l_3 - l_2 \\ b < l_2 - l_1 + v \\ d > (1-\beta)(l_3 + b - l_2 - v) \\ b < v - \beta l_1 - (1-\beta) l_3 + l_2 \end{cases} \quad \text{or} \quad \begin{cases} b < l_2 - l_1 \\ v < l_3 - l_2 \\ d > (1-\beta)(l_3 + b - l_2 - v) \\ b < l_2 - l_3 + \dfrac{v}{1-\beta} \end{cases} \quad \text{or} \quad \begin{cases} b < \beta(l_3 - l_1) \\ v > l_3 - l_2 \\ d > (1-\beta) b \end{cases} \tag{A.65}$$

$$\text{(S2)} \quad \begin{cases} b > \beta(l_3 - l_1) \\ b < l_3 - l_1 \\ v > l_3 - l_2 \\ d < \beta(l_3 - l_1 - b) \end{cases} \quad \text{or} \quad \begin{cases} b < \beta(l_3 - l_1) \\ v > l_3 - l_2 \\ d < (1-\beta) b \end{cases} \tag{A.66}$$

$$\text{(S3)} \quad \begin{cases} b > \beta(l_3 - l_1) \\ b < l_3 - l_1 \\ v > l_3 - l_2 \\ d > \beta(l_3 - l_1 - b) \end{cases} \quad \text{or} \quad \begin{cases} b > l_3 - l_1 \\ v > l_3 - l_2 \end{cases} \tag{A.67}$$

$$\text{(S4)} \quad \begin{cases} b < l_2 - l_1 \\ v < l_3 - l_2 \\ b > l_2 - l_3 + \dfrac{v}{1-\beta} \\ d > \beta v \end{cases} \tag{A.68}$$

$$\text{(S5)} \quad \begin{cases} b > l_2 - l_1 \\ b < \beta(l_3 - l_1) \\ v < l_3 - l_2 \\ b < l_2 - l_1 + v \\ d > \beta(l_2 - l_1 - b + v) \\ b > v - \beta l_1 - (1-\beta) l_3 + l_2 \end{cases} \text{ or } \begin{cases} b > \beta(l_3 - l_1) \\ b < l_3 - l_1 \\ v < l_3 - l_2 \\ b < l_2 - l_1 + v \\ d > \beta(l_2 - l_1 - b + v) \end{cases} \text{ or } \begin{cases} b > l_2 - l_1 \\ b < l_3 - l_1 \\ b > l_2 - l_1 + v \\ v < l_3 - l_2 \end{cases} \text{ or } \begin{cases} b > l_3 - l_1 \\ v < l_3 - l_2 \end{cases} \tag{A.69}$$

$$\text{(S6)} \quad \begin{cases} b > l_2 - l_1 \\ b < \beta(l_3 - l_1) \\ v < l_3 - l_2 \\ b < l_2 - l_1 + v \\ d < \beta(l_2 - l_1 - b + v) \\ d < (1-\beta)(l_3 + b - l_2 - v) \end{cases} \text{ or } \begin{cases} b > \beta(l_3 - l_1) \\ b < l_3 - l_1 \\ v < l_3 - l_2 \\ b < l_2 - l_1 + v \\ d < \beta(l_2 - l_1 - b + v) \end{cases} \text{ or } \begin{cases} b < l_2 - l_1 \\ v < l_3 - l_2 \\ d < (1-\beta)(l_3 + b - l_2 - v) \\ d < \beta v \end{cases} \tag{A.70}$$

A4.1 Explanations about Figure 3-Figure 5 in the main manuscript

We graph the optimal strategies, holding one cost parameter among (b,d,v) fixed (See C1-C3). We take Figure 3-Figure 5 in the main manuscript as examples to explain how farmer's optimal strategy varies with cost parameters. Figure 3 depicts unregulated farmer's optimal strategies in the *b-d* plane when veterinary services are sufficiently expensive to outweigh the loss reduction from veterinary services (i.e., $v > l_3 - l_2$, recalling that l_3 is the loss incurred without any disease management practice and l_2 is the loss incurred under veterinarian oversight). Three solid lines divide the *b-d* plane into three areas:

1) When self-test cost is high but antibiotics are cheap, the farmer prefers to use antibiotics precautiously without purchasing information (labeled as strategy S1). As self-test cost decreases until the expected cost saving associated with informed antibiotic use (i.e., $(1-\beta)b$) exceeds information cost (d), the farmer's optimal strategy changes to S2, which is to use self-

test information to guide antibiotic administrations. The boundary condition (i.e., $d=(1-\beta)b$) for the farmer to switch from strategy S1 to S2 is depicted as an upward line in Figure 3.

2) When both self-tests and antibiotics are expensive, the farmer prefers to neither purchase information nor administer antibiotics (i.e., strategy S3). As self-test cost decreases until the expected loss reduction associated with informed antibiotic use (i.e., $\beta(l_3-l_1-b)$) exceeds information cost (d), the farmer's optimal strategy changes to performing a self-test and then using antibiotics accordingly (i.e., strategy S2). The boundary condition (i.e., $d=\beta(l_3-l_1-b)$) for the farmer switching from strategy S3 to S2 is depicted as a downward line in Figure 3.

3) The critical value to determine whether the farmer without information prefers precautious antibiotic use or no use is depicted as the vertical line (i.e., $b=\beta(l_3-l_1)$) in Figure 3. When antibiotic use cost (b) exceeds the expected loss reduction associated with its use (i.e., $\beta(l_3-l_1)$), then the farmer prefers to not use antibiotics; otherwise the farmer uses antibiotic.

Figure 4 depicts unregulated farmer's optimal strategies in the *b-v* plane when self-testing costs too much. Thus our discussion focuses on veterinary service and antibiotic choices. Five solid lines divide the *b-v* plane into four areas:

1) In the left upper area, when veterinary services are expensive but antibiotics are cheap, the farmer does not call a veterinarian but instead always uses antibiotics to treat infections (i.e., strategy S1). The boundary condition (i.e., $b=\beta(l_3-l_1)$) for the farmer's optimal strategy switching from strategy S1 to S3 (i.e., between left-upper and right upper area) has been discussed in analysis of Figure 3.

2) When veterinary service and antibiotic cost are both cheap, in the left bottom area, the farmer prefers to purchase information through a veterinarian, and then administer antibiotics accordingly (i.e., strategy S4). As antibiotic cost increases until its cost (b) exceeds the

additional loss reduction caused by antibiotic treatment compared with alternative treatments in type E infection (i.e., $l_2 - l_1$), the farmer's optimal strategy changes to calling a veterinarian but not using antibiotics in any infection cases (see strategy S5). The boundary condition (i.e., $b = l_2 - l_1$) for farmer's optimal strategy switching from S4 to S5 is depicted as a vertical line in Figure 4.

3) Consider now a situation in the upper left area with low antibiotic cost $b < l_2 - l_1$. As veterinary service cost decreases until its cost (v) is below expected loss reduction from informed antibiotic use and veterinary services (i.e., $(1-\beta)(l_3 - l_2 + b)$), the farmer's optimal strategy changes from S1 to S4. The boundary condition (i.e., $v = (1-\beta)(l_3 - l_2 + b)$) is depicted as an upward line crossing v Axis in Figure 4.
4) Consider instead the upper left area with lower medium antibiotic cost $l_2 - l_1 < b < \beta(l_3 - l_1)$. As veterinary service cost decreases until the benefit from replacing precautious antibiotic use with veterinary services (i.e., $b + \beta l_1 + (1-\beta)l_3 - l_2$) outweighs veterinary service cost (v), the farmer's optimal strategy changes from S1 to S5. The boundary condition $v = b + \beta l_1 + (1-\beta)l_3 - l_2$ is depicted as the other upward line in Figure 4.
5) Finally consider the upper right area. As veterinary service cost decreases until its cost (v) is lower than the loss reduction from veterinary services (i.e., $l_3 - l_2$), the farmer's optimal strategy changes from S3 to S5. The boundary condition ($v = l_3 - l_2$) is depicted as a horizontal line in Figure 4.

Figure 5 illustrates unregulated farmer's optimal strategies in the d-v plane when antibiotics are sufficiently inexpensive that it is profit-increasing to use antibiotics in type E infection cases under veterinarian oversight. Five solid lines divide the d-v plane into four areas:

1) When both veterinary services and self-tests are expensive, the farmer acts following strategy

S1, i.e., does not purchase any information but instead always administers antibiotics in the right-upper area. As self-test cost decreases, the farmer's optimal strategy changes from S1 to S2 (i.e., using a self-test to obtain information and then administering antibiotics accordingly. See the left-upper area). The boundary condition (i.e., $d=(1-\beta)b$) for the farmer's optimal strategy switching from strategy S1 to S2 (i.e., between right-upper and left-upper area) has been discussed in analysis of Figure 3 and is depicted as the vertical lines in Figure 5.

2) The boundary condition $v=(1-\beta)(l_3+b-l_2)$ for the farmer's optimal strategy to switch from S1 to S4 (i.e., between right-upper and right-bottom area) has been discussed in analysis of Figure 4 and is depicted as a horizontal line in Figure 5.

3) To determine when the farmer's optimal strategy changes from precautious antibiotic use without information (S1) to heterogeneous treatments with information (S6), we need to compare information cost (d) with the benefit increase induced by information (i.e., $(1-\beta)(l_3+b-l_2-v)$). The switching condition $d=(1-\beta)(l_3+b-l_2-v)$ can be depicted as a downward line in Figure 5.

4) The boundary condition (i.e., $v=l_3-l_2$) between left-upper area (corresponding to S2) and left-bottom area (corresponding to S6), as depicted by a horizontal line, is straightforward. The farmer prefers to call a veterinarian in type I infection cases as long as the loss reduction associated with veterinarian use (i.e., l_3-l_2) exceeds its cost (v); otherwise she prefers to not call.

5) The boundary condition (i.e., $d=\beta v$) between the left-bottom area (corresponding to S6) and the right-bottom area (corresponding to S4), depicted as an upward line through the origin, is straightforward. The farmer prefers to obtain information through self-tests as long as the expected cost saving from heterogenous veterinary service decisions induced by self-test

information (i.e., βv) exceeds its cost (d); otherwise she prefers to not perform a self-test.

A4.2 Explanations about *Summary 1 Optimal antibiotic choices*

In situations where neither performing a self-test nor calling a veterinarian are optimal, the optimal antibiotic administration decision varies with antibiotic cost at information set ⑦. The farmer uses antibiotics whenever their cost is low, but not otherwise. For example, in Figure 3 precautious use is preferred whenever antibiotic cost satisfies $b < \beta(l_3 - l_1)$ but otherwise no use is preferred. In situations where performing a self-test is optimal at information set ①, the farmer uses antibiotics at information set ⑥ in *E* type infection cases but does not use antibiotics at information sets ⑧ and ⑨ in *I* type infection cases. Information set ⑤ is not discussed here since it is off the optimal strategy paths.

Consider now situations where calling a veterinarian is optimal at information set ①. When veterinary services reveal *I*, the farmer does not use antibiotics at information set ⑩. When veterinary services reveal the converse result then the optimal antibiotic administration decision depends on antibiotic cost at information set ④. The farmer uses antibiotics when the cost is less than the additional loss reduction caused by antibiotic treatment under veterinarian oversight in type *E* infection (i.e., $b < l_2 - l_1$); otherwise she does not administer and instead adopts alternative treatments as provided by the called veterinarian. Hence,

Summary 1. (<u>Optimal antibiotic choices</u>) When purchasing no information is optimal, the farmer prefers precautious antibiotic use whenever antibiotics are inexpensive. When purchasing information through a self-test is optimal, the farmer prefers to use antibiotics for type E infections and to not use for type I infections. When purchasing information through a veterinarian is optimal, i) in type E infection cases, the farmer prefers to use antibiotic treatment given a low antibiotic cost while replacing antibiotic treatment with alternative treatments given a high antibiotic cost, ii) in type I infection cases, the farmer prefers to not use antibiotics unambiguously.

A4.3 Explanations about *Summary 2 Optimal choices regarding veterinarian visits and alternative treatments*

In situations where performing a self-test is optimal at information set ①, the farmer can call for veterinary services after knowing infection type from the self-test. When the self-test has revealed *I*, then the optimal veterinary service decision at information set ③ varies with veterinary service cost. The farmer will call a veterinarian to seek alternative treatments and eliminate contagion risk in her herd whenever $v < l_3 - l_2$; otherwise, she does not call a veterinarian since the veterinary service cost exceeds the loss reduction from veterinary services (See Figure 3). When the self-test has revealed *E*, the farmer does not call a veterinarian at information set ②. This is because veterinary services are not beneficial given that antibiotics are administered whenever self-testing reveals type *E* infection cases (see Summary 1). Hence, we have

Summary 2. (<u>Optimal choices regarding veterinarian visits and alternative treatments</u>) When purchasing information through a self-test is optimal and the self-test has revealed I, i) the farmer will call a veterinarian to seek alternative treatments and eliminate contagion risk in the herd whenever the cost is low; ii) otherwise, calling a veterinarian cannot be the optimal choice. When purchasing information through a self-test is optimal and the self-test has revealed E, the farmer prefers to not call a veterinarian.

A4.4 Explanations about *Summary 3 Optimal information acquisition decisions*

We take Figure 5 as an example to summarize optimal testing choices. When both veterinary services and self-tests are expensive, then the farmer does not purchase any information, see the right-upper area. Given low self-test cost and high veterinary service cost, the farmer obtains information through a self-test instead of through a veterinarian (i.e., the left-upper area). As self-test cost increases and veterinary service cost decreases, the farmer substitutes veterinary services for self-tests to obtain information (i.e., the right-bottom area). Self-tests and veterinary services substitute in information acquisition decision-making except when antibiotics are sufficiently expensive (i.e., $b > l_3 - l_1$). In that case, the antibiotic treatment is not a profit-increasing choice regardless of infection type and therefore is never applied. Thus information is useless so that the farmer does not perform self-tests at all. She calls a veterinarian in order to obtain alternative treatments whenever veterinary services are inexpensive compared with the benefit from veterinarian use (i.e., $v < l_3 - l_2$).

Summary 3. *(<u>Optimal information acquisition decisions</u>) Self-tests and veterinary services substitute in information acquisition decision-making except when antibiotics are too expensive. When antibiotics are too expensive, then information is useless since the farmer does not use antibiotics regardless of infection type. In that case, the farmer does not perform self-tests, while the farmer calls a veterinarian in order to obtain alternative treatments whenever veterinary services are inexpensive.*

A4.5 Interactions between antibiotics and self-tests/veterinary services

Since optimal choices regarding self-tests, veterinary services and antibiotics are jointly determined by cost parameters, we are interested in investigating interactions between these choices. The interaction between self-tests and antibiotics varies with antibiotic cost. For instance, in Figure 3 given high antibiotic cost $b > \beta(l_3 - l_1)$, say at level b_H, the expected antibiotic use decreases as self-test cost increases from the level below the boundary condition $d = \beta(l_3 - l_1 - b)$ to above the boundary condition, suggesting that antibiotics and self-tests complement. This situation arises when informed antibiotic decisions do not necessarily induce a decrease in antibiotic input. Conversely, given low antibiotic cost $b < \beta(l_3 - l_1)$, say at level b_L, the expected antibiotic use increases as self-test cost increases from the level below boundary condition $d = (1-\beta)b$ to above the boundary condition, suggesting that antibiotics and self-tests substitute. In this situation, more information can reduce antibiotic use, a conclusion that is consistent with comments made by Krömker and Leimbach (2017) regarding the causality between lack of diagnosis and antibiotic over-use/inappropriate use.

Veterinary services and antibiotics always substitute. Taking Figure 4 as an example, a decrease in veterinary service cost can change optimal strategy from S1 to S5, and so decrease the expected antibiotic use from 1 to 0. In this case, the farmer fully replaces antibiotics with veterinary services since alternative treatments provided by a veterinarian are more cost-effective.

A4.6 Interaction between self-tests and veterinary services

The interaction between self-tests and veterinary services varies with veterinary service cost. As illustrated in Figure 5 when veterinary service cost is at low level $v_L < (1-\beta)(l_3 + b - l_2)$ then veterinary service demand increases as self-test cost increases, suggesting that self-tests and veterinary services substitute in respect to information revelation. When veterinary service cost is sufficiently high that $(1-\beta)(l_3 + b - l_2) < v_H < l_3 - l_2$, then veterinary service demand decreases as self-test cost increases. In this situation, self-tests and veterinary services complement since veterinary services function as alternative treatments instead of revealing information. Hence,

Summary 4. *(Interactions between choices) Antibiotics and veterinary services substitute, while the interaction between antibiotics and self-tests varies with antibiotic cost. Antibiotics and self-tests complement (substitute) given a high (low) antibiotic cost. The interaction between self-tests and veterinary services varies with veterinary service cost: when veterinary service cost is i) low then self-tests and veterinary services substitute in regard to purchasing information; ii) high then they complement since veterinary services function as alternative treatments.*

A5 Social optimum and biases in privately optimal choices

Figure C-11 and Figure C-12 are samples of comparisons between farmer's optimal and socially optimal choices based on Figures 3 and 4 in the main manuscript. Dotted lines and solid lines represent boundary conditions for optimal strategy switching in favor of social welfare and farmer's profit respectively. The fact that dotted lines can be reproduced by translating solid lines leftward ω units, in accord with $b \to b + \omega$, is consistent with antibiotic resistance resulting in a divergence between social optimum and private optimum.

Figure C-11 shows where discrepancies between socially optimal and privately optimal choices occur across areas A1-A3 when veterinary service cost is high. In areas A1 and A2, the farmer prefers to use antibiotics without information since the private cost of antibiotics is sufficiently low. The socially optimal choices differ from the privately optimal choices due to the additional cost of antibiotic resistance. In area A1 it is socially optimal to perform a self-test and then use antibiotics according to self-test results while in are A2 neither using antibiotics nor purchasing information is socially optimal. As antibiotic cost increases, in area A3 the farmer prefers to reduce some unnecessary expenditure on antibiotics, so she tests and then uses antibiotics whenever in type E infection cases. For the social planner, the area A2 optimal strategy of neither using antibiotics nor purchasing information expands to A3.

