Supplementary Material for

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

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SM 1 Farmer's problem without regulations

In this supplementary material, we present the formulated optimization problem without regulations and then show how the solutions are derived step by step.

SM 1.1 Farmer's optimization problem formulation

In this section, we first list all possible payoffs in Figure 2 and then explain in detail how the farmer's optimization problem is formulated.

SM 1.1.1 Possible payoffs for unregulated farmers

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

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

$$\Phi_E^{NTe,C,NTr} = \Phi_E\left(x_{\text{①}} = 0, y_{\text{①}} = 1, z_{\text{④}}^E = 0\right) = a - l_2 - v; \tag{A.2}$$

$$\Phi_E^{Te,C,Tr} = \Phi_E\left(x_{\text{①}} = 1, y_{\text{①}} = 0, y_{\text{②}}^E = 1, z_{\text{⑤}}^E = 1\right) = a - l_1 - b - d - v; \tag{A.3}$$

$$\Phi_E^{Te,C,NTr} = \Phi_E\left(x_{\text{①}} = 1, y_{\text{①}} = 0, y_{\text{②}}^E = 1, z_{\text{⑤}}^E = 0\right) = a - l_2 - d - v; \tag{A.4}$$

$$\Phi_E^{Te,NC,Tr} = \Phi_E\left(x_{\text{①}} = 1, y_{\text{①}} = 0, y_{\text{②}}^E = 0, z_{\text{⑥}}^E = 1\right) = a - l_1 - b - d; \tag{A.5}$$

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

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

$$\Phi_E^{NTe,NC,NTr} = \Phi_E\left(x_{\text{①}} = 0, y_{\text{①}} = 0, z_{\text{⑦}} = 0\right) = a - l_3; \tag{A.8}$$

$$\Phi_I^{NTe,NC,Tr} = \Phi_I\left(x_{\text{①}} = 0, y_{\text{①}} = 0, z_{\text{⑦}} = 1\right) = a - l_3 - b; \tag{A.9}$$

$$\Phi_I^{NTe,NC,NTr} = \Phi_I\left(x_{\text{①}} = 0, y_{\text{①}} = 0, z_{\text{⑦}} = 0\right) = a - l_3; \tag{A.10}$$

$$\Phi_I^{Te,C,Tr} = \Phi_I\left(x_{\text{①}} = 1, y_{\text{①}} = 0, y_{\text{③}}^I = 1, z_{\text{⑧}}^I = 1\right) = a - l_2 - b - d - v; \tag{A.11}$$

$$\Phi_I^{Te,C,NTr} = \Phi_I\left(x_{\text{①}} = 1, y_{\text{①}} = 0, y_{\text{③}}^I = 1, z_{\text{⑧}}^I = 0\right) = a - l_2 - d - v; \tag{A.12}$$

$$\Phi_I^{Te,NC,Tr} = \Phi_I\left(x_{①} = 1, y_{①} = 0, y_{③}^I = 0, z_{⑨}^I = 1\right) = a - l_3 - b - d; \tag{A.13}$$

$$\Phi_I^{Te,NC,NTr} = \Phi_I\left(x_{①} = 1, y_{①} = 0, y_{③}^I = 0, z_{⑨}^I = 0\right) = a - l_3 - d; \tag{A.14}$$

$$\Phi_I^{NTe,C,Tr} = \Phi_I\left(x_{①} = 0, y_{①} = 1, z_{⑩}^I = 1\right) = a - l_2 - v - b; \tag{A.15}$$

$$\Phi_I^{NTe,C,NTr} = \Phi_I\left(x_{①} = 0, y_{①} = 1, z_{⑩}^I = 0\right) = a - l_2 - v. \tag{A.16}$$

SM 1.1.2 Antibiotic administration decisions at information sets ④-⑩

As mentioned in main text section 3.2, we set up the maximization problem in temporally reversed order. In Subsection SM 1.1.2 we first explain the maximization problem for the antibiotic administration decisions. Then in Subsection SM 1.1.3 based on optimal antibiotic administration decisions, we set up maximization problem regarding veterinary services. Finally in Subsection SM 1.1.4 based on the optimal decisions in previous two steps, we explain optimization problem of information purchasing.

At information set ④, a veterinarian reveals the infection to be 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 because the infection type is unknown to the farmer.

SM 1.1.3 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 SM 1.1.2 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, $\Phi_E^{Te,C,z_{⑤}^E}$ and $\Phi_E^{Te,NC,z_{⑥}^E}$. 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 $y_{②}^E$ 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 $y_{③}^I$.

SM 1.1.4 Testing decisions at information set ①

To solve for optimal testing decisions, we take the optimal decisions in sections SM 1.1.2 and SM 1.1.3 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;

$$V^{Te} = \beta\Phi_E^{Te,y_{②}^E,\lambda} + (1-\beta)\Phi_I^{Te,y_{③}^E,NTr};$$
$$\text{where } \lambda = \begin{cases} z_{⑤}^E & \text{whenever } y_{②}^E = C; \\ z_{⑥}^E & \text{whenever } y_{②}^E = NC; \end{cases} \quad \text{(A.17)}$$

$$V^C = \beta\Phi_E^{NTe,C,z_{④}^E} + (1-\beta)\Phi_I^{NTe,C,NTr}; \quad \text{(A.18)}$$

$$V^{NTe,NC} = \beta\Phi_E^{NTe,NC,z_{⑦}} + (1-\beta)\Phi_I^{NTe,NC,z_{⑦}}. \quad \text{(A.19)}$$

Thus, the farmer's expected payoff maximization problem is

$$V = \max\{V^{Te}, V^C, V^{NTe,NC}\}. \quad \text{(A.20)}$$

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

SM 1.2 Farmer's optimization problem solution

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

SM 1.2.1 Optimal antibiotic administration given infection types as well as self-test and veterinary service 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*.

SM 1.2.1.1 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

$$\Phi_E^{NTe,C,Tr} > \Phi_E^{NTe,C,NTr}, \quad \text{(A.21)}$$

or

$$\Phi_E^{Te,C,Tr} > \Phi_E^{Te,C,NTr}. \qquad (A.22)$$

These two inequalities are equivalent and can be simplified to

$$b < l_2 - l_1. \qquad (A.23)$$

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

SM 1.2.1.2 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.

SM 1.2.1.3 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

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

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

$$b_3 = l_3 - l_1. \quad \text{(A.30)}$$

Reservation value b_1 is the antibiotic cost that makes the farmer indifferent between Tr and NTr in the type E infection cases when 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 $b_2 < b \le b_3$;

iv) high antibiotic cost $b > b_3$.

We summarize the optimal antibiotic decisions across four antibiotic cost categories. In scenarios with a low antibiotic cost $b < b_1$, at information sets ④-⑦ the farmer uses antibiotics. In scenarios with lower medium antibiotic cost $b_1 < b < b_2$, at information sets ④ and ⑤ the farmer does not use antibiotics but at information sets ⑥ and ⑦ the farmer uses antibiotics. In scenarios with upper medium antibiotic cost $b_2 < b < b_3$, at information sets ④, ⑤, and ⑦ the farmer does not use antibiotics but at information sets ⑥ the farmer uses antibiotics. In scenarios with a high antibiotic cost $b > b_3$, at information sets ④-⑦ the farmer does not use antibiotics.

SM 1.2.2 Optimal veterinary service decisions given that a self-test has been performed

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. Recall that optimal antibiotic administration decisions vary across four antibiotic cost regions, i)-iv) above. Therefore in subsections SM 1.2.2.1- SM 1.2.2.2 veterinary service decisions at each antibiotic cost level are discussed.

SM 1.2.2.1 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 for each of three antibiotic cost regions. These are:

(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

$$\Phi_E^{Te,C,Tr} > \Phi_E^{Te,NC,Tr}. \tag{A.31}$$

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

(2) Lower medium antibiotic cost $b_1 < b \le b_2$ and upper medium antibiotic cost $b_2 < b \le b_3$

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

$$v < b + l_1 - l_2. \quad \text{(A.33)}$$

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

$$\Phi_E^{Te,C,NTr} > \Phi_E^{Te,NC,NTr}, \quad \text{(A.34)}$$

which can be written as

$$v < l_3 - l_2. \quad \text{(A.35)}$$

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

SM 1.2.2.2 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. The optimal antibiotic administration decisions at information sets ⑧ and ⑨ are "NTr". Then 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

$$\Phi_I^{Te,C,NTr} > \Phi_I^{Te,NC,NTr}. \quad \text{(A.36)}$$

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.

SM 1.2.3 Optimal 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 decisions, taking subsequent optimal decisions derived in sections SM 1.2.1 and SM 1.2.2 as given. Then we compare these expected payoffs to solve for optimal testing decisions.

SM 1.2.3.1 Calling a veterinarian

The expected payoff from calling a veterinarian is the average of payoffs at information sets ④ and ⑩ when 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;

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

SM 1.2.3.2 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, we need to consider the expected payoff from performing a self-test under different cost parameter combinations.

(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 depends on other parameter values. 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

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

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

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

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

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

which reduces to

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

(2) Lower medium antibiotic cost $b_1 < b \le b_2$ and upper medium antibiotic cost $b_2 < b \le b_3$

With medium antibiotic cost $b_1 < b \le b_3$, the optimal decisions at information sets ② and ③ depends on other parameter values. 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

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

which can be re-stated as

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

When veterinary service cost is at some medium level such that inequality (A.35) holds but (A.33) is violated[1], 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

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

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

which abbreviates to

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

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, where she receives payoffs $\Phi_E^{Te,NC,Tr}$ and $\Phi_I^{Te,NC,NTr}$, respectively. The expected payoff from performing a self-test is

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

The equation may be re-written as

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

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

With high antibiotic cost $b > b_3$, the optimal decisions at information sets ② and ③ depends on the value of v. 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 respective payoffs $\Phi_E^{Te,C,NTr}$ and $\Phi_I^{Te,C,NTr}$. Therefore, the expected payoff from performing a self-test is written as

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

Cancellations then lead to the equivalent expression

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

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

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

and so, upon simplification,

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

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

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

This branched function resolves to

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

SM 1.2.3.3 No information purchases

The expected payoff from purchasing no information is the payoff at information set ⑦. This 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

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

This branched function resolves to

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

SM 1.2.3.4 Compare the expected payoffs from the testing decisions

Having calculated the expected payoffs associated with self-tests, veterinary services and no tests, we compare them for different cost parameter regions. From (A.38), (A.48), and (A.50), the expected payoffs depends on values of antibiotic cost b. Therefore in subsections (1) through (4) we compare the expected payoffs for low antibiotic cost, lower medium antibiotic cost, upper medium antibiotic cost and high antibiotic cost respectively. The general rule is that the farmer prefers the one resulting in the largest expected payoff.