Figure C-12 shows where discrepancies between socially optimal and privately optimal choices occur across areas A1-A4. In areas A1-A3, the farmer prefers to use antibiotics without any information purchase. The privately optimal choices are not socially optimal because the additional cost of antibiotic resistance is not taken into consideration. In area A1 it is socially optimal to call a veterinarian, then use antibiotics for type E infections and use alternative treatments for type I infections. In area A2, the social optimum is to call a veterinarian but not administer antibiotics. In area A3, the social optimum is to neither purchase information nor administer antibiotics. In area A4, the farmer prefers to call a veterinarian, then use antibiotics for type E infections and use alternative treatments for type I infections. In this area, however, the social planner prefers to replace antibiotics with alternative treatments for any infections due to the additional cost on society of antibiotic use.

A5.1 Antibiotic over-use

In situations where the farmer's optimal antibiotic choices diverge from social optimum, the farmer over-uses antibiotics. For example in the A areas in Figure C-11 and Figure C-12, farmer demands excessive antibiotics. The farmer makes decisions so that expected private payoff is maximized. However, farmers may have little incentive to include the impact of their antibiotic actions on the development of antibiotics resistance and so ultimately on losses to society through deaths and additional costs for alternative treatments. The damage is done through widespread use, which is beyond an individual's control, and where a farmer who refrains from private use will compete with those who do not. That explains why privately optimal use is likely to far exceed what is best for society.

A5.2 Under-test or over-test?

Demand for self-tests is below the socially optimal level when antibiotic cost is low and above the socially optimal level when this cost is high. For example in area A1 of Figure C-11 the farmer uses fewer self-tests than is socially optimal level, while in area A3 she overuses self-tests. In our setting, when veterinary service cost is high, the only reason to perform a self-test is to make distinct antibiotic treatment decisions for different types of infections. Therefore when antibiotic cost is low, precautious use is preferred from the farmer's perspective while the social planner facing an additional cost of potential antibiotic resistance is incentivized to use more self-tests in order to reduce needless antibiotic use for type I infections. When antibiotic cost is high such that the farmer prefers informed antibiotic administrations, then the social planner may lack motivation to use antibiotics regardless. This is because the social planner takes account of resistance cost associated with antibiotic use. In that case, the farmer uses excessive self-tests.

The farmer under-uses veterinary services compared to social optimum. For example in areas A1-A2 of Figure C-12, the farmer uses antibiotics without information. In area A1 the social planner acting upon an additional resistance cost substitutes in an information input (in this case veterinary services) in order to reduce antibiotic use for type I infections. In area A2 the antibiotic resistance cost motivates the social planner to go so far as to substitute alternative treatments in instead of antibiotic treatment for type E infections. Therefore the farmer uses veterinary services less often than is socially optimal level.

Summary 5. (Biases in privately optimal choices) Absent government interventions the farmer over-uses antibiotics but under-uses veterinary services compared to the social optimum.

Whether the farmer demands fewer self-tests depends on antibiotic cost. Given low (high) antibiotic cost the farmer underuse (overuse) self-tests compared to the social optimum.

B Farmer's problem under prescription regulation (PR)

PR moves those medically important antibiotics that had been over-the-counter (OTC) to being overseen by a veterinarian. Thus the farmer is not allowed to use antibiotics without a veterinary visit, i.e. at information sets ⑥, ⑦ and ⑨ in Figure 2, or with a veterinary visit but no prescriptions allowing antibiotic use, i.e., at information sets ⑧, and ⑩. There are two antibiotic decisions remaining: 1) when a veterinarian reveals E at information set ④; 2) when a self-test reveals E and a veterinarian is called at information set ⑤.

B1 Antibiotic administration decisions under PR

While antibiotic administrations at information sets ⑥-⑩ are banned under PR, antibiotic administration decisions at information sets ④ and ⑤ are unchanged. Recall that the farmer prefers to administer antibiotics at information sets ④ and ⑤ whenever antibiotic cost is low such that inequality (A.23) holds. Otherwise, the farmer prefers not to use antibiotics.

B2 Veterinary service decisions after self-tests

When the farmer chooses to perform a self-test to obtain information, a series of follow-up decisions are 1) whether to call a veterinarian when the self-test has revealed E type infection at information set ②; 2) whether to call a veterinarian when the self-test has revealed I type infection at information set ③. When solving for these decisions at information sets ② and ③, we take optimal antibiotic administration decisions at subsequent information sets as given.

B2.1 Veterinary service decisions after self-tests at information set ②

(1) Low antibiotic cost: $b < b_1$

When antibiotic cost is low, the farmer chooses Tr at information set ⑤ and NTr at information set ⑥. Thus, the farmer calls a veterinarian whenever

$$\Phi_E^{Te,C,NTr} > \Phi_E^{Te,NC,NTr}; \tag{A.71}$$

which simplifies to

$$v < l_3 - l_1 + b. \tag{A.72}$$

That is, the farmer calls a veterinarian when veterinary service cost is low such that (A.72) holds. Otherwise, she does not call a veterinarian.

(2) Medium and high antibiotic cost: $b > b_1$

When antibiotic cost is medium and high, the farmer chooses NTr at both information sets ⑤ and ⑥. Thus, the farmer's veterinary service decision is the same as that in section A3.2.1(3). The farmer calls a veterinarian if and only if inequality (A.35) holds.

B2.2 Veterinary service decisions after self-tests at information set ③

At information set ③, the farmer decides whether to call a veterinarian when a self-test has revealed that antibiotics are ineffective for the infection case. We know that subsequent antibiotic administration decisions are NTr at information sets ⑧ and ⑨. Therefore the farmer's veterinary service decision is the same as that in section A3.2.2. The farmer calls a veterinarian if and only if the cost is low enough to satisfy inequality (A.35).

B3 Testing decisions

At information set ①, the farmer makes testing decisions just after observing a suspected infection case where she has three testing choices. One constraint is that veterinarian oversight is required before antibiotic use. Following the same steps as in Section A, we first calculate expected payoffs from three testing choices, taking subsequent optimal decisions derived in B1 and B2 as given. Then we compare these expected payoffs to solve for optimal testing decisions under PR.

B3.1 Calling a veterinarian

PR does not influence the antibiotic decisions when a veterinarian is called. Therefore the expected payoff from choosing C is unchanged and is a function of cost parameters (see equation (A.38)).

B3.2 Performing a self-test

The expected payoff from performing a self-test is an average of payoffs at information sets ② and ③ weighted by the probabilities of infection type. Since optimal decisions at information sets ② and ③ depend on cost parameters so do the corresponding payoffs. Therefore, the expected payoff from performing a self-test varies with cost parameters.

(1) Low antibiotic cost: $b < b_1$

When antibiotic cost is low, the farmer's optimal veterinary service decisions at information sets ② and ③ are functions of veterinary service cost. When service cost is low such that inequality (A.35) holds, then the farmer chooses C at both information sets ② and ③, and receives respective payoffs $\Phi_E^{Te,C,Tr}$ and $\Phi_I^{Te,C,NTr}$. Therefore expected payoff from Te is written as

$$V^{Te} = \beta\Phi_E^{Te,C,Tr} + (1-\beta)\Phi_I^{Te,C,NTr}, \tag{A.73}$$

which some algebra shows to be

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)l_2 - d - v. \tag{A.74}$$

When veterinary service cost is high such that inequality (A.35) does not hold but (A.72) holds, then the farmer chooses C at information set ② but chooses NC at information set ③, and receives, respectively, $\Phi_E^{Te,C,Tr}$ and $\Phi_I^{Te,NC,NTr}$. Therefore the expected payoff becomes

$$V^{Te} = \beta\Phi_E^{Te,C,Tr} + (1-\beta)\Phi_I^{Te,NC,NTr}. \tag{A.75}$$

Equation (A.75) can be written as a function of cost parameters:

$$V^{Te} = a - \beta(l_1 + b + v) - (1-\beta)l_3 - d. \tag{A.76}$$

When veterinary service cost is high such that neither inequality (A.35) nor inequality (A.72) hold, the farmer chooses NC at both information sets ② and ③, and receives $\Phi_E^{Te,NC,NTr}$ and $\Phi_I^{Te,NC,NTr}$. Therefore the expected payoff is the same as in equation (A.46) in section A3.3.2(3).

(2) Medium and high antibiotic cost: $b > b_1$

When antibiotic cost is medium and high, the farmer's optimal veterinary service decisions at information sets ② and ③ are functions of costs in the following way. When veterinary service cost is low and satisfies the inequality (A.35), the farmer prefers C at both information sets ② and ③, and receives $\Phi_E^{Te,C,NTr}$ and $\Phi_I^{Te,C,NTr}$. Therefore the expected payoff is as in equation (A.44) in section A3.3.2(2).

Conversely, when veterinary service cost is high such that inequality (A.35) does not hold, the farmer prefers *NC* at both information sets ② and ③, receiving $\Phi_E^{Te,NC,NTr}$ for ② and $\Phi_I^{Te,NC,NTr}$ for ③. Therefore the expected payoff is the same as in equation (A.46) in section A3.3.2(3).

B3.3 No information purchases

Antibiotic use without veterinarian oversight is not allowed under PR, and therefore the payoff from purchasing no information at information set ⑦ can be as given in equation (A.50)-2.

B3.4 Compare the expected payoffs from testing choices

Having established the expected payoffs associated with self-tests, veterinary services and no tests, we compare these payoffs. The farmer prefers the one resulting in the largest expected payoff.

B3.4.1 Low antibiotic cost: $b < b_1$

(1) When the veterinary service cost is low such that inequality (A.35) holds, the expected payoffs from choosing *C*, *Te* and *NTe, NC* are

$$V^{Te} = a - \beta(l_1 + b) - (1-\beta)l_2 - d - v; \quad \text{(A.74)}$$

$$V^{C} = a - \beta(l_1 + b) - (1-\beta)l_2 - v; \quad \text{(A.37)-1}$$

$$V^{NTe,NC} = a - l_3. \quad \text{(A.50)-2}$$

Te is dominated by *C*, and therefore we only need to compare payoffs from choosing *C* with *NTe, NC*. Given $b < b_1$, it follows that V^C is greater than $V^{NTe,NC}$. Therefore, the optimal testing decision here is *C*.

(2) When the veterinary service cost is high such that inequality (A.35) does not hold but inequality (A.72) holds, the expected payoff from choosing *Te* changes to

$$V^{Te} = a - \beta(l_1 + b + v) - (1-\beta)l_3 - d, \quad \text{(A.76)}$$

while payoffs from choosing other two choices *C* and *NTe, NC* are unchanged compared with (1). The optimal testing decision is *C* when the following condition set is satisfied,

$$\begin{cases} d > (1-\beta)(l_2 + v - l_3); \\ b < \frac{1}{\beta}\left[l_3 - (1-\beta)l_2 - v\right] - l_1. \end{cases} \quad \text{(A.77)}$$

The optimal testing decision is *Te* whenever

$$d < \min[(1-\beta)(l_2 + v - l_3), \beta(l_3 - l_1 - b - v)]. \quad \text{(A.78)}$$

The optimal testing decision is *NTe, NC* when the following condition pair is satisfied,

$$\begin{cases} d < \beta(l_3 - l_1 - b - v); \\ b > \frac{1}{\beta}\left[l_3 - (1-\beta)l_2 - v\right] - l_1. \end{cases} \quad \text{(A.79)}$$

(3) When the veterinary service cost is sufficiently high that inequalities (A.35) and (A.72) do not hold, while the payoffs from choosing *C* and *NTe, NC* are unchanged compared with (1), then the expected payoff from choosing *Te* changes to

$$V^{Te} = a - l_3 - d. \quad \text{(A.46)}$$

Te is dominated by *NTe, NC*, and therefore we only need to compare the payoffs from choosing *C* with *NTe, NC*. The optimal testing decision is *C* whenever

$$b < \frac{1}{\beta}\left[l_3 - (1-\beta)l_2 - v\right] - l_1. \quad \text{(A.80)}$$

Given $b < b_1$ and also that inequality (A.35) is violated, then (A.80) does not hold. Therefore, *C* is not optimal in this case. The optimal testing decision is *NTe, NC*.

B3.4.2 Medium or high antibiotic cost: $b > b_1$

(1) When the veterinary service cost is low such that inequality (A.35) holds, then the expected payoffs from choosing *C*, *Te* and *NTe, NC* are

$$V^{Te} = a - l_2 - v - d; \quad \text{(A.44)}$$

$$V^{C} = a - l_2 - v; \quad \text{(A.37)-2}$$

$$V^{NTe,NC} = a - l_3. \quad \text{(A.50)-2}$$

Te is dominated by *C*. Given that inequality (A.35) holds, V^{C} is greater than $V^{NTe,NC}$. Thus the optimal testing decision is *C*.

(2) When the veterinary service cost is high such that inequality (A.35) does not hold, while the payoffs from choosing *C* and *NTe, NC* are unchanged compared with (1), the expected payoff from choosing *Te* changes to

$$V^{Te} = a - l_3 - d. \tag{A.46}$$

Te is dominated by *NTe, NC*. Given that inequality (A.35) does not hold, it follows that V^{C} is less than $V^{NTe,NC}$. Thus the optimal testing decision is *NTe, NC*.

B4 Summary of optimal strategies under PR

There are four possible optimal strategies under PR. Note that strategies S3-S5 have been defined as optimal strategies without regulations, see Section A4, while S7 is a new strategy.

S3: Neither call a veterinarian nor perform a self-test at information set ①, never treat with antibiotics at information set ⑦

S4: Call a veterinarian at information set ①, in type *E* infection cases treat with antibiotics (at information set ④), in type *I* infection cases do not treat with antibiotics (at information set ⑩)

S5: Call a veterinarian at information set ①, do not treat with antibiotics at information sets ④ and ⑩

S7: Self-test at information set ①, in type *E* infection cases call a veterinarian (at information set ②) and treat with antibiotics (at information set ⑤), in type *I* infection cases neither call a veterinarian (at information set ③) nor treat with antibiotics (at information set ⑨)

We summarize and organize the conditions on cost parameters under which each strategy is optimal. The conditions under which S3-S5 and S7 are satisfied are as follows:

$$(S3)\quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b < l_3 - l_1 - v \\ d > \beta(l_3 - l_1 - b - v) \\ b > \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \text{ or } \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b > l_3 - l_1 - v \\ b > \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \text{ or } \begin{cases} v > l_3 - l_2 \\ b > l_2 - l_1 \end{cases} \quad (A.81)$$

$$(S4)\quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b < l_3 - l_1 - v \\ d > (1-\beta)(l_2 + v - l_3) \\ b < \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \text{ or } \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b > l_3 - l_1 - v \\ b < \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \text{ or } \begin{cases} v < l_3 - l_2 \\ b < l_2 - l_1 \end{cases} \quad (A.82)$$

$$(S5)\quad \begin{cases} v < l_3 - l_2 \\ b > l_2 - l_1 \end{cases} \quad (A.83)$$

$$(S7)\quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b < l_3 - l_1 - v \\ d < (1-\beta)(l_2 + v - l_3) \\ d < \beta(l_3 - l_1 - b - v) \end{cases} \quad (A.84)$$

B5 Explanations for optimal strategies depicted in Figure 6-Figure 8

Figure 6 illustrates the farmer's optimal strategies under PR when the veterinary service cost is sufficiently high that veterinary services are not preferred before PR is implemented. However, under the same cost parameters, the PR-constrained farmer may prefer veterinary services. This is because PR disproportionately favors information through a veterinarian and induces farmers to substitute away from self-test information. Three dashed lines divide the *b*-*d* plane into three areas: (1) When antibiotics are inexpensive but the self-test cost is high, the farmer prefers to call a veterinarian directly and then use antibiotics according to the prescription (S4). As self-tests become cheaper, the farmer's optimal strategy changes to performing a self-test, then calling a veterinarian and using antibiotics in type E infection cases and taking no actions in type I infection cases (S7). The boundary condition under which the optimal strategy changes from S4 to S7 is $d = (1-\beta)(l_2 + v - l_3)$, see the horizontal line in Figure 6. This boundary condition suggests that self-tests are chosen whenever the cost is less than the benefit from induced heterogeneous veterinary service decisions; otherwise calling a veterinarian directly is in the farmer's best interest.

(2) When antibiotics and self-tests are both expensive (see right-upper area in the figure), then the farmer prefers to neither purchase information nor treat absent information (S3). As antibiotic cost decreases, the optimal strategy changes from taking no actions (S3) to informed antibiotic administrations following S4. The switch happens whenever expected cost of actions, $v + \beta b$, is outweighed by the associated expected loss reduction, $l_3 - (1-\beta)l_2 - \beta l_1$. The boundary condition is depicted as the vertical line in Figure 6.

(3) Consider a situation when the farmer takes strategy S7. As antibiotic cost increases, the farmer's optimal strategy changes from informed antibiotic administrations following S7 to taking no actions (S3). The switch happens whenever expected cost of actions, $d + \beta(v+b)$, exceeds the respective expected loss reduction, $\beta(l_3 - l_1)$. This boundary condition is depicted as the downward sloping line in Figure 6.

Figure 7 illustrates the farmer's optimal strategies under PR when self-test cost is sufficiently high that self-tests are not preferred under constraints placed by PR. Three dashed lines divide the b-v plane into three areas:

(1) When antibiotics and veterinary services are inexpensive, the farmer prefers to call a veterinarian and then administer antibiotics according to the prescription (S4). As antibiotic cost increases, the farmer substitutes alternative treatments in for antibiotic treatment so that she calls a veterinarian but does not administer antibiotics at all (S5). The farmer's optimal strategies changes

from S4 to S5 when additional antibiotic cost, b, exceeds the additional loss reduction, $l_2 - l_1$. The boundary condition is depicted as the vertical line in Figure 7.