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

In scenarios with low antibiotic cost, the expected payoff associated with self-test also depends on values of veterinary service cost v. Therefore in subsections (1-1) and (1-2) we compare the expected payoffs associated with self-tests, veterinary services and no tests for scenarios with low veterinary service cost and scenarios with high veterinary service cost.

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

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

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

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

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

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

The optimal testing decision is *Te* whenever

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

Finally, the optimal testing decision is *NTe, NC* whenever both

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

(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 $b < b_1$ (as $b_1 < b_2$), it follows that condition (A.54)-(2) does not hold. Therefore, choosing C is not optimal in this case.

The optimal testing decision is Te whenever both

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

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

The optimal testing decision is *NTe, NC* whenever both

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

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 ($b_1 < b < b_2$)

In scenarios with lower medium antibiotic cost, the expected payoff associated with self-test also depends on values of veterinary service cost v. Therefore in subsections (2-1) through (2-3) we compare the expected payoffs associated with self-tests, veterinary services and no tests for three different veterinary service cost levels.

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

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

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

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

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 testing decisions.

(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

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

The optimal testing decision is *C* whenever both

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

The optimal testing decision is *Te* when

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

The optimal testing decision is *NTe, NC* whenever both

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

(2-3) Veterinary service cost that breaches the value set satisfying inequality (A.35) also violates (A.33). While the payoffs from choosing *C* and *NTe, NC* are unchanged when compared with (2-1), the expected payoff from choosing *Te* changes to

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

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

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

However, cost parameters violating inequality (A.35) but satisfying condition $b < b_2$ imply that

(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) is violated, (A.61)-(2) becomes a sufficient condition for (A.61)-(1).

The optimal testing decision is *NTe, NC* whenever

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

Cost parameters violating inequality (A.35) but satisfying condition $b < b_2$ imply that (A.62)-(1) does not bind.

(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. The changes depend on values of veterinary service cost v and antibiotic cost b. In subsections (3-1) through (3-3) we discuss how the change arises for three different veterinary service cost levels.

(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

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

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 testing decisions.

(3-2) When veterinary service cost is low enough to satisfy inequality (A.35) but still violate (A.33), while the payoffs from choosing *C* and *Te* are unchanged compared with (2-2), the expected payoff from choosing *NTe, NC* changes to

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

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) A high veterinary service cost such that inequality (A.35) is violated implies that (A.33) is also violated. Under such cost parameter values, 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

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

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

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

In scenarios with high antibiotic cost, the expected payoff associated with self-test also depends on values of veterinary service cost v. Therefore in subsections (4-1) and (4-2) we compare the expected payoffs associated with self-tests, veterinary services and no tests for scenarios with low veterinary service cost and scenarios with high veterinary service cost.

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

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

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

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

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

(4-2) Consider a scenario with a high veterinary service cost such that inequality (A.35) is violated. While the payoffs from choosing *C* and *NTe*, *NC* do not change compared with (4-1), the expected payoff from choosing *Te* changes to

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

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 decision in this situation.

SM 1.2.4 Summary of optimal strategies

At this point, we have solved for the optimal strategies. The following are six possible optimal strategies without policy interventions:

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

S2: At information set ①, perform a self-test; in type *E* infection cases at information set ② do not call a veterinarian but at information set ⑥ treat with antibiotics; in type *I* infection cases at information set ③ do not call a veterinarian and at information set ⑨ do not treat with antibiotics.

S3: At information set ①, neither call a veterinarian nor perform a self-test; at information set ⑦ do not treat with antibiotics.

S4: At information set ①, call a veterinarian; in type *E* infection cases at information set ④, treat with antibiotics; in type *I* infection at information set ⑩ cases do not treat with antibiotics.

S5: At information set ①, call a veterinarian; at information sets ④ and ⑩, do not treat with antibiotics.

S6: At information set ①, perform a self-test; in type *E* infection cases at information set ② infection cases do not call a veterinarian but at information set ⑥ treat with antibiotics; in type *I* infection cases at information set ③ call a veterinarian but at information set ⑧ do not treat with antibiotics.

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

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

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

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

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

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

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

SM 1.3 Explanations for optimal strategies

SM 1.3.1 Explanations for Figure 3 in the main manuscript

We graph the optimal strategies, holding one cost parameter among (b, d, v) fixed (See SM 5.1-SM 5.3). We take Figure 3 in the main manuscript as an example 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 the 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 the 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 subsequently using antibiotics as appropriate (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 sloping 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. An antibiotic use cost (b) that exceeds the expected loss reduction associated with its use (i.e., $\beta(l_3 - l_1)$) implies that the farmer prefers to not use antibiotics; with an antibiotic cost less than the expected loss reduction attribute to its use, the farmer elects to use antibiotic.

SM 1.3.2 Interactions between antibiotics and self-tests/veterinary services

Since optimal decisions regarding self-tests, veterinary services and antibiotics are jointly determined by cost parameters, we are interested in investigating interactions between these decisions. The interaction between self-testing 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 below boundary condition $d = \beta(l_3 - l_1 - b)$ to above this boundary condition, suggesting that antibiotic and self-test inputs are complements. 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 are substitutes. In this situation, more information can reduce antibiotic use, a conclusion that is consistent with comments made by Krömker and Leimbach (2017, page 23) regarding causality between lack of diagnosis and antibiotic over-use/inappropriate use.

Veterinary services and antibiotics are substitutes when antibiotic cost is low. Taking Figure 6 as an example, at a low antibiotic cost b_L 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. At high antibiotic cost b_H, using antibiotics for any infection type does not increase profit. So the farmer does not use antibiotics regardless of any change in veterinary service cost. Antibiotic use and veterinary service use do not interact in scenarios when antibiotic cost is high.

SM 1.3.3 Interactions between self-tests and veterinary services

The interaction between self-tests and veterinary services varies with veterinary service cost. As illustrated in Figure 7 a low veterinary service cost such that $v_L < (1-\beta)(l_3 + b - l_2)$ implies that veterinary service demand increases as self-test cost increases. This indicates that self-tests and veterinary services are substitutes in respect to information revelation. A relatively high veterinary service cost such that $(1-\beta)(l_3 + b - l_2) < v_H < l_3 - l_2$ implies that veterinary service demand decreases as self-test cost increases. In this situation, self-tests and veterinary services are complements since veterinary services function as alternative treatments instead of revealing information. Hence,

Result 1 (<u>Interactions between decisions</u>) Decisions on antibiotic administration, veterinary services and self-tests interact. (a) Antibiotics and veterinary services are substitutes when antibiotic cost is low. They are not related when antibiotic cost is high. (b) Antibiotics and self-tests are complements (substitutes) given a high (low) antibiotic cost. (c) Self-tests and veterinary services are substitutes (complements) given low (high) veterinary service cost.

SM 1.3.4 Social optimum and biases in privately optimal decisions

Figure 11 and 12 are sample comparisons between farmer's optimal and socially optimal decisions based on Figure 4 and Figure 6. 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 $b \rightarrow b+\omega$, is consistent with antibiotic resistance resulting in a divergence between social optimum and private optimum.

Figure 11 shows where discrepancies between socially optimal and privately optimal decisions 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 decisions differ from the privately optimal decisions 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 area 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 12 shows where discrepancies between socially optimal and privately optimal decisions occur across areas A1-A4. In areas A1-A3, the farmer prefers to use antibiotics without any information purchase. The privately optimal decisions 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, and then use antibiotics for type E infections but 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, and then use antibiotics for type E infections but use alternative treatments for type I infections. In this area, however, due to the additional cost to society of antibiotic use the social planner prefers to replace antibiotics with alternative treatments for any infections.

SM 1.3.5 Antibiotic over-use

In situations where the farmer's optimal antibiotic strategies diverge from social optimum, the farmer over-uses antibiotics. For example, in the A areas in Figure 11 and Figure 12 a farmer demands socially excessive amounts of 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.

SM 1.3.6 Under-test or over-test?

Demand for self-tests is below the socially optimal level when antibiotic cost is low, and is above the socially optimal level when this cost is high. For example in area A1 of Figure 11 the farmer uses fewer self-tests than is socially optimal level, while in area A3 she over-uses 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. With a high antibiotic cost such that the farmer prefers informed antibiotic administrations, the social planner may lack motivation to use antibiotics regardless. This is because the social planner takes account of the 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 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 the socially optimal level.

Result 2 (Biases in privately optimal decisions) 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 under-uses (over-uses) self-tests compared to the social optimum.

SM 2 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. The following are possible optimal strategies under PR. Note that strategies S3-S5 have been defined as optimal strategies without regulations, see Section A3, 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:

$$\text{(S3)} \quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b < l_3 - l_1 - v \\ d > \beta(l_3 - l_1 - b - v) \\ b > \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \quad \text{or} \quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b > l_3 - l_1 - v \\ b > \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \quad \text{or} \quad \begin{cases} v > l_3 - l_2 \\ b > l_2 - l_1 \end{cases} \qquad \text{(A.71)}$$

$$\text{(S4)} \quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b < l_3 - l_1 - v \\ d > (1-\beta)(l_2 + v - l_3) \\ b < \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \quad \text{or} \quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b > l_3 - l_1 - v \\ b < \dfrac{l_3 - (1-\beta)l_2 - v}{\beta} - l_1 \end{cases} \quad \text{or} \quad \begin{cases} v < l_3 - l_2 \\ b < l_2 - l_1 \end{cases} \qquad \text{(A.72)}$$

$$\text{(S5)} \quad \begin{cases} v < l_3 - l_2 \\ b > l_2 - l_1 \end{cases} \qquad \text{(A.73)}$$

$$\text{(S7)} \quad \begin{cases} v > l_3 - l_2 \\ b < l_2 - l_1 \\ b < l_3 - l_1 - v \\ d < (1-\beta)(l_2 + v - l_3) \\ d < \beta(l_3 - l_1 - b - v) \end{cases} \qquad \text{(A.74)}$$

SM 2.1 Explanations for optimal strategies depicted in Figure 4

Figure 4 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 while 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 4. This boundary condition suggests that self-tests are chosen whenever the cost is less than the benefit it confers; otherwise calling a veterinarian directly is in the farmer's best interest.

(2) Both expensive antibiotics and expensive self-tests (see right-upper area in the figure) imply that 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 4.

(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 4.

SM 3 Heterogeneity across farmer's characteristics

To investigate how farm characteristic heterogeneity affects the merits of PR regulation, we categorize dairy farms by herd size, located state and productivity. We extrapolate possible values for parameters in our model using survey data from different groups of dairy farms. Similar to estimates explained above, cost data medians and loss data medians are used to set parameter values (see Table 4-1 through Table 4-3). Given the assumed parameter values, Figure 37 through Figure 45 compare farmer's optimal strategies with and without PR. These figures are equivalent to Figure 5 in the main text. Figure 46 through Figure 54 represent comparisons between PR regulated farmer's optimal strategy and social optimal strategies These figures are equivalent to Figure 6 in the main text, but are magnified to focus on the relevant area. Red circled data points represent the current optimal strategy for the corresponding type of dairy farms.