(2) Consider now the left-bottom area where antibiotics and veterinary services are inexpensive. Then the farmer prefers strategy S4. As veterinary service cost increases, the farmer's optimal strategy changes to neither purchasing information nor administering antibiotics (S3). The boundary condition, which is depicted as the downward sloping line, has been examined when explaining Figure 6.

(3) Consider the right-bottom area where antibiotic cost is high but veterinary services are inexpensive. In this area the farmer prefers strategy S5. As veterinary service cost increases, the farmer's optimal strategy changes to S3 whenever veterinary service cost, v, exceeds the loss reduction by veterinary services, $l_3 - l_2$. The boundary condition is depicted as the horizontal line in Figure 7.

Figure 8 illustrates the farmer's optimal choices under PR given low antibiotic cost. Three dashed lines divide the d-v plane into three areas:

(1) Consider a situation where self-tests are inexpensive but veterinary services are profit-increasing whenever in type E infection cases. Then the farmer prefers to use cheap self-test information to guide veterinary service decisions. That is, the farmer prefers to perform a self-test, and then call a veterinarian and administer antibiotics if and only if the self-test reveals E (S7). As veterinary service cost decreases, the farmer's optimal strategy changes to calling a veterinarian and then using antibiotics according to professional advice (S4) when expected cost saving derived from self-test information, $(1-\beta)v - d$, exceeds the additional expected loss due to the savings, $(1-\beta)(l_3 - l_2)$. The boundary is depicted as the upward sloping line in Figure 8.

(2) Consider again a situation where the farmer prefers S7. As veterinary service cost increases, the farmer's optimal strategy changes to neither purchasing information nor administering antibiotics

(S3). The switching condition, which is depicted as the downward sloping line, has been discussed when considering Figure 6.

(3) When self-test cost is high but veterinary services are inexpensive, the farmer prefers to call a veterinarian and make informed antibiotic administration decisions (S4). As veterinary service cost increases, the farmer's optimal strategies changes to S3. This boundary condition, which is depicted as the horizonal line, has been addressed when discussing Figure 6.

C Figures

To illustrate how farmer's disease management decisions are determined by key parameters in our model (i.e., self-test cost, veterinary service cost, and antibiotic cost), we graph the optimal strategies each time, holding one cost parameter among (b, d, v) fixed. C1-C3 summarize the optimal strategies in the b-d, b-v and d-v planes correspondingly. C4 summarizes comparisons between unregulated private strategies and social optimum. C5-C7 summarize the optimal strategies under PR in the b-d, b-v and d-v planes correspondingly. Within each section, we investigate how optimal strategy outcomes vary with cost parameters. To assess the impact of PR on the farmer's optimal strategies, we compare the privately optimal strategies without and with PR in C8-C10 in the b-d, b-v and d-v planes correspondingly and compare the privately optimal strategies under PR with social optimum in C11.

C1 Farmer's optimal strategies without PR in the b-d plane

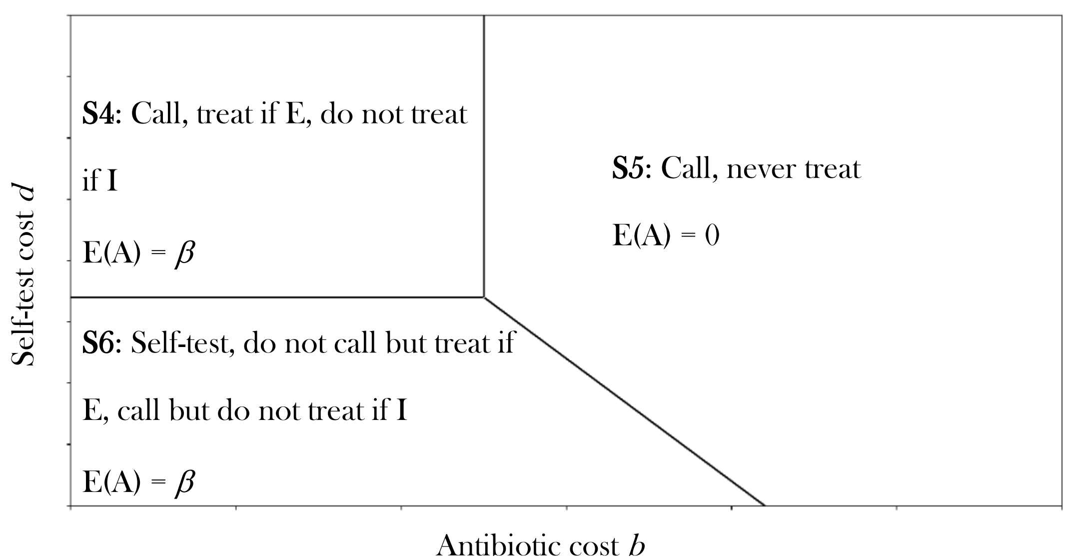

Figure C-1 Farmer's optimal strategies in the b-d plane given low veterinary service cost $v < (1-\beta)(l_3 - l_2)$.

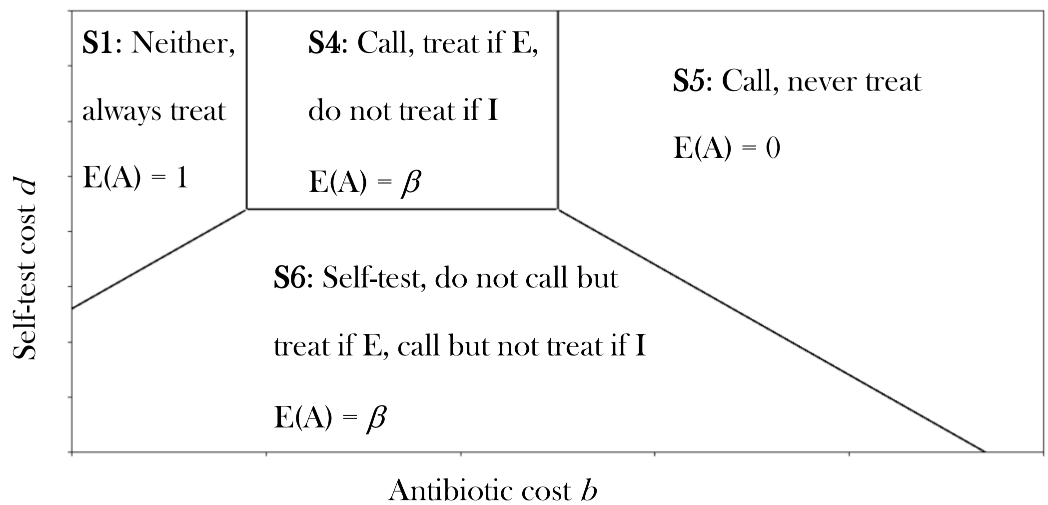

Figure C-2 Farmer's optimal strategies in the *b*-*d* plane given lower medium veterinary service cost $(1-\beta)(l_3-l_2) < v < (1-\beta)(l_3-l_1)$.

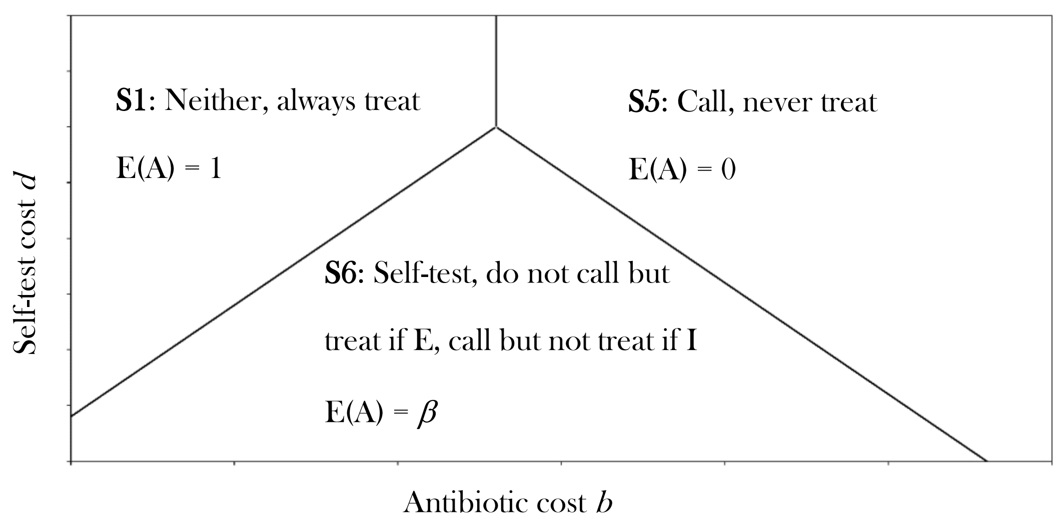

Figure C-3 Farmer's optimal strategies in the *b*-*d* plane given upper medium veterinary service cost $(1-\beta)(l_3-l_1) < v < l_3-l_2$.

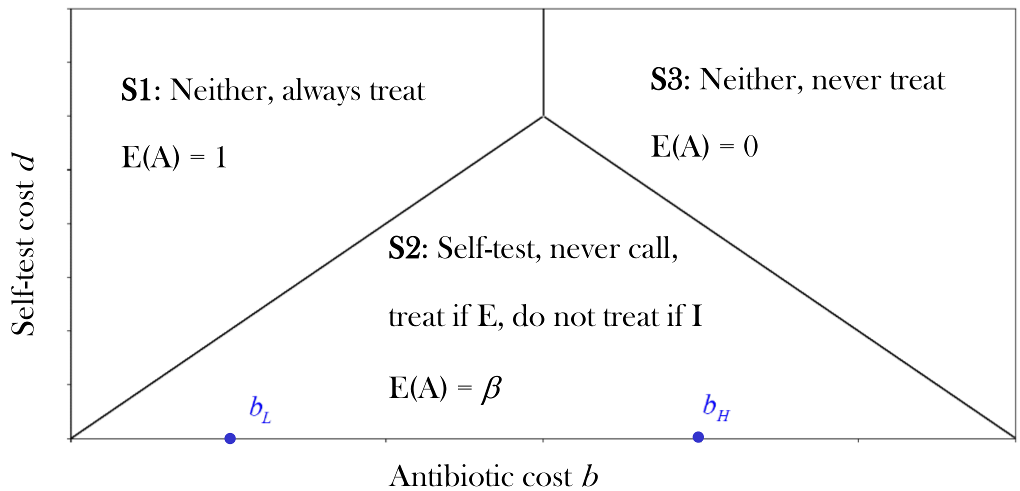

Figure C-4 Farmer's optimal strategies in the *b*-*d* plane given high veterinary service cost $v > l_3 - l_2$.

C2 Farmer's optimal strategies without PR in the *b*-*v* plane

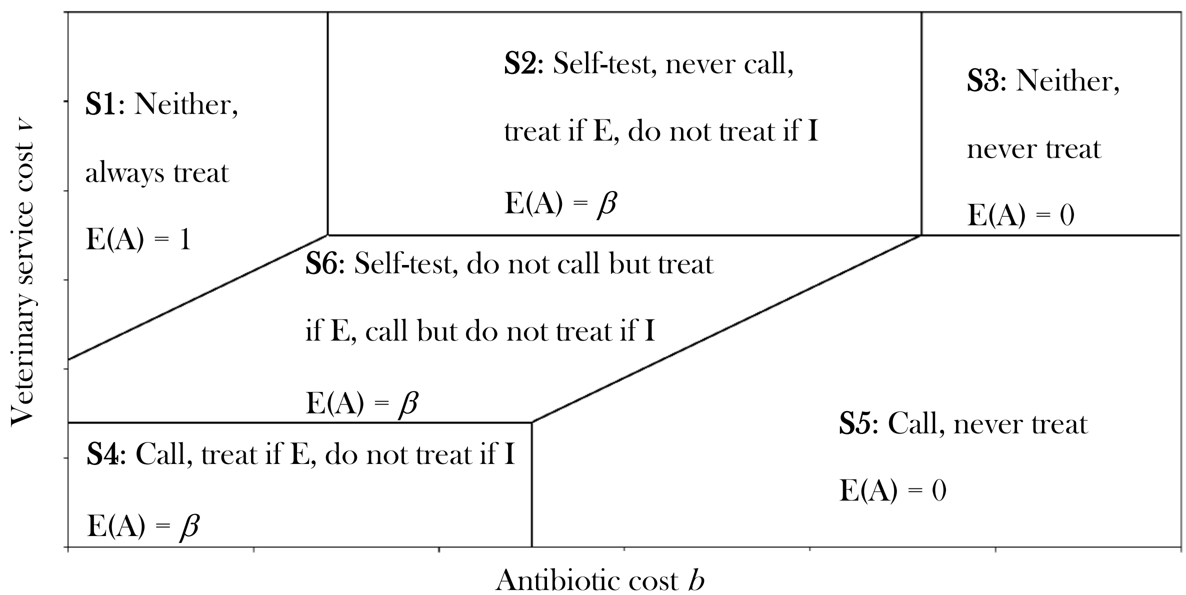

Figure C-5 Farmer's optimal strategies in the *b*-*v* plane given low self-test cost $d < \beta(1-\beta)(l_3 - l_1)$.

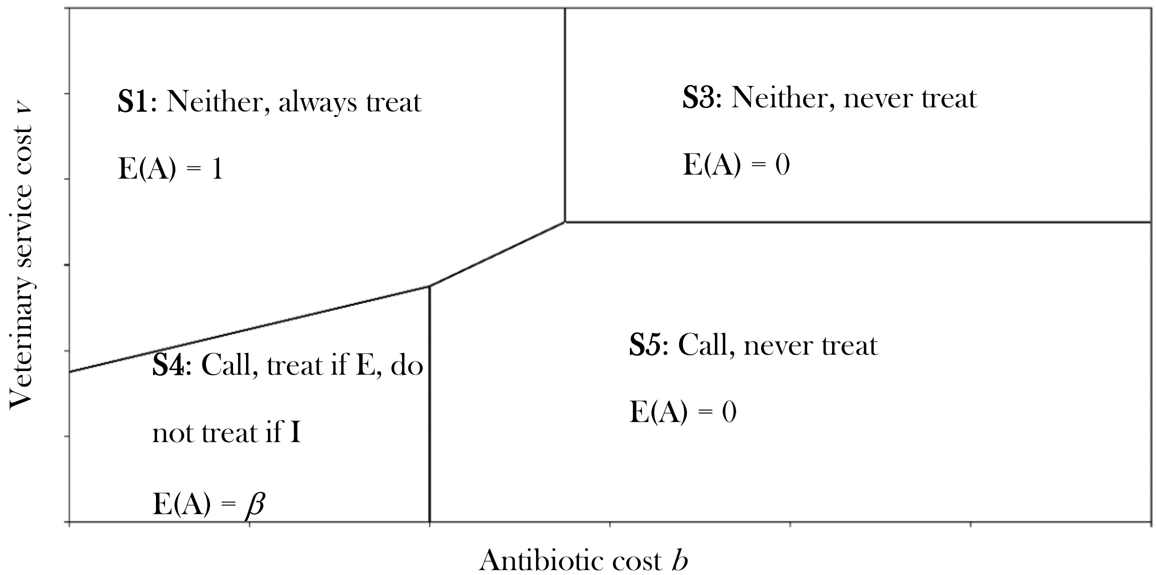

Figure C-6 Farmer's optimal strategies in the b-v plane given high self-test cost $d > \beta(1-\beta)(l_3 - l_1)$.

C3 Farmer's optimal strategies without PR in the d-v plane

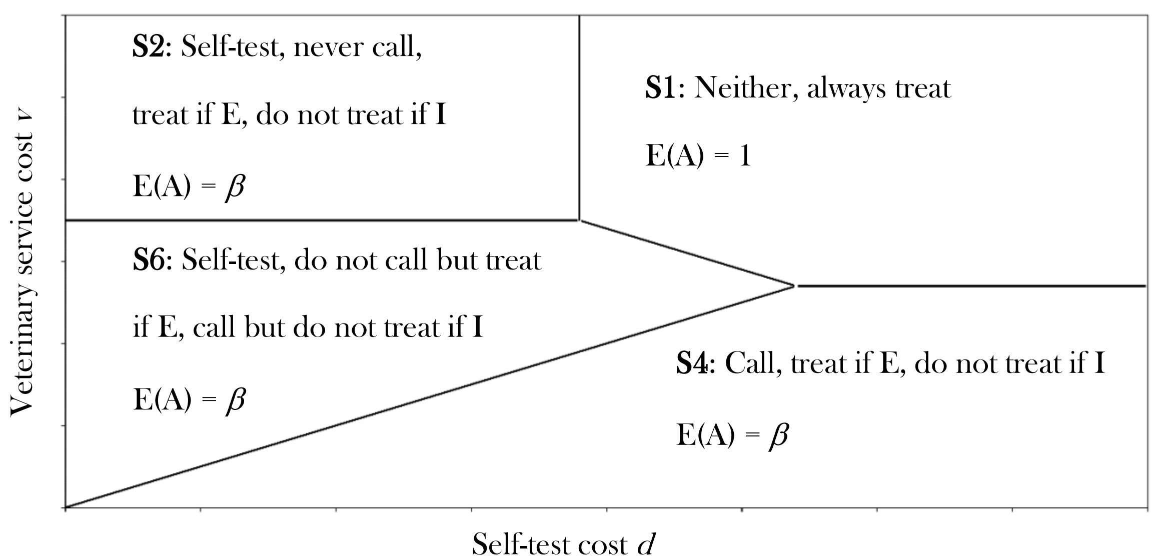

Figure C-7 Farmer's optimal strategies in the d-v plane given low antibiotic cost $b < l_2 - l_1$.

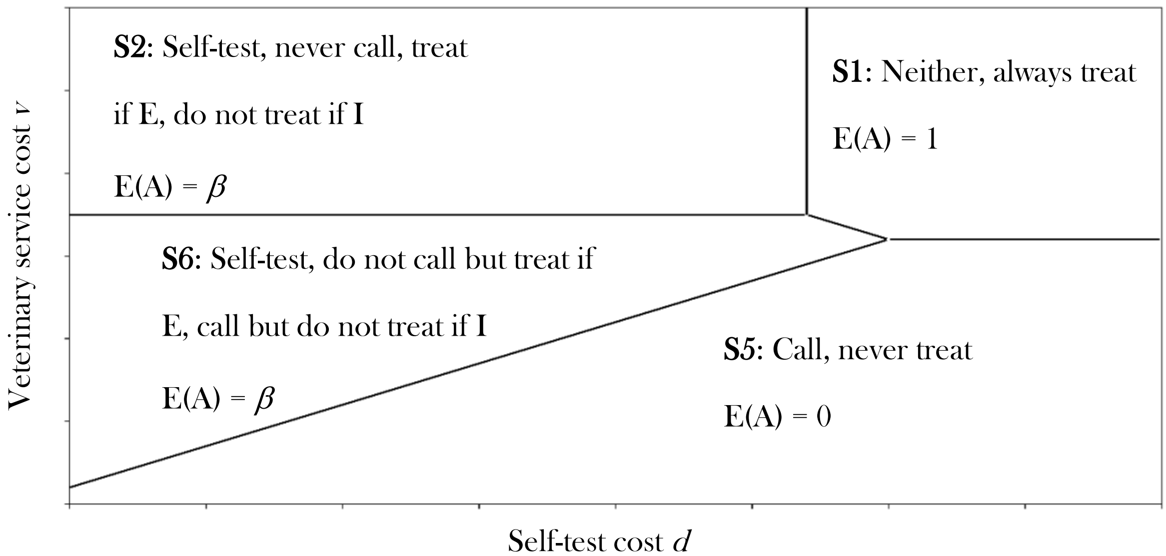

Figure C-8 Farmer's optimal strategies in the *d*-*v* plane given lower medium antibiotic cost $l_2 - l_1 < b < \beta(l_3 - l_1)$.

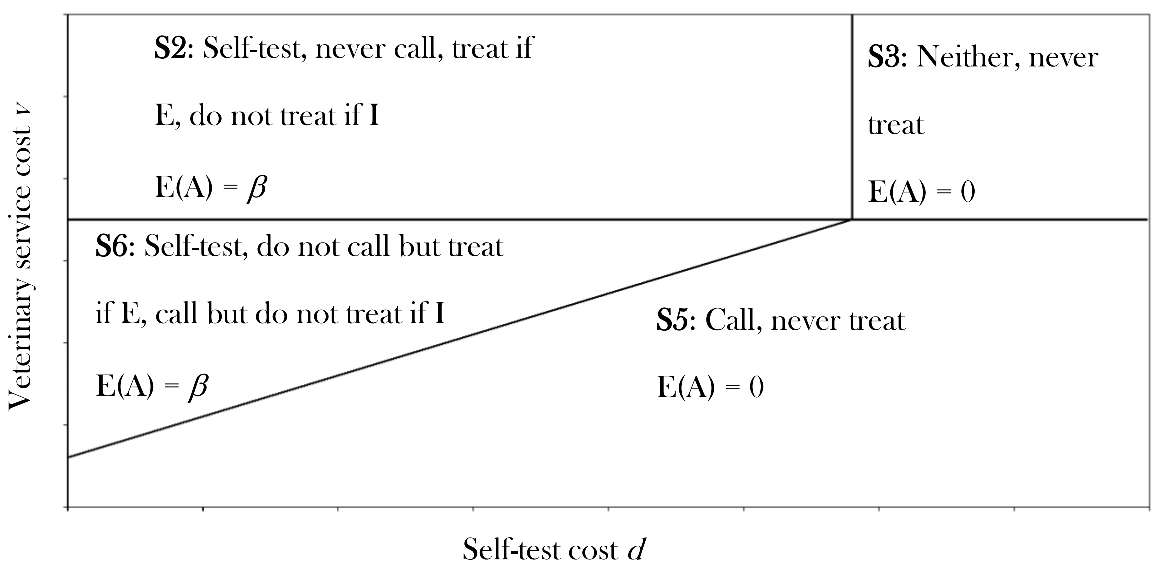

Figure C-9 Farmer's optimal strategies in the *d*-*v* plane given upper medium antibiotic cost $\beta(l_3 - l_1) < b < l_3 - l_1$.

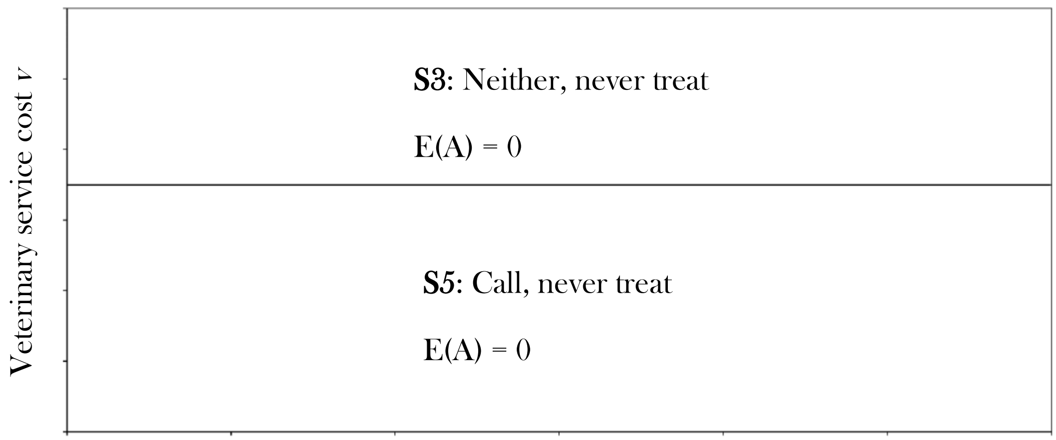

Figure C-10 Farmer's optimal strategies in the *d*-*v* plane given high antibiotic cost.

C4 Compare privately optimal decisions with socially optimal decisions

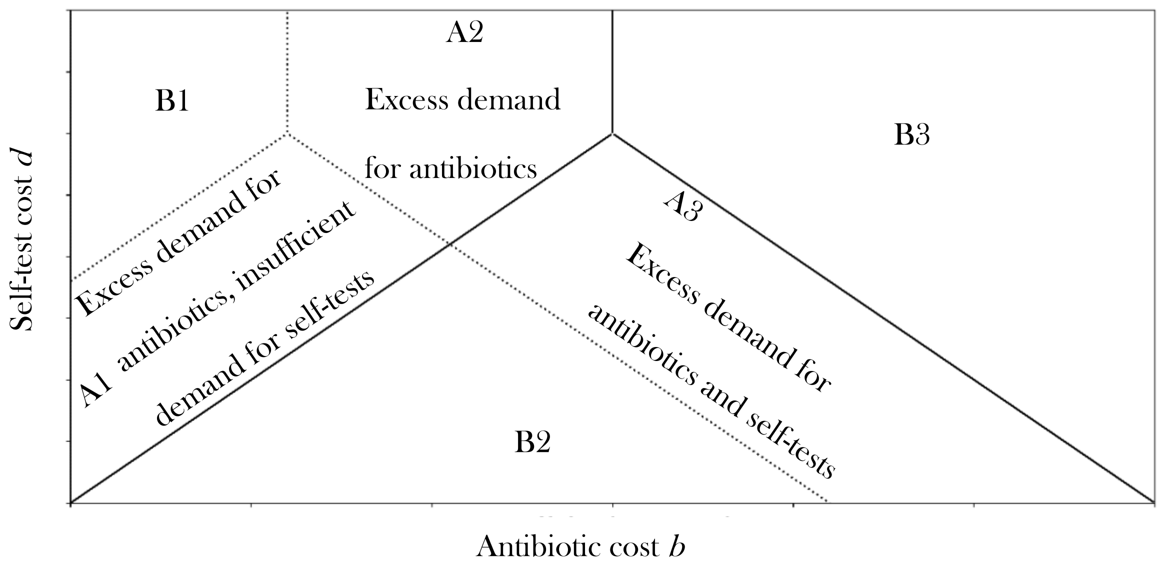

Figure C-11 Comparison between farmer's optimal strategies and social optimum in the b-d plane given high veterinary service cost $v > l_3 - l_2$

Area	Farmer's optimal strategies	Social optimum
A1	**S1**: Neither call nor self-test, always treat	**S2**: Self-test, never call, treat if *E*, do not treat if *I*
A2	**S1**: Neither call nor self-test, always treat	**S3**: Neither call nor self-test, never treat
A3	**S2**: Self-test, never call, treat if *E*, do not treat if *I*	**S3**: Neither call nor self-test, never treat
B1	**S1**: Neither call nor self-test, always treat	Same
B2	**S2**: Self-test, never call, treat if *E*, do not treat if *I*	Same
B3	**S3**: Neither call nor self-test, never treat	Same

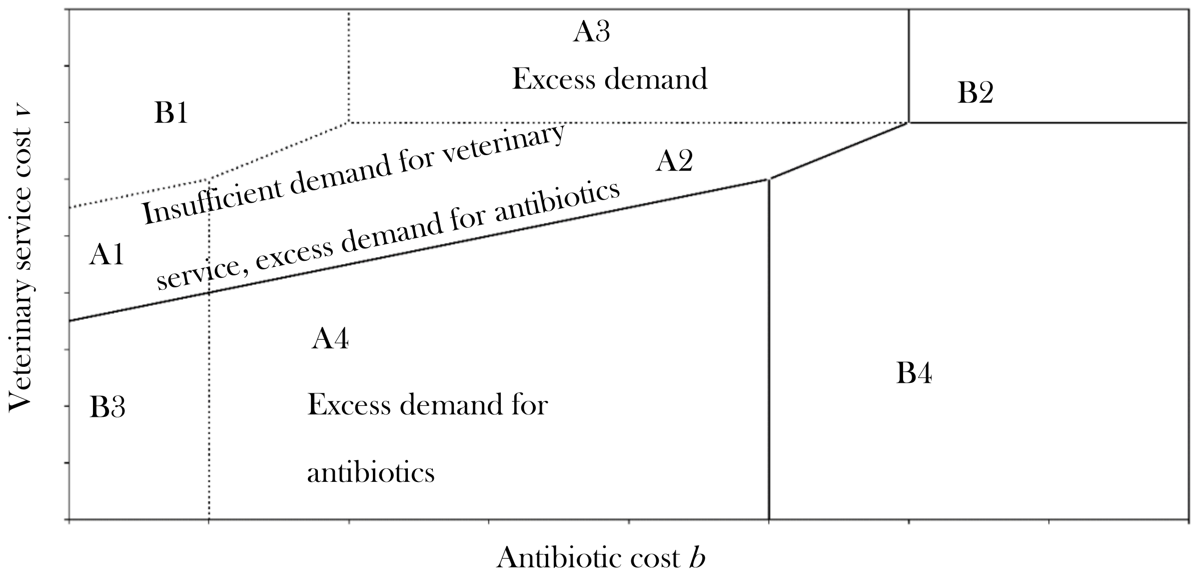

Figure C-12 Comparison between farmer's optimal strategies and social optimum in the *b-v* plane given high self-test cost $d > \beta(1-\beta)(l_3 - l_1)$

Area	**Farmer's optimal strategies**	**Social optimum.**
A1	**S1**: Neither call nor self-test, always treat	**S4**: Call, treat if *E*, do not treat if *I*
A2	**S1**: Neither call nor self-test, always treat	**S5**: Call, never treat
A3	**S1**: Neither call nor self-test, always treat	**S3**: Neither call nor self-test, never treat
A4	**S4**: Call, treat if *E*, do not treat if *I*	**S5**: Call, never treat
B1	**S1**: Neither call nor self-test, always treat	Same
B2	**S3**: Neither call nor self-test, never treat	Same
B3	**S4**: Call, treat if *E*, do not treat if *I*	Same
B4	**S5**: Call, never treat	Same

C5 Farmer's optimal strategies under PR in the *b*-*d* plane

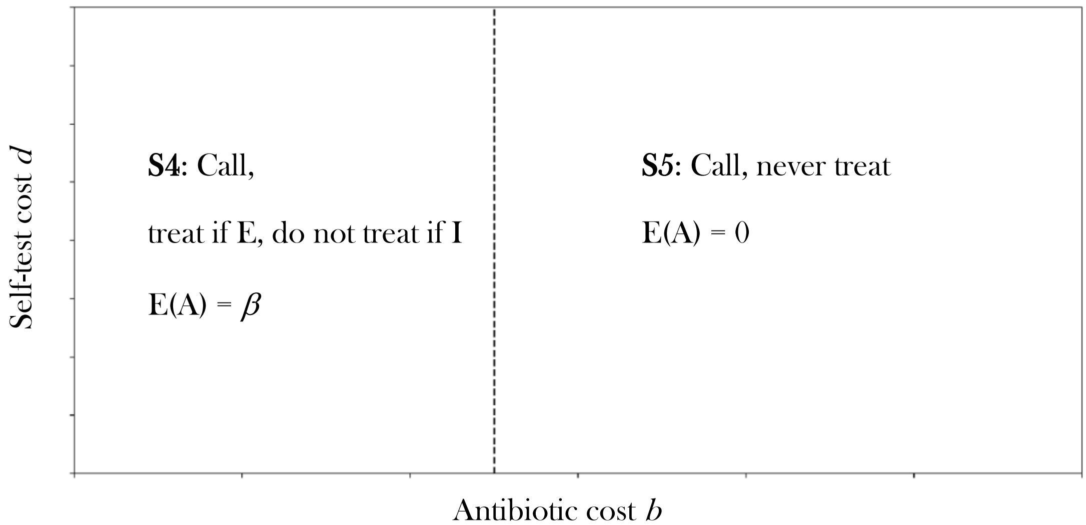

Figure C-13 Farmer's optimal strategies under PR in the *b*-*d* plane given low veterinary service cost $v < l_3 - l_2$.

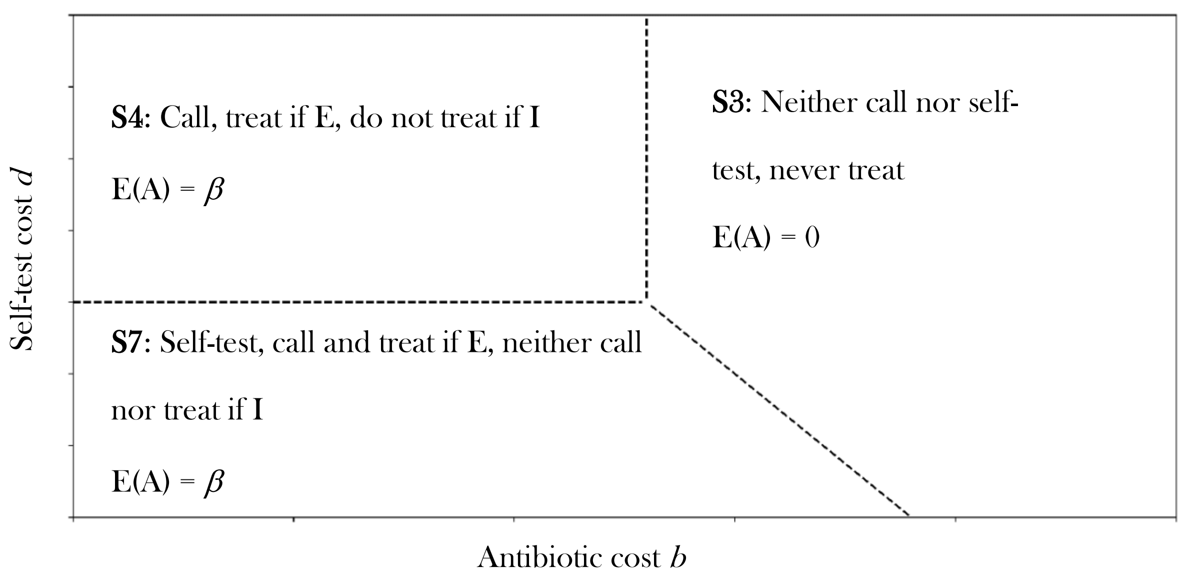

Figure C-14 Farmer's optimal strategies under PR in the *b*-*d* plane given lower medium veterinary service cost $l_3 - l_2 < v < l_3 - \beta l_1 - (1-\beta) l_2$.

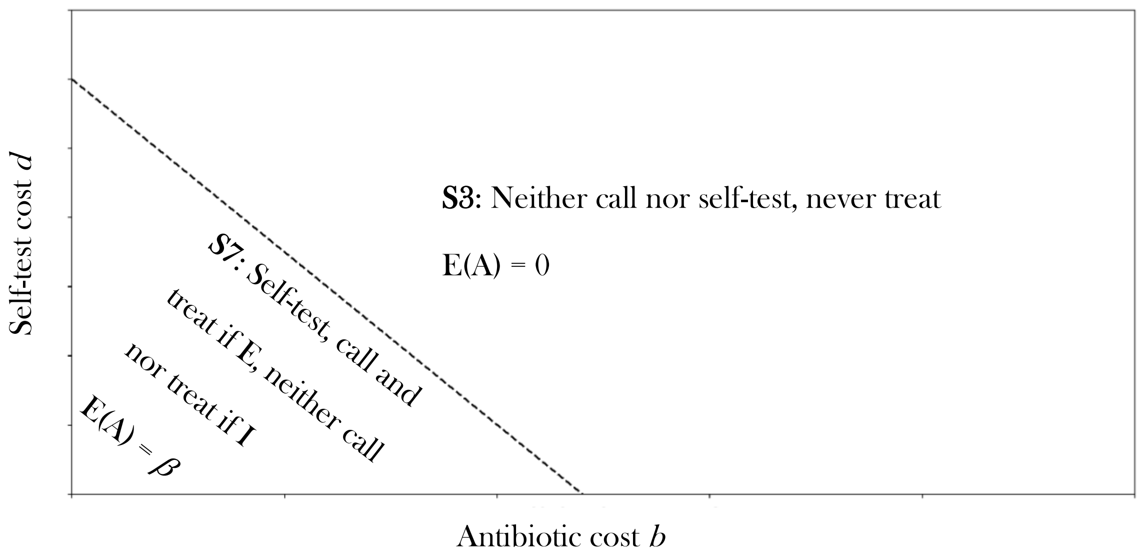

Figure C-15 Farmer's optimal strategies under PR in the *b*-*d* plane given upper medium veterinary service cost $l_3 - \beta l_1 - (1-\beta) l_2 < v < l_3 - l_1$.