Before PR implemented, farms with different herd size have the same optimal strategy. The PR regulation uniformly leads to a consistent strategy across farms with different herd size to a strategy: calling veterinarians and then using antibiotics according to prescription. From this perspective we do not find heterogeneity in the action consequence of the PR regulation. However data point locations relative to boundary conditions differ across figures, suggesting the uniform effect of PR across herd size may not be robust. Specifically, large farms are located closer to boundary conditions when compared with small and medium-sized farms. In a case where self-test cost increase slightly, the optimal strategy for large farms may switch from "Self-tests, do not call but treat if *E*, call but do not treat if *I*" (area A) to "Call, treat if *E*, do not treat if *I*" (area B). However, small and medium-sized farms optimal strategy may remain unchanged. So the optimal strategy for unregulated large farms complies with the PR requirement. Our data suggest then that PR has no impact on large farms but lowers small and medium-sized farms' profit.

We also investigate heterogeneity across state location and productivity. Based on the survey data, the effect of PR is homogenous in that PR enforces a farmer's optimal strategy to switch from

“Self-tests, do not call but treat if *E*, call but do not treat if *I*” to “Call, treat if *E*, do not treat if *I*”. The representations of comparison between regulated farmer’s optimal strategy and social optimum are similar across farm groups except for high productivity farms. In the dark grey area at the right bottom corner of Figure 54, it is socially optimal to not use antibiotics for high productivity farms while PR regulated farms still use antibiotics. This is an example where PR does not reduce antibiotic use sufficiently. Given the same veterinary service and self-test cost values, it is socially optimal for farms with lower productivity to use antibiotics under veterinary oversight. A PR regulated farmer’s optimal strategy is consistent with social optimum and so the corresponding areas in Figure 52 and Figure 53 are colored in pink.

SM 4 Tables

Table 4-1 Description of assumed parameter values across different farm sizes.

	Small farms (<100 cows)	Medium farms (101 - 350 cows)	Large farms (>350 cows)	Whole sample
d	1	10	5	5
b	28.5	40	25	30
v	40.5	45.5	17.5	27.5
β	0.35	0.35	0.35	0.35
l_1	90	95	110	95
l_2	150	150	150	150
l_3	800	820	565	630

Table 4-2 Description of assumed parameter values across located different states.

	Michigan	Minnesota	Wisconsin	Whole sample
d	2	10	5	5
b	25	25	30	30
v	15.5	35.5	35.5	27.5
β	0.35	0.35	0.35	0.35
l_1	70	92.5	105	95
l_2	150	150	150	150
l_3	575	627.5	761	630

Table 4-3 Description of assumed parameter values across productivity levels.

	Annual yield <25th percentile	Annual yield 25th percentile-75 percentile	Annual yield >75th percentile	Whole sample
d	0	5	6.5	5
b	20	30	30	30
v	15.5	35.5	25.5	27.5
β	0.35	0.35	0.35	0.35
l_1	60	107	120	95
l_2	150	150	150	150
l_3	510	791.5	650	630

SM 5 Figures

To illustrate how farmer's disease management decisions are determined by the key parameters in our model (i.e., self-test cost, veterinary service cost, and antibiotic cost), we graph the optimal strategies, holding one cost parameter among (b, d, v) fixed. SM 5.1-SM 5.3 present the optimal strategies without policy interventions in the b-d, b-v and d-v planes respectively. SM 5.4 summarizes comparisons between unregulated private strategies and social optimum. SM 5.5-SM 5.7 present the optimal strategies under PR in the b-d, b-v and d-v planes respectively. To assess the impact of PR on the farmer's optimal strategies, we compare the privately optimal strategies without and with PR in SM 5.8 through SM 5.10 in the b-d, b-v and d-v planes correspondingly and compare the privately optimal strategies under PR with social optimum as given in SM 5.11.