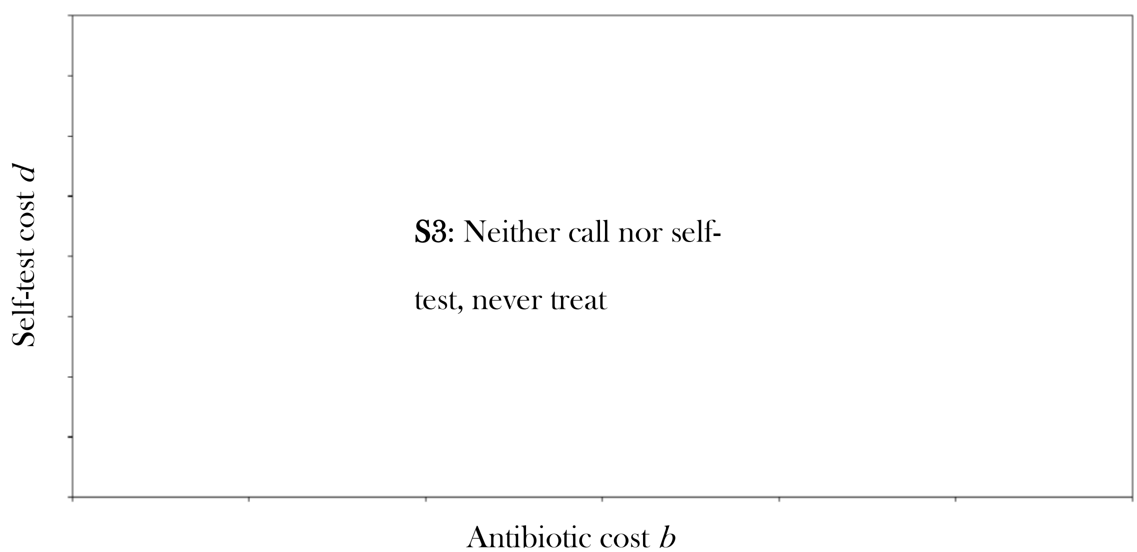

Figure C-16 Farmer's optimal strategies under PR in the *b*-*d* plane given high veterinary service cost $v > l_3 - l_1$.

C6 Farmer's optimal strategies under PR in the b-v plane

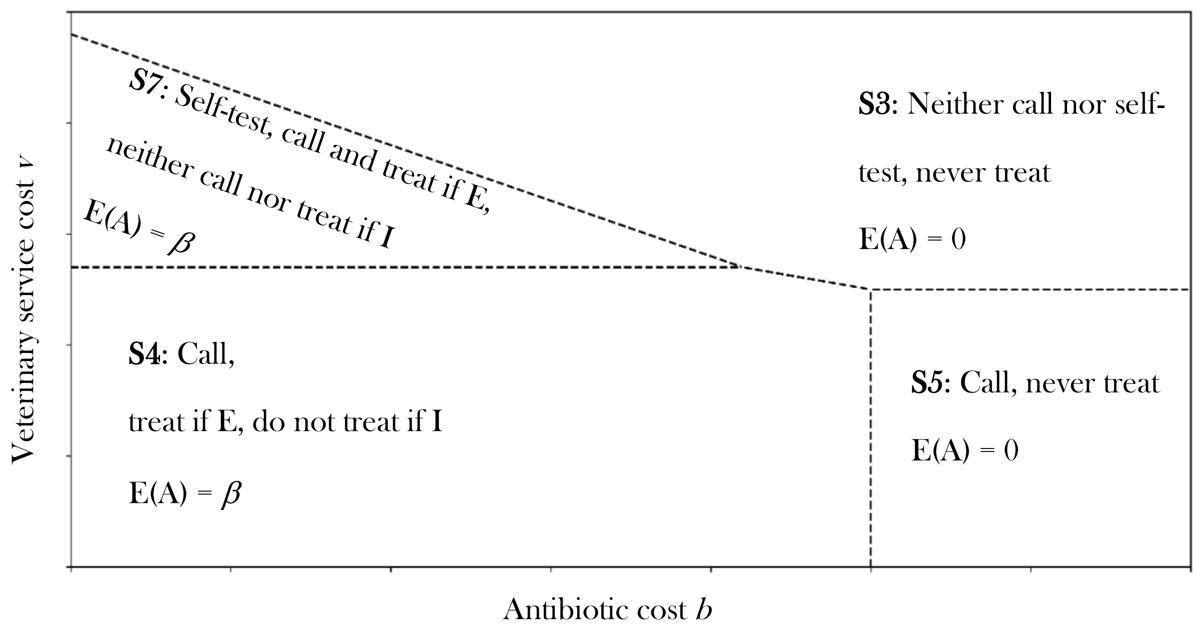

Figure C-17 Farmer's optimal strategies under PR in the b-v plane given low self-test cost $d < \beta(1-\beta)(l_2 - l_1)$.

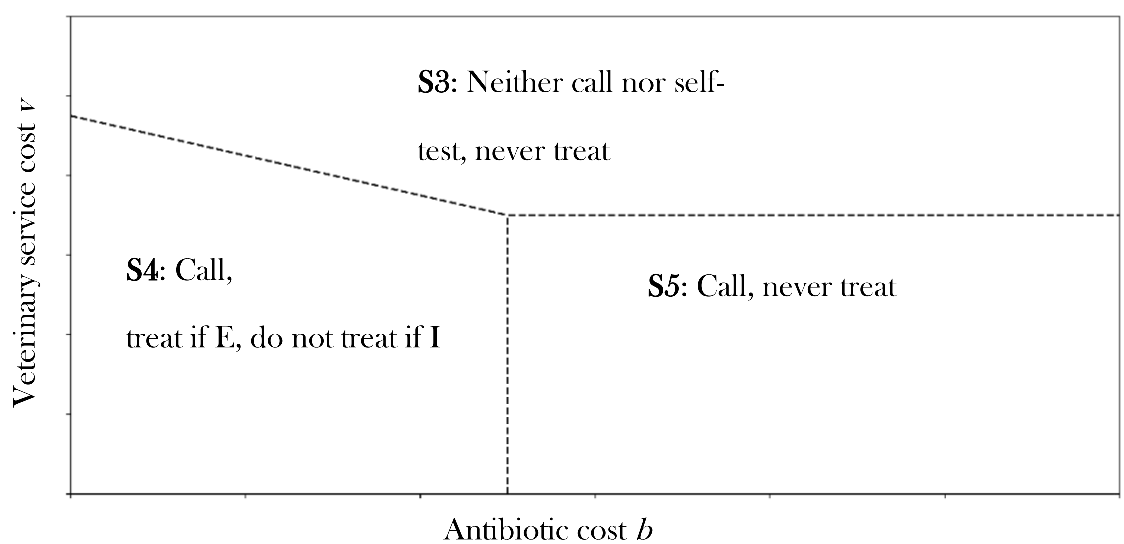

Figure C-18 Farmer's optimal strategies under PR in the b-v plane given high self-test cost $d > \beta(1-\beta)(l_2 - l_1)$.

C7 Farmer's optimal strategies under PR in the d-v plane

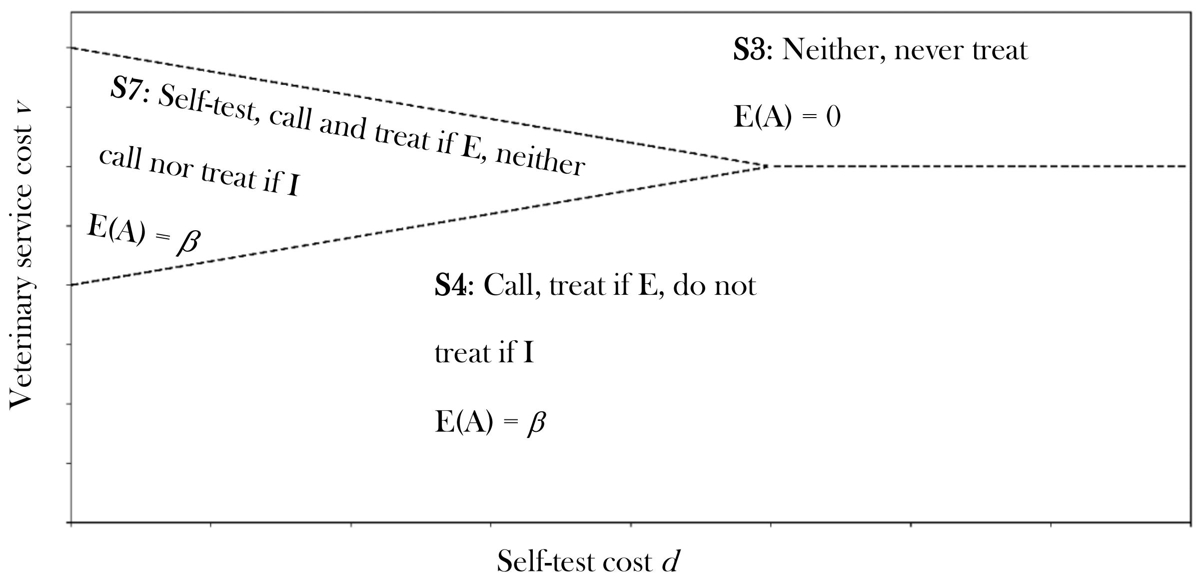

Figure C-19 Farmer's optimal strategies under PR in the d-v plane given low antibiotic cost such that $b < l_2 - l_1$.

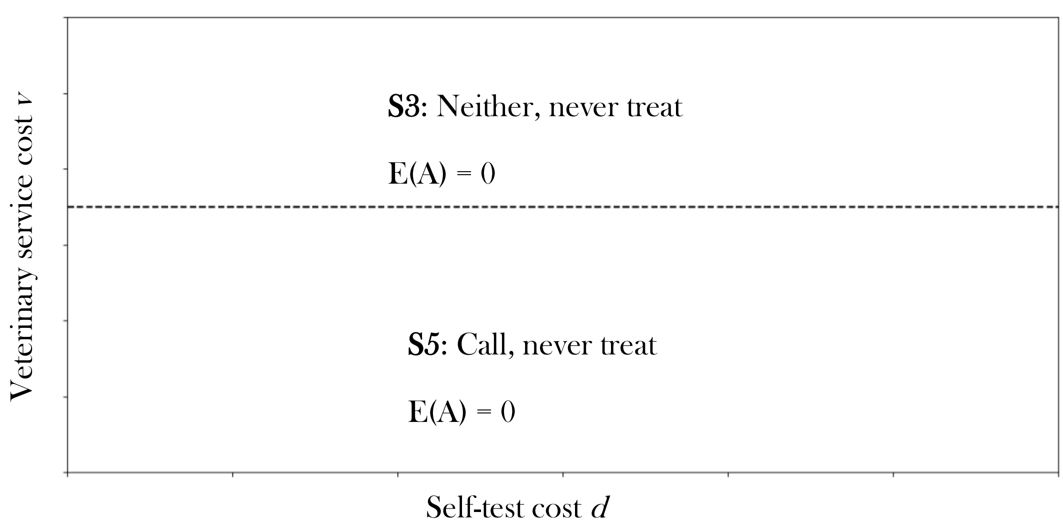

Figure C-20 Farmer's optimal strategies under PR in the d-v plane given high antibiotic cost $b > l_2 - l_1$.

C8 Compare farmer's optimal strategies without and with PR in the *b*-*d* plane

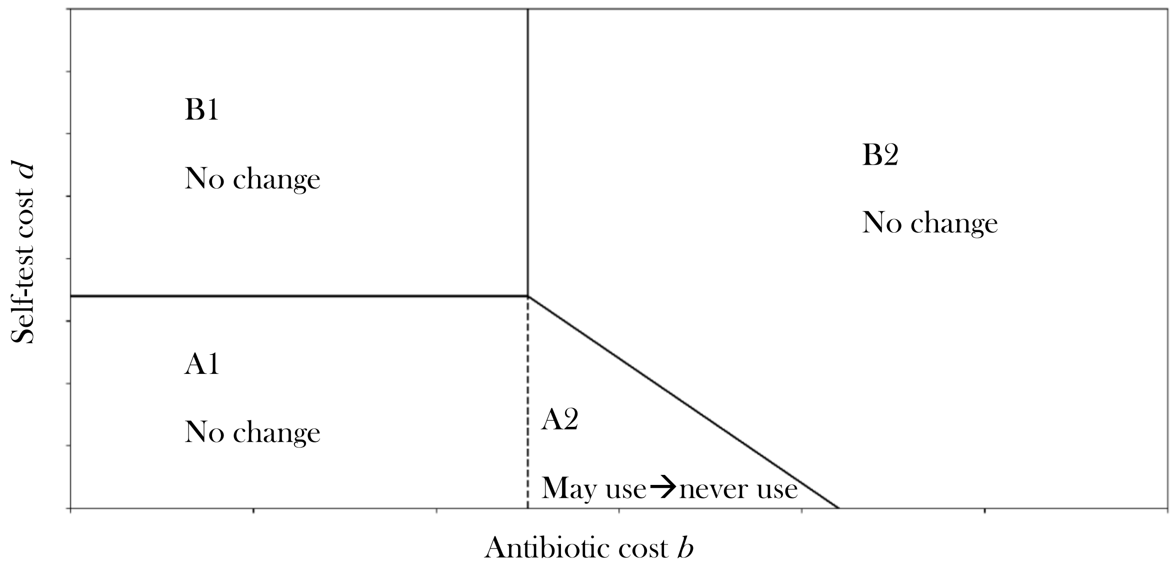

Figure C-21 Comparison between farmer's optimal strategies with and without PR in the *b*-*d* plane when veterinary service cost satisfies $v < (1-\beta)(l_3 - l_2)$.

	Without PR	**Under PR**
A1	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, treat if *E*, do not treat if *I*
A2	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, never treat
B1	Call, treat if *E*, do not treat if *I*	Same
B2	Call, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

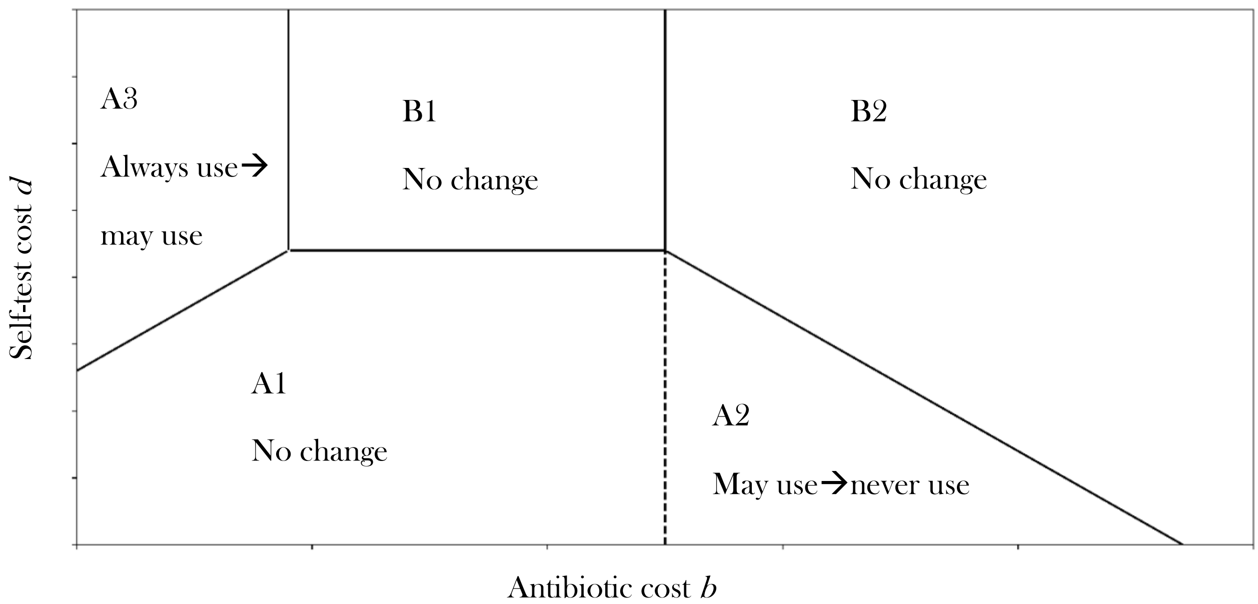

Figure C-22 Comparison between farmer's optimal strategies with and without PR in the *b*-*d* plane when veterinary service cost satisfies $(1-\beta)(l_3-l_2)<v<(1-\beta)(l_3-l_1)$.

	Without PR	**Under PR**
A1	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, treat if *E*, do not treat if *I*
A2	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, never treat
A3	Neither, always treat	Call, treat if *E*, do not treat if *I*
B1	Call, treat if *E*, do not treat if *I*	Same
B2	Call, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

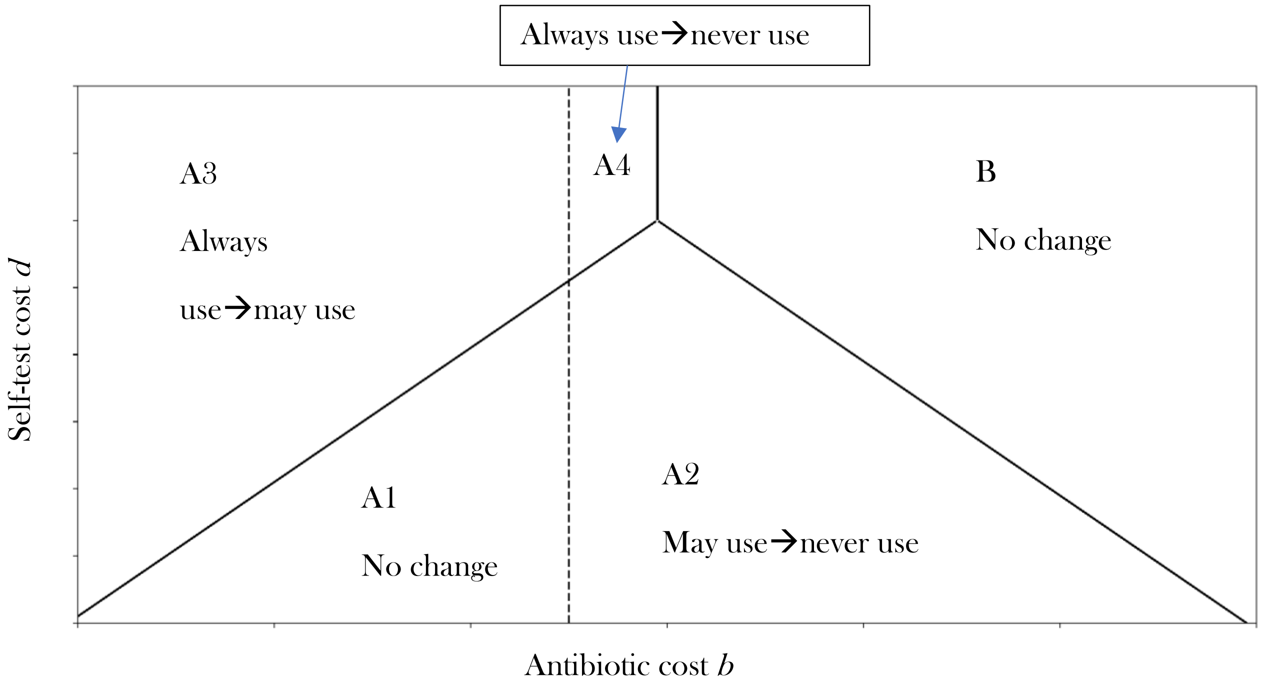

Figure C-23 Comparison between farmer's optimal strategies with and without PR in the *b*-*d* plane when veterinary service cost satisfies $(1-\beta)(l_3 - l_1) < v < l_3 - l_2$.

	Without PR	**Under PR**
A1	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, treat if *E*, do not treat if *I*
A2	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, never treat
A3	Neither, always treat	Call, treat if *E*, do not treat if *I*
A4	Neither, always treat	Call, never treat
B	Call, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

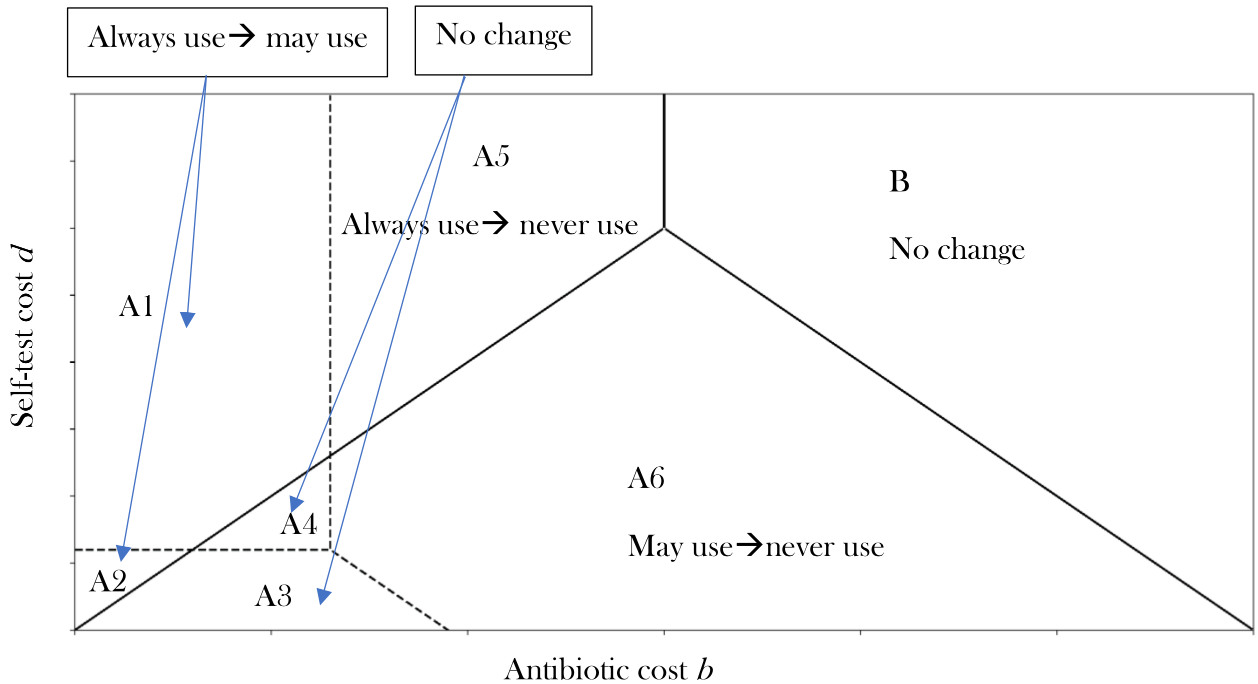

Figure C-24 Comparison between farmer's optimal strategies without and with PR in the *b*-*d* plane when veterinary service cost satisfies $l_3 - l_2 < v < l_3 - \beta l_1 - (1-\beta) l_2$.

	Without PR	**Under PR**
A1	Neither, always treat	Call, treat if *E*, do not treat if *I*
A2	Neither, always treat	Self-test, call and treat if *E*, neither call nor treat if *I*
A3	Self-tests, never call, treat if *E*, do not treat if *I*	Self-test, call and treat if *E*, neither call nor treat if *I*
A4	Self-tests, never call, treat if *E*, do not treat if *I*	Call, treat if *E*, do not treat if *I*
A5	Neither, always treat	Neither, never treat
A6	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
B	Neither, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

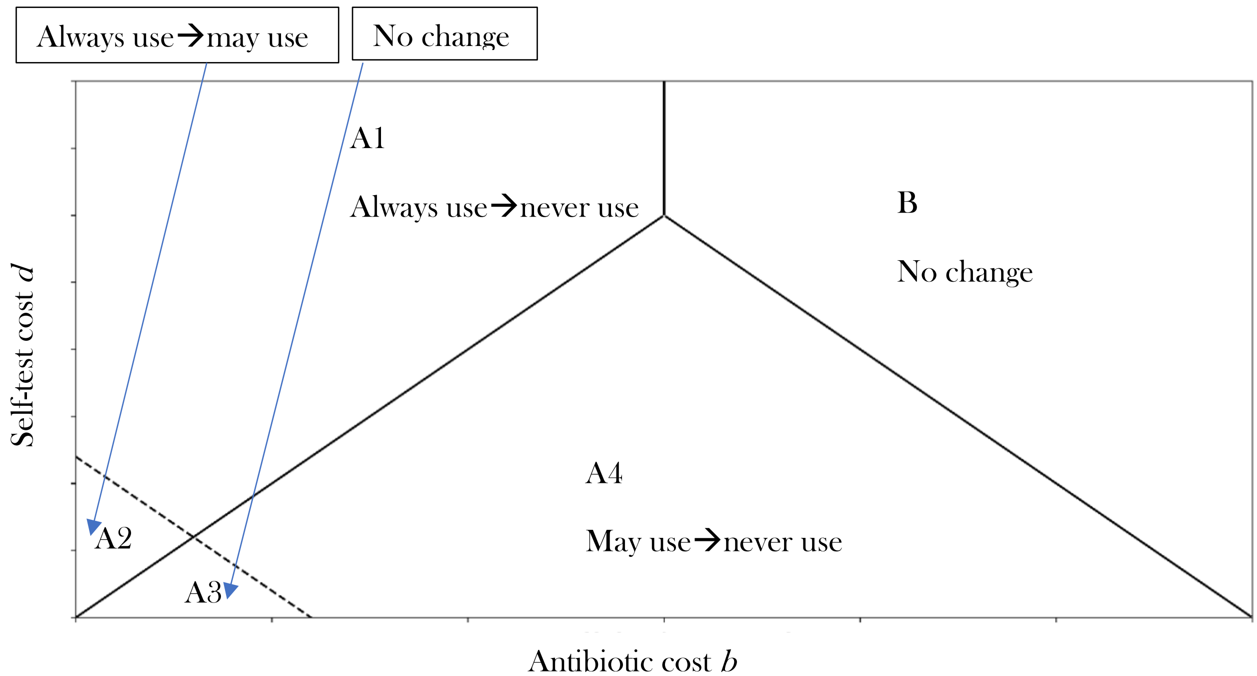

Figure C-25 Comparison between farmer's optimal strategies without and with PR in the *b-d* plane when veterinary service cost satisfies $l_3 - \beta l_1 - (1-\beta) l_2 < v < l_3 - l_1$.

	Without PR	**Under PR**
A1	Neither, always treat	Neither, never treat
A2	Neither, always treat	Self-test, call and treat if *E*, neither call nor treat if *I*
A3	Self-tests, never call, treat if *E*, do not treat if *I*	Self-test, call and treat if *E*, neither call nor treat if *I*
A4	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
B	Neither, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

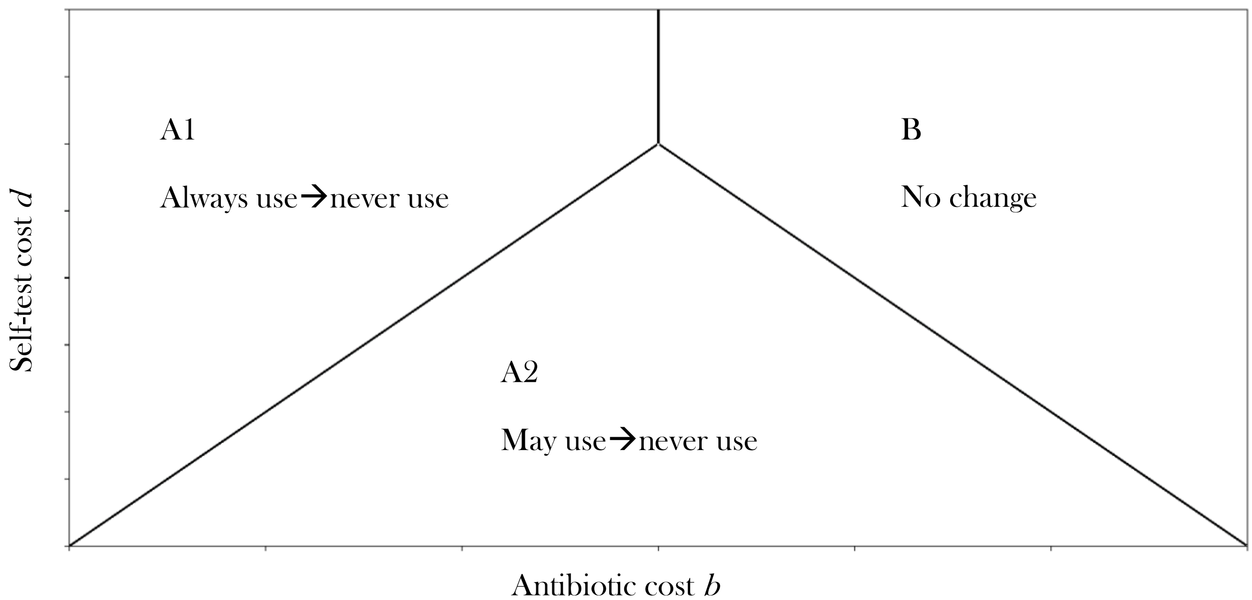

Figure C-26 Comparison between farmer's optimal strategies without and with PR in the *b-d* plane when veterinary service cost satisfies $v > l_3 - l_1$.

	Without PR	**Under PR**
A1	Neither, always treat	Neither, never treat
A2	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
B	Neither, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

C9 Compare farmer's optimal strategies without and with PR in the *b-v* plane

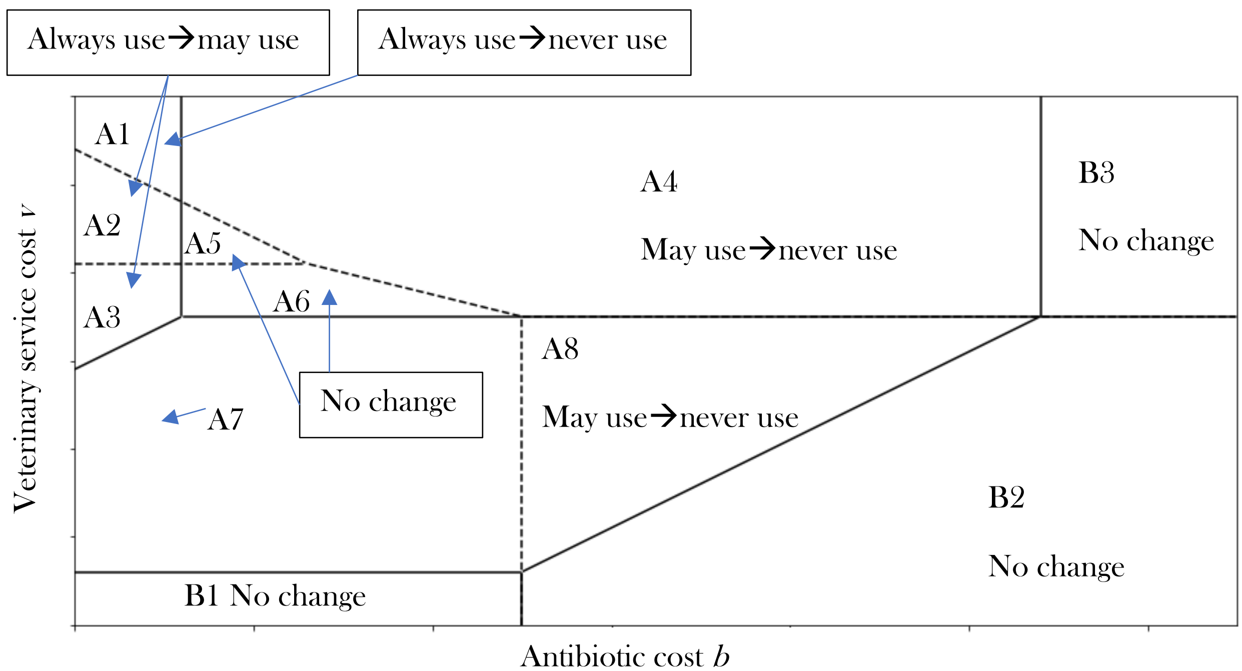

Figure C-27 Comparison between farmer's optimal strategies without and with PR in the *b*-*v* plane when self-test cost satisfies $d < \beta(1-\beta)(l_2 - l_1)$.

	Without PR	**Under PR**
A1	Neither, always treat	Neither, never treat
A2	Neither, always treat	Self-test, call and treat if *E*, neither call nor treat if *I*
A3	Neither, always treat	Call, treat if *E*, do not treat if *I*
A4	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
A5	Self-tests, never call, treat if *E*, do not treat if *I*	Self-test, call and treat if *E*, neither call nor treat if *I*
A6	Self-tests, never call, treat if *E*, do not treat if *I*	Call, treat if *E*, do not treat if *I*
A7	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, treat if *E*, do not treat if *I*
A8	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, never treat
B1	Call, treat if *E*, do not treat if *I*	Same
B2	Call, never treat	Same
B3	Neither, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

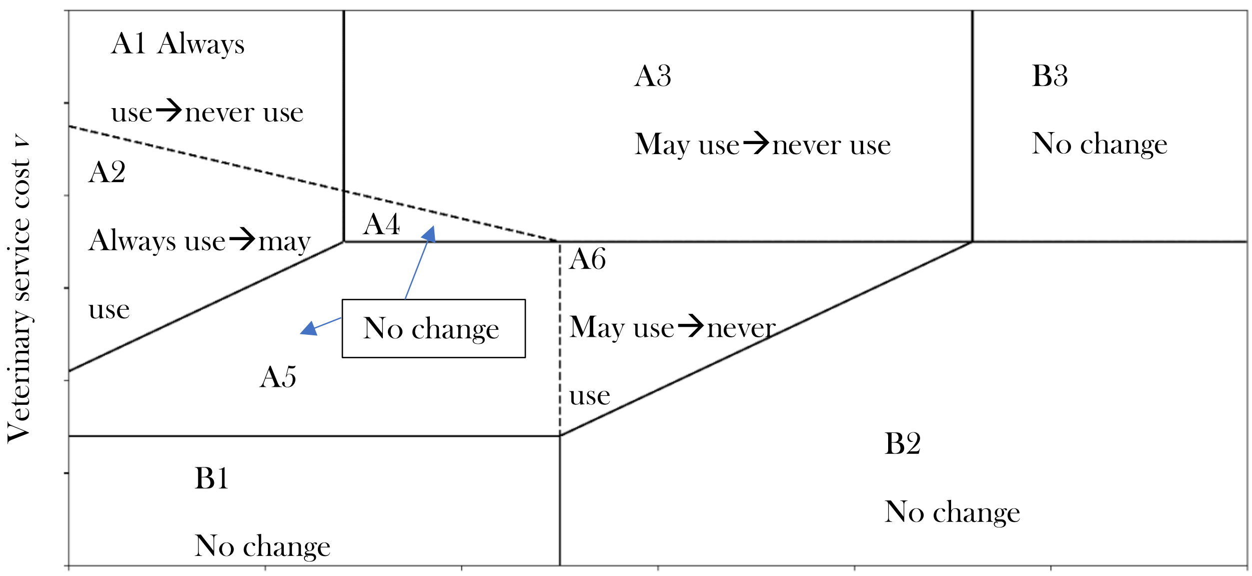

Figure C-28 Comparison between farmer's optimal strategies without and with PR in the *b*-*v* plane when self-test cost satisfies $\beta(1-\beta)(l_2-l_1) < d < \beta(1-\beta)(l_3-l_1)$.