SM 5.1 Farmer's optimal strategies without PR in the *b*-*d* plane

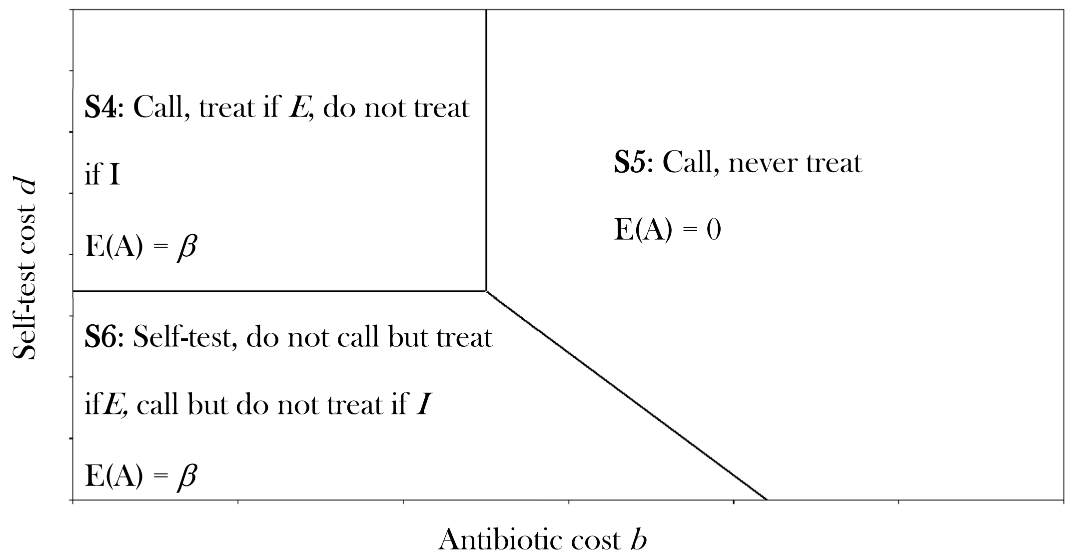

Figure 1 Farmer's optimal strategies in the *b*-*d* plane given low veterinary service cost $v < (1-\beta)(l_3 - l_2)$.

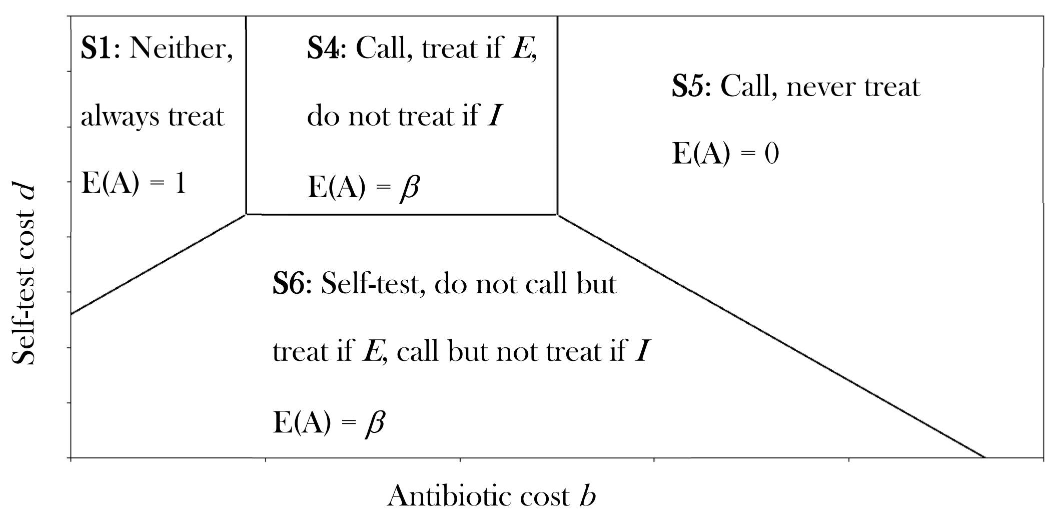

Figure 2 Farmer's optimal strategies in the *b*-*d* plane given lower medium veterinary service cost $(1-\beta)(l_3 - l_2) < v < (1-\beta)(l_3 - l_1)$.

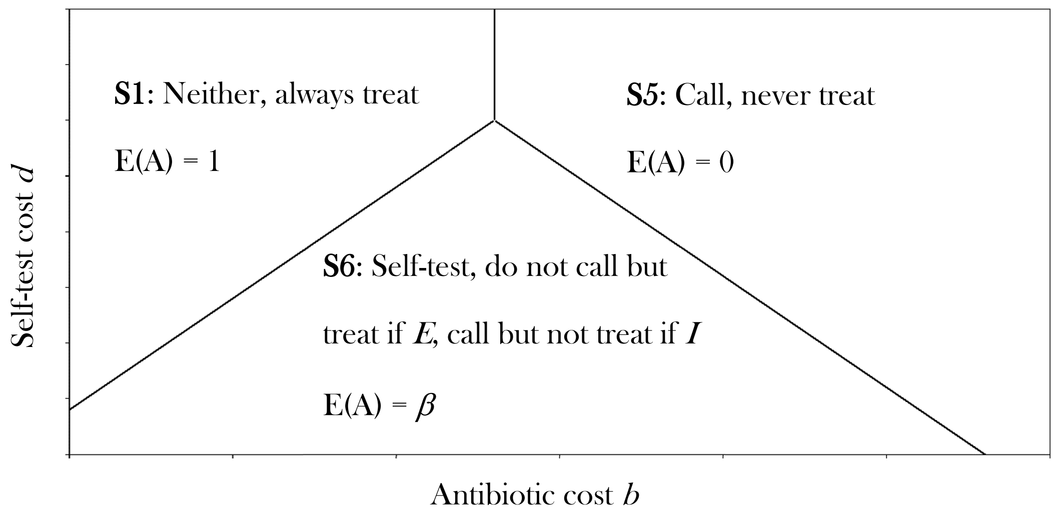

Figure 3 Farmer's optimal strategies in the b-d plane given upper medium veterinary service cost $(1-\beta)(l_3 - l_1) < v < l_3 - l_2$.