	Without PR	**Under PR**
A1	Neither, always treat	Neither, never treat
A2	Neither, always treat	Call, treat if *E*, do not treat if *I*
A3	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
A4	Self-tests, never call, treat if *E*, do not treat if *I*	Call, treat if *E*, do not treat if *I*
A5	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, treat if *E*, do not treat if *I*
A6	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, never treat
B1	Call, treat if *E*, do not treat if *I*	Same
B2	Call, never treat	Same
B3	Neither, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

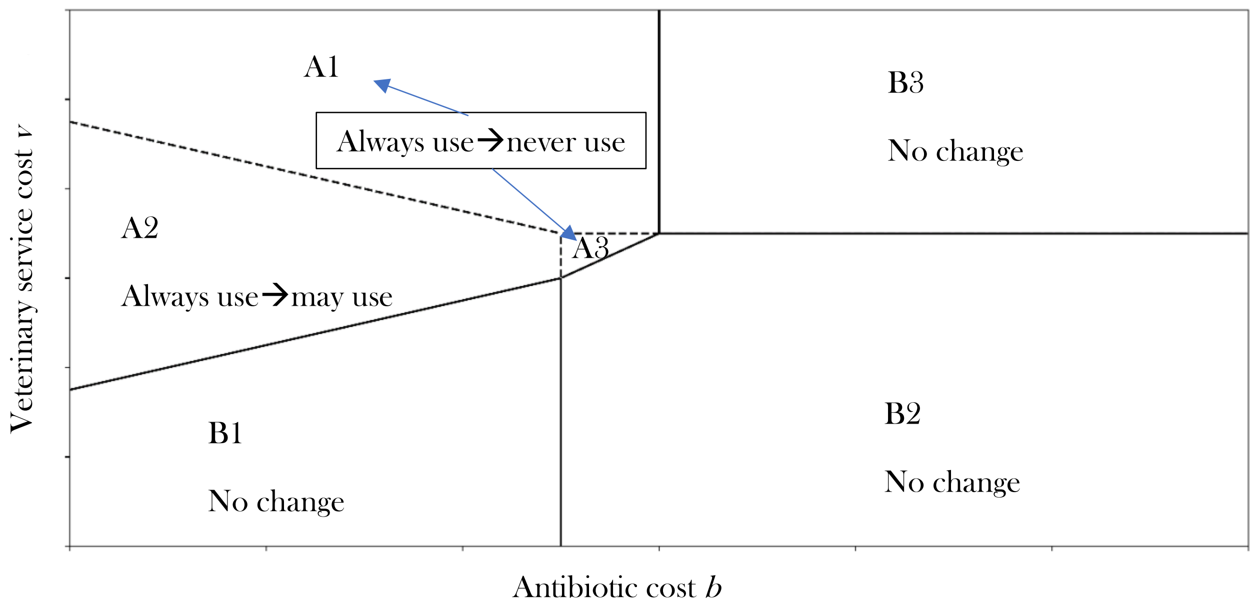

Figure C-29 Comparison between farmer's optimal strategies without and with PR in the b-v plane when self-test cost satisfies $d > \beta(1-\beta)(l_3 - l_1)$.

	Without PR	**Under PR**
A1	Neither, always treat	Neither, never treat
A2	Neither, always treat	Call, treat if *E*, do not treat if *I*
A3	Neither, always treat	Call, never treat
B1	Call, treat if *E*, do not treat if *I*	Same
B2	Call, never treat	Same
B3	Neither, never treat	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

C10 Compare farmer's optimal strategies without and with PR in the d-v plane

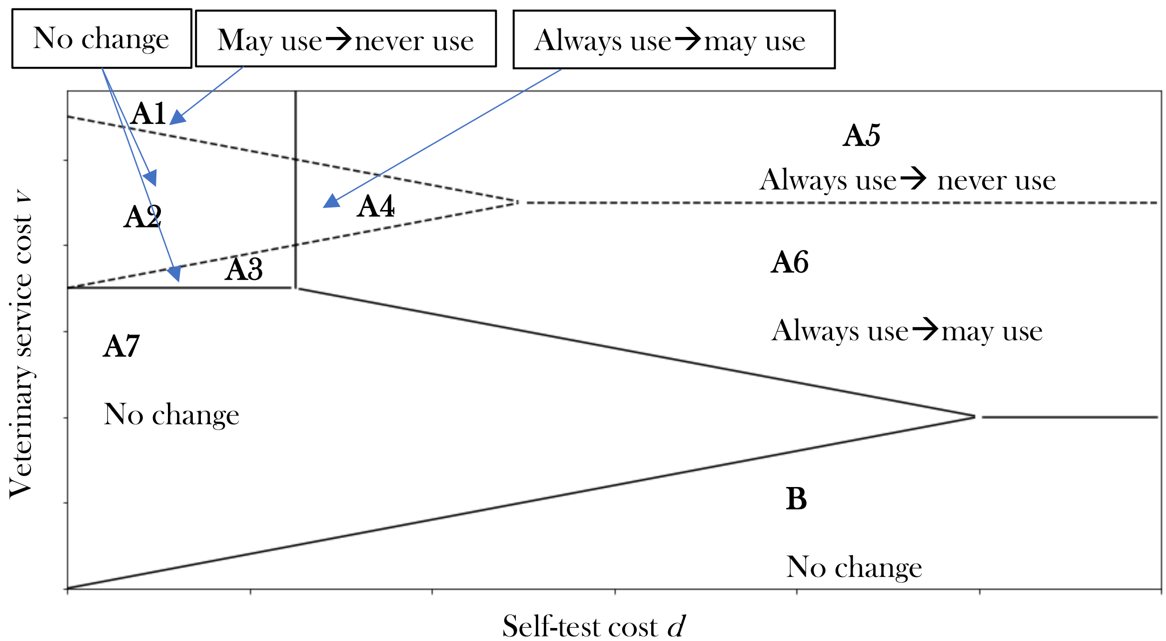

Figure C-30 Comparison between farmer's optimal strategies without and with PR in the d-v plane when low antibiotic cost $b < l_2 - l_1$

	Without PR	Under PR
A1	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
A2	Self-tests, never call, treat if *E*, do not treat if *I*	Self-test, call and treat if *E*, neither call nor treat if *I*
A3	Self-tests, never call, treat if *E*, do not treat if *I*	Call, treat if *E*, do not treat if *I*
A4	Neither, always treat	Self-test, call and treat if *E*, neither call nor treat if *I*
A5	Neither, always treat	Neither, never treat
A6	Neither, always treat	Call, treat if *E*, do not treat if *I*
A7	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, treat if *E*, do not treat if *I*
B	Call, treat if *E*, do not treat if *I*	Same

Notes: Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

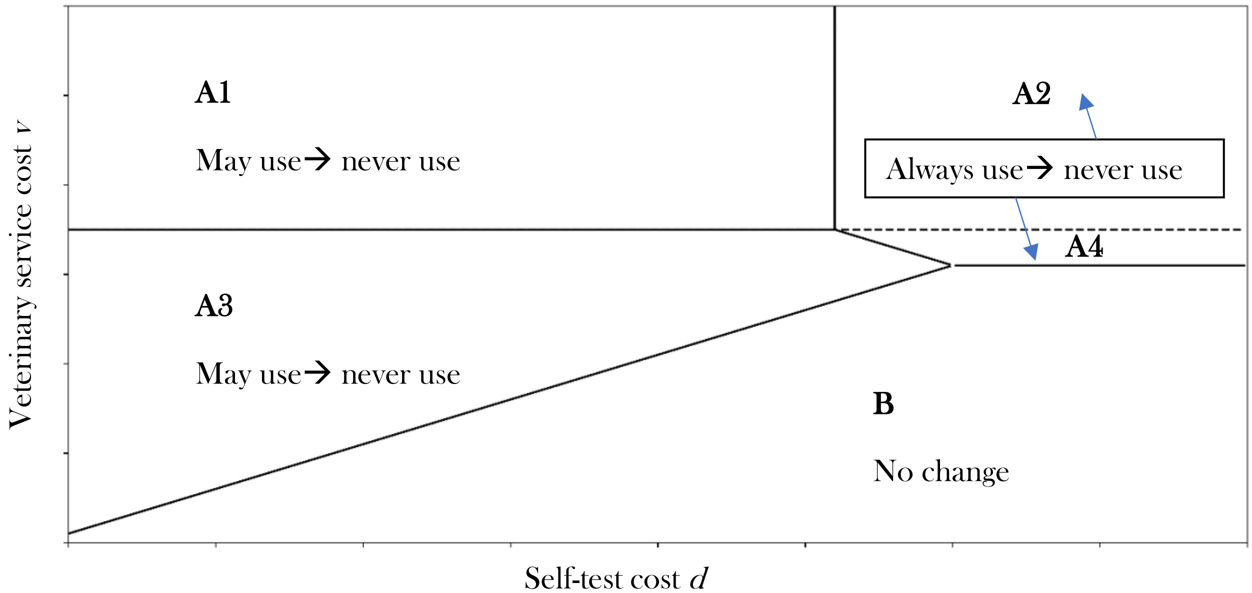

Figure C-31 Comparison between farmer's optimal strategies with and without PR in the d-v plane when antibiotic cost satisfies $l_2 - l_1 < b < l_3 - l_1$.

	Without PR	**Under PR**
A1	Self-tests, never call, treat if *E*, do not treat if *I*	Neither, never treat
A2	Neither, always treat	Neither, never treat
A3	Self-tests, do not call but treat if *E*, call but do not treat if *I*	Call, never treat
A4	Neither, always treat	Call, never treat
B	Call, never treat	Same

Notes: (1) Solid lines and dashed lines indicate optimal strategies for farmers without and with constraints respectively.

(2) When $b > l_3 - l_1$, the farmer's optimal strategies without and with PR are the same. Therefore, the comparison figure is not included.

C11 Comparing farmer's optimal strategies under PR with social optimal decisions

We put both the farmer's optimal strategies under PR and socially optimal strategies in the same modified Figure C-30 (in the d-v plane) so as to better illustrate how PR performs from the perspective of social welfare. We assume low, medium and high antibiotic resistance cost and add dotted lines in Figure C-32, Figure C-33 and Figure C-34, respectively, to indicate the social optimum varying with cost parameters. We also provide an example comparison in the b-d plane. Based on Figure C-24, we assume low and high antibiotic resistance cost and add dotted lines in Figure C-35 and Figure C-36.

We use colors to illustrate an assessment of PR efficiency. In the white area, PR reduces social welfare: the unregulated farmer's choices realize social optimum while PR changes the wedge between actual choices and socially optimal choices. In dark grey areas, PR may change sub-optimal private choices and either improve or worsen welfare but does not produce social optimum. Neither farmer's choices without PR nor choices under PR attain social optimum. In light grey areas, PR improves the farmer's choices and produces social optimum. In pink area, the farmer's choices without and with PR both realize social optimum.

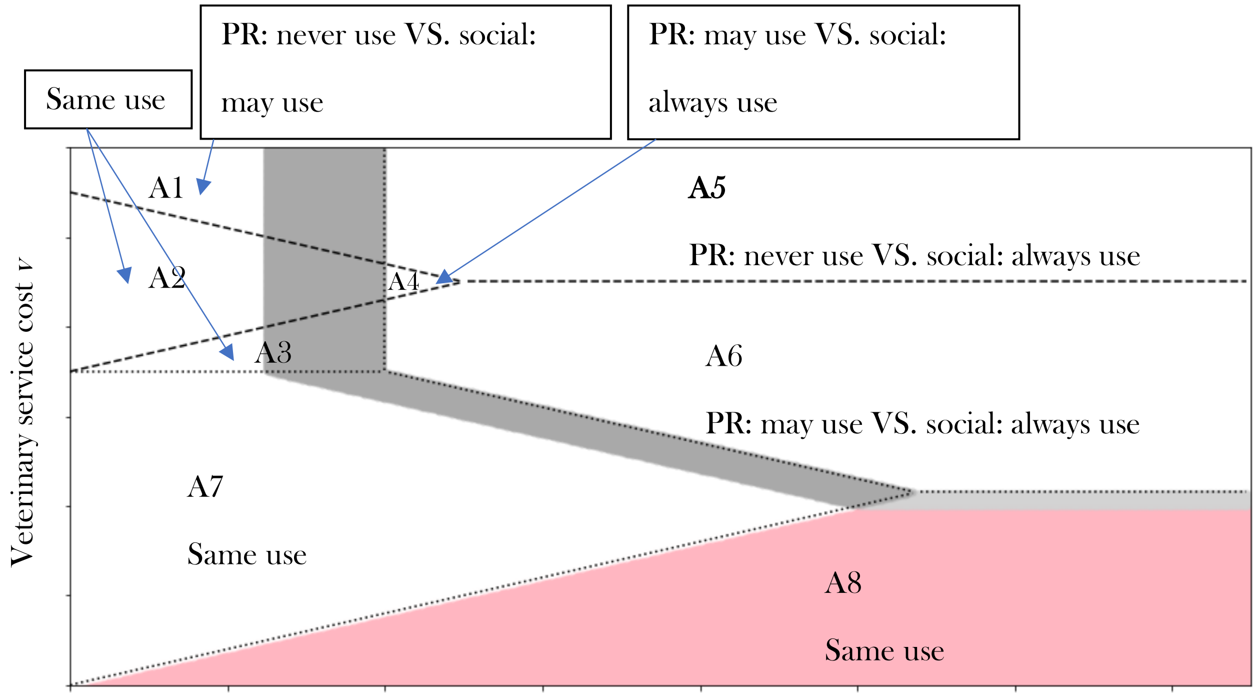

Figure C-32 Comparison between farmer's optimal strategies under PR and social optimum assuming low antibiotic cost $b < l_2 - l_1$ and low antibiotic resistance cost.

	Under PR	**Social optimum**
A1	Neither, never treat	Self-tests, never call, treat if *E*, do not treat if *I*
A2	Self-test; call and treat if *E*, neither call nor treat if *I*	Self-tests, never call, treat if *E*, do not treat if *I*
A3	Call, treat if *E*, do not treat if *I*	Self-tests, never call, treat if *E*, do not treat if *I*
A4	Self-test, call and treat if *E*, neither call nor treat if *I*	Neither, always treat
A5	Neither, never treat	Neither, always treat
A6	Call, treat if *E*, do not treat if *I*	Neither, always treat
A7	Call, treat if *E*, do not treat if *I*	Self-tests, do not call but treat if *E*, call but do not treat if *I*
A8	Call, treat if *E*, do not treat if *I*	**Same**

Notes: (1) Dashed lines indicate optimal strategies for farmers under PR. Dotted lines indicate social optimum.
(2) In the white area, the unregulated farmer's choices realize social optimum while PR changes the wedge between actual choices and socially optimal choices. In dark grey areas, neither farmer's choices without PR nor choices under PR attain social optimum. In light grey areas, PR improves the farmer's choices and produces social optimum. In pink area, the farmer's choices without and with PR both realize social optimum.

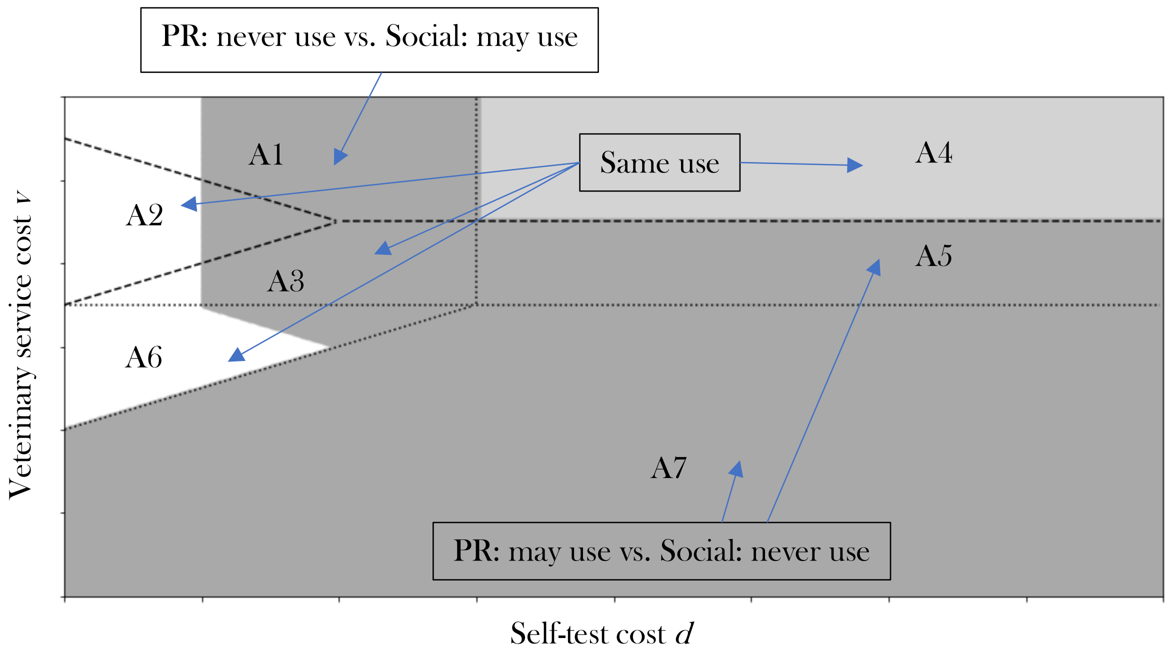

Figure C-33 Comparison between farmer's optimal strategies under PR and social optimum

assuming low antibiotic cost $b < l_2 - l_1$ and medium antibiotic resistance cost

	Under PR	**Social optimum**
A1	Neither, never treat	Self-tests, never call, treat if *E*, do not treat if *I*
A2	Self-test; call and treat if *E*, neither call nor treat if *I*	Self-tests, never call, treat if *E*, do not treat if *I*
A3	Call, treat if *E*, do not treat if *I*	Self-tests, never call, treat if *E*, do not treat if *I*
A4	Neither, never treat	**Same**
A5	Call, treat if *E*, do not treat if I	Neither, never treat
A6	Call, treat if *E*, do not treat if *I*	Self-tests, do not call but treat if *E*, call but not treat if *I*
A7	Call, treat if *E*, do not treat if *I*	Call, never treat

Notes: (1) Dashed lines indicate optimal strategies for farmers under PR. Dotted lines indicate social optimum.
2) In the white area, the unregulated farmer's choices realize social optimum while PR changes the wedge between actual choices and socially optimal choices. In dark grey areas, neither farmer's choices without PR nor choices under PR attain social optimum. In light grey areas, PR improves the farmer's choices and produces social optimum.

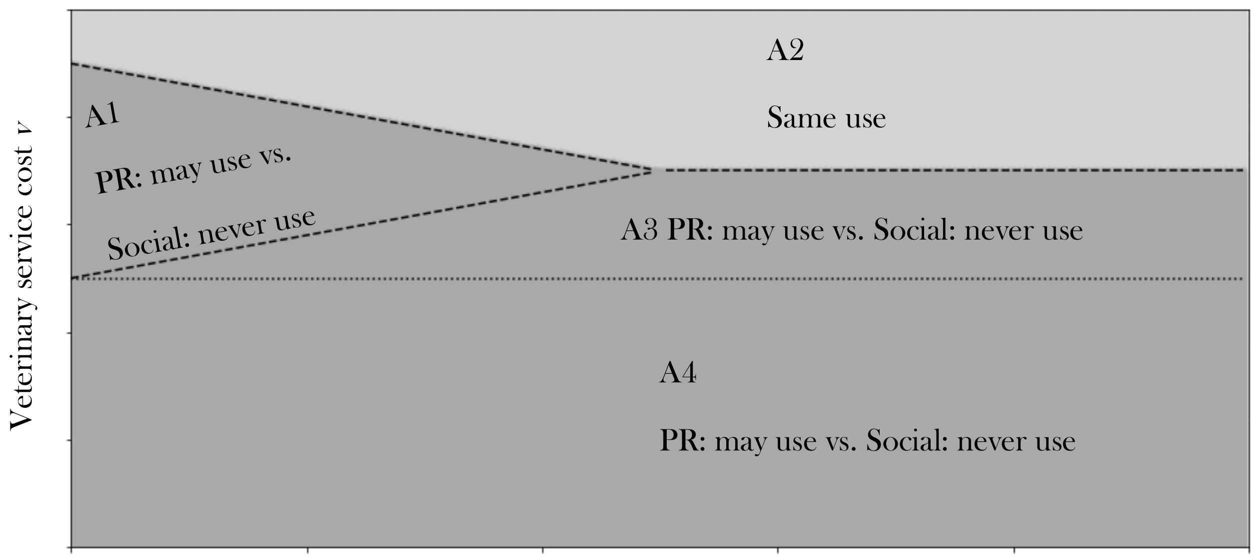

Figure C-34 Comparison between farmer's optimal strategies under PR and social optimum assuming low antibiotic cost $b < l_2 - l_1$ and high antibiotic resistance cost.

	Under PR	**Social optimum**
A1	Self-test; call and treat if *E*, neither call nor treat if *I*	Neither, never treat
A2	Neither, never treat	**Same**
A3	Call, treat if *E*, do not treat if *I*	Neither, never treat
A4	Call, treat if *E*, do not treat if *I*	Call, never treat

Notes: (1) Dashed lines indicate optimal strategies for farmers under PR. Dotted lines indicate social optimum.
(2) In dark grey areas, neither farmer's choices without PR nor choices under PR attain social optimum. In light grey areas, PR improves the farmer's choices and produces social optimum.

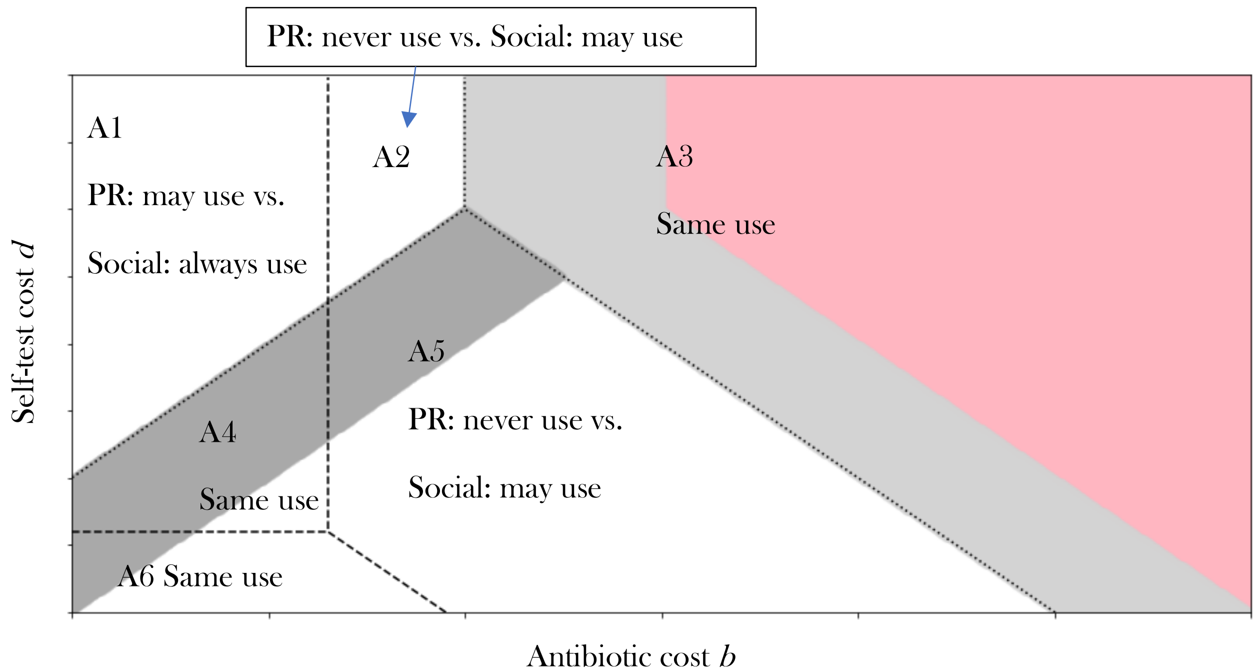

Figure C-35 Comparison between farmer's optimal strategies under PR and social optimum assuming high veterinary service cost $v > l_3 - l_2$ and low antibiotic resistance cost.

Area	**Under PR**	**Social optimum**
A1	Call, treat if *E*, do not treat if *I*	Neither call nor self-test, always treat
A2	Neither call nor self-test, never treat	Neither call nor self-test, always treat
A3	Neither call nor self-test, never treat	**Same**
A4	Call, treat if *E*, do not treat if *I*	Self-test, never call, treat if *E*, do not treat if *I*
A5	Neither call nor self-test, never treat	Self-test, never call, treat if *E*, do not treat if *I*
A6	Self-test, call and treat if *E*, neither call nor treat if *I*	Self-test, never call, treat if *E*, do not treat if *I*

Notes: (1) Dashed lines indicate optimal strategies for farmers under PR. Dotted lines indicate social optimum.
2) In the white area, the unregulated farmer's choices realize social optimum while PR changes the wedge between actual choices and socially optimal choices. In dark grey areas, neither farmer's choices without PR nor choices under PR attain social optimum. In light grey areas, PR improves the farmer's choices and produces social optimum. In pink area, the farmer's choices without and with PR both realize social optimum.

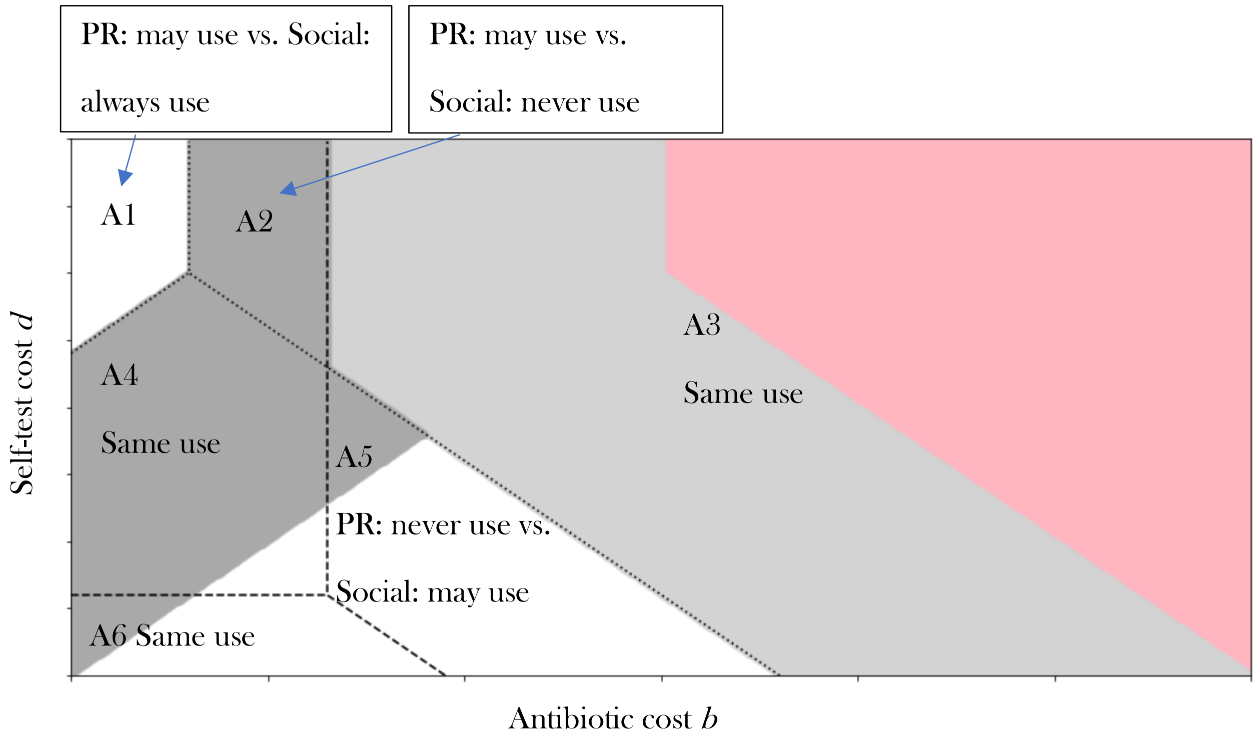

Figure C-36 Comparison between farmer's optimal strategies under PR and social optimum assuming high veterinary service cost $v > l_3 - l_2$ and high antibiotic resistance cost.

Area	**Under PR**	**Social optimum**
A1	Call, treat if *E*, do not treat if *I*	Neither call nor self-test, always treat
A2	Call, treat if *E*, do not treat if I	Neither call nor self-test, never treat
A3	Neither call nor self-test, never treat	**Same**
A4	Call, treat if *E*, do not treat if *I*	Self-test, never call, treat if *E*, do not treat if *I*
A5	Neither call nor self-test, never treat	Self-test, never call, treat if *E*, do not treat if *I*
A6	Self-test, call and treat if *E*, neither call nor treat if *I*	Self-test, never call, treat if *E*, do not treat if *I*

Notes: (1) Dashed lines indicate optimal strategies for farmers under PR. Dotted lines indicate social optimum.
2) In the white area, the unregulated farmer's choices realize social optimum while PR changes the wedge between actual choices and socially optimal choices. In dark grey areas, neither farmer's choices without PR nor choices under PR attain social optimum. In light grey areas, PR improves the farmer's choices and produces social optimum. In pink area, the farmer's choices without and with PR both realize social optimum.

D Dairy survey data statistics

During the summer of 2017, a stratified design survey was circulated to dairy producers. Feng et al. (2018) provide some details on survey design. A total of 660 useable surveys were received, accounting for about 4% of all registered dairy herds in these states and 17% response rate. The survey consists of three parts. Parts I and II of the survey inquired about farm resources, farmer demographics, overall views on the milk production business environment, and farmer expansion/contraction plans for the next three years. Antibiotic use and management behaviors, as well as perceived advantages and costs, were all investigated in Part III. Table D-1 summarizes statistics of costs to producers' herds for a mastitis case.

Table D-1 Descriptive statistics of costs to producers' herds for a mastitis case in the survey data

Variable	N	Mean	SD	Median
$ Diagnosis	273	20.28	43.62	5.00
$ Therapeutics (i.e., as medicine)	410	47.32	130.67	30.00
$ Non-saleable milk	420	124.54	325.52	80.00
$ Veterinary service	275	65.62	312.59	12.00
$ Labor	312	28.66	64.39	15.00
$ Death loss	253	356.80	675.35	35.00
$ Total direct costs per case	392	405.60	807.08	170.00
$ Loss Future Milk Production	331	447.69	856.63	200.00
$ Loss from premature culling	295	560.93	966.68	200.00
$ Loss from future reproduction	261	404.26	871.51	100.00
$ Total indirect costs per case	313	1,172.29	1,948.26	500.00
Average Total Cost Per Case	331	1,256.97	2,007.11	590.00

E Empirically parameterized model

We extrapolate possible values for parameters in our model from the survey data and extant literature. Table E-1 summarizes parameter values in baseline scenario and scenarios where an increase or a decrease of 20% in parameters occurs.

Table E-1 Description of assumed costs (baseline) and an increase/decrease of 20% scenarios

Notation	Baseline	+20%	-20%
d	\$5	\$6	\$4
b	\$10	\$12	\$8
v	\$27.5	\$33	\$22
β	0.35	0.42	0.28
l_1	\$95	\$114	\$76
l_2	\$150	\$180	\$120
l_3	\$630	\$756	\$504
ω	\$2.2-\$3.9	\$2.64-\$4.68	\$1.76-\$3.12

For self-test cost, we use the median diagnosis cost in our dataset as a baseline level, i.e., $d = \$5$. This is also a reasonable value compared with estimates in the literature (\$6 in Pinzón-Sánchez, Cabrera, and Ruegg (2011); \$10 in Cha et al. (2011)). We asked about therapeutics cost in the dairy survey and therapeutics cost can include antibiotic cost but also some other veterinary drugs as well. The median therapeutics cost in our dataset is \$30 and is higher than the antibiotic cost estimated in literature (\$7-\$25 in Ruegg (2020); \$4-\$8 in Cha et al. (2011); \$6.75 in Pinzón-Sánchez, Cabrera, and Ruegg (2011)). Therefore we extrapolate a reasonable antibiotic cost $b = \$10$ from the survey dataset and literature. To be consistent with our assumptions, veterinary service cost estimate should include hourly rates paid for veterinarians and costs associated with alternative treatment. The median veterinary service cost is \$12 in the dataset and this is a reasonable number given that U.S. Department of Agriculture (2016) estimates veterinary service cost associated with a mastitis case on dairy farms to be in the range of \$1.45-\$9.21. Cha et al. (2011) estimate the cost of treatment other than antibiotics to be \$15.5. We combine veterinary service cost (\$12) and other treatment cost (\$15.5) and assume veterinary service cost parameter d

to be \$27.5. This estimate is comparable to the numbers provided (\$19.16 ± 15.27) in Liang et al. (2017).

Parameter β indicates the probability that mastitis occurs for which antibiotic treatment is effective. For most cases, antibiotics should be used to treat mastitis caused by gram-positive pathogens, while farmers should avoid antibiotic use for mastitis caused by gram-negative pathogens or when no pathogens are recovered. The incidence of mastitis caused by gram-positive pathogens is assumed to be 35% (Pinzón-Sánchez, Cabrera, and Ruegg 2011).

Labor cost and non-saleable milk cost are inevitable for a mastitis case even when antibiotics cure the mastitis case, while other losses such as death loss, loss from future milk production, loss from premature culling and loss from future reproduction are more likely to occur when the mastitis case is not treated effectively. Therefore we use the sum of median labor cost (\$15) and median non-saleable milk cost (\$80) to parameterize l_1; we added all costs and losses incurred in a mastitis case to parameterize l_3. Median total cost is \$630. We posit l_2 to be greater than l_1 but less than l_3. When we parameterize l_2, we should make sure it satisfies the assumption we made in Section 3.1 in the main manuscript, i.e., $l_2 - l_1 < \beta(l_3 - l_1)$. Thus, $l_2 \in (\$95, \$282.25)$. We assume $l_2 = \$150$ as a baseline level. Economic losses assumed are comparable to estimates in literature (Cha et al. 2011; Liang et al. 2017; Ruegg 2020).

In our speculative estimations, the total cost of antibiotic resistance in the United States consists of three parts: death due to antibiotic resistance, losses of extra health care cost incurred, and economic losses due to lost productivity. Antibiotic resistance caused \$20 billion (in 2008 dollars) extra health care costs and \$35 billion economic losses due to lost productivity annually (US CDC 2013). To place a monetary value on death caused by antibiotic resistance, we multiply the number of deaths 35,900 by the value of a statistical life estimate \$11.1 million (in 2015 dollars) (Kniesner and Viscusi 2019; U.S. Centers for Disease Control and Prevention [US CDC] 2019). Therefore, total cost is (20+35)*1.1 (inflation factor) + 11.1*35.9 = \$458.99 billion (in 2015 dollars). We tentatively assume that 5% of the total cost can be attributed to antibiotic use in livestock production. The total sale of antibiotics in livestock production is 10,449,476 kg and medically important antibiotics account for 57% of total sales in 2020 (U.S. Food and Drug Administration 2021). When we assume a homogenous impact of medically important antibiotics and non-medically important antibiotics on resistance development, antibiotic resistance cost associated with 1 kg medically important antibiotic use in animals is $2,196.23. When we assume that antibiotic resistance arising from non-medically important antibiotic use can be ignored, the antibiotic resistance cost associated with 1 kg medically important antibiotic use in animals is $3,853.04. We infer that the amount of antibiotic use in a mastitis case is about 1g (Ruegg 2020). Therefore antibiotic resistance cost associated with antibiotic use in one mastitis case is $2.2-$3.9.

Using these parameter values, we can indicate which scenario is most likely relevant to practices on U.S. dairy farms. In order to perform robustness checks, we also examine how an increase or decrease of 20% in each of these parameters affects the impact of PR.

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