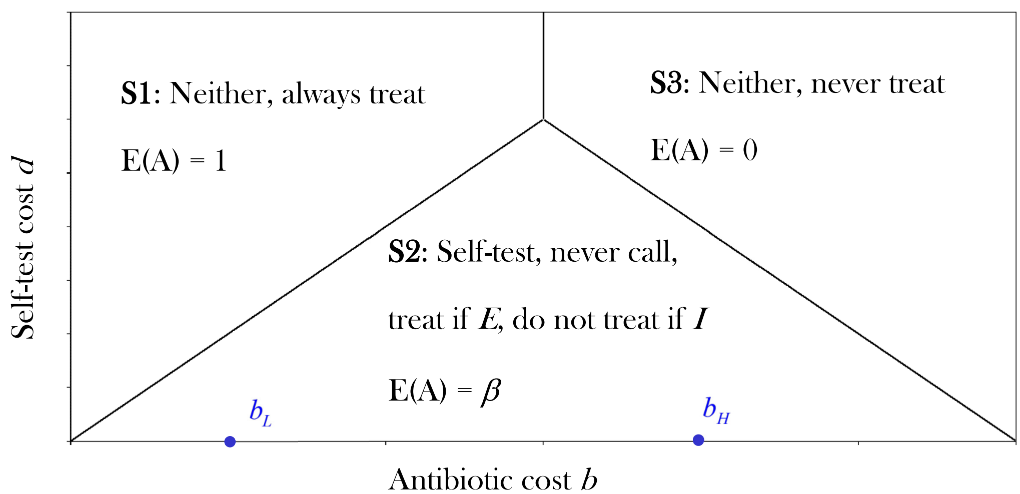

Figure 4 Farmer's optimal strategies in the b-d plane given high veterinary service cost $v > l_3 - l_2$.

SM 5.2 Farmer's optimal strategies without PR in the b-v plane

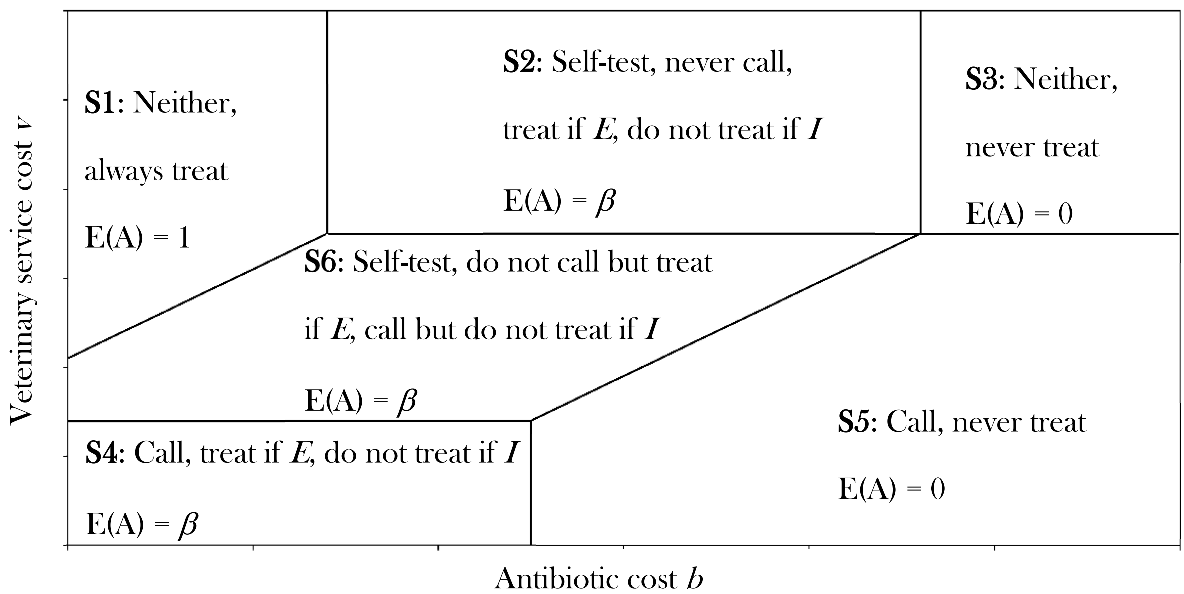

Figure 5 Farmer's optimal strategies in the *b*-*v* plane given low self-test cost $d < \beta(1-\beta)(l_3 - l_1)$.

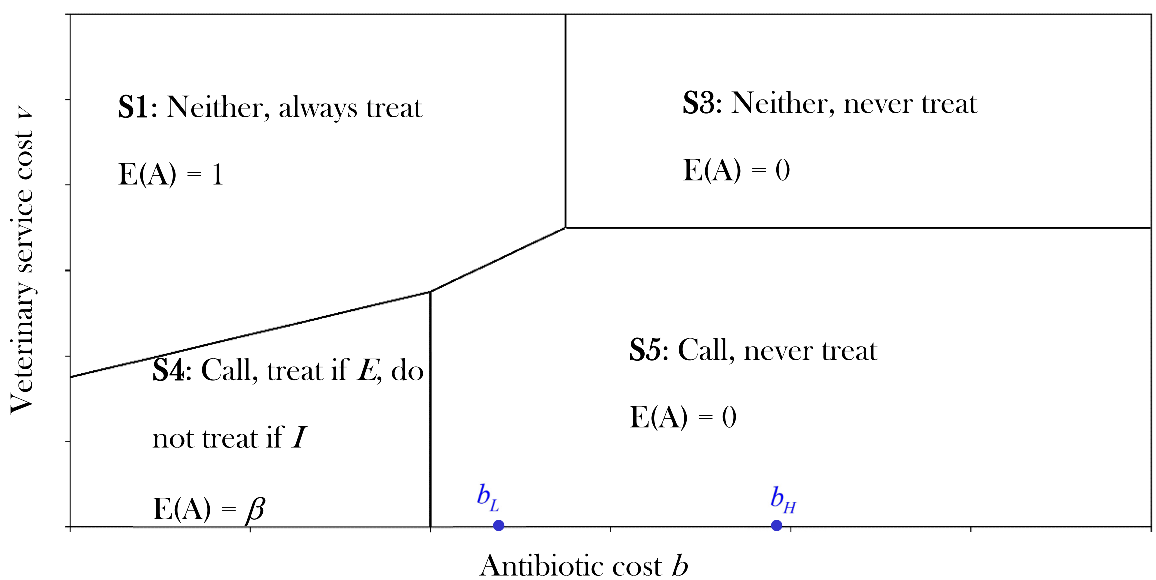

Figure 6 Farmer's optimal strategies in the *b*-*v* plane given high self-test cost $d > \beta(1-\beta)(l_3 - l_1)$.

SM 5.3 Farmer's optimal strategies without PR in the *d*-*v* plane

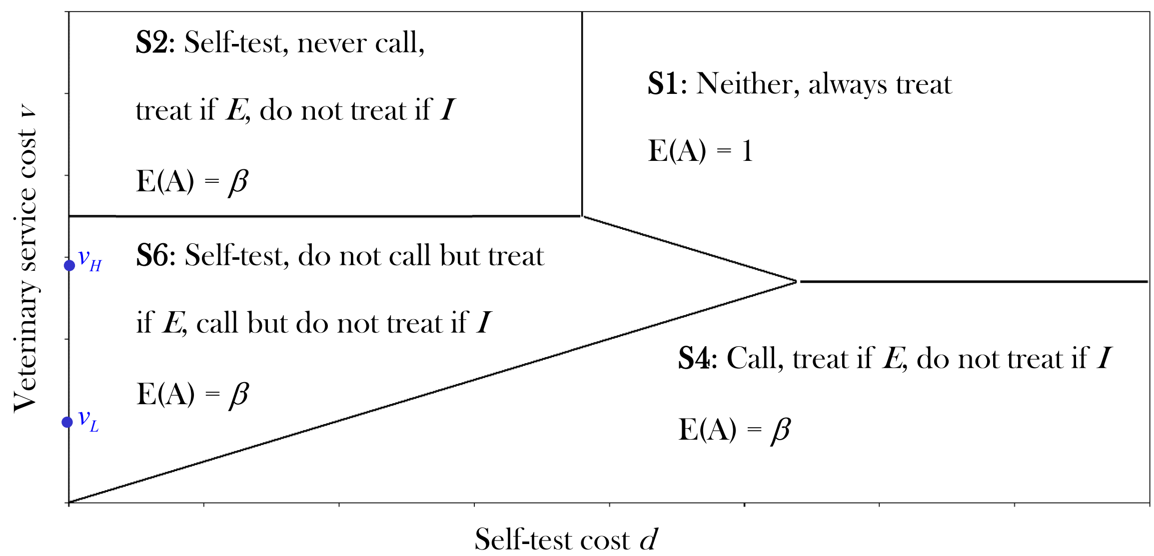

Figure 7 Farmer's optimal strategies in the *d*-*v* plane given low antibiotic cost $b < l_2 - l_1$.

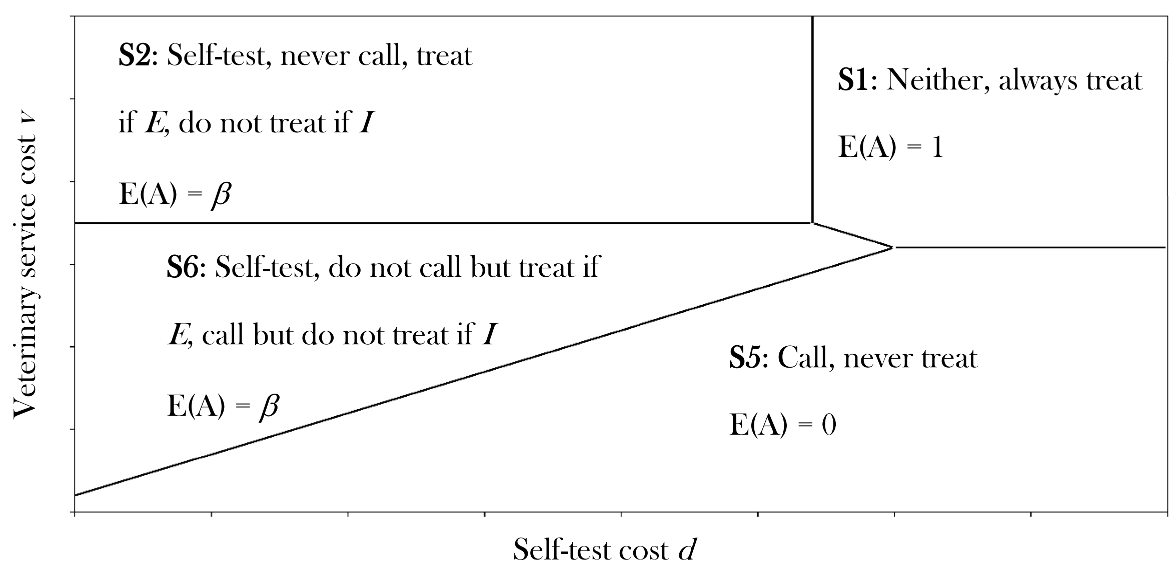

Figure 8 Farmer's optimal strategies in the *d*-*v* plane given lower medium antibiotic cost $l_2 - l_1 < b < \beta(l_3 - l_1)$.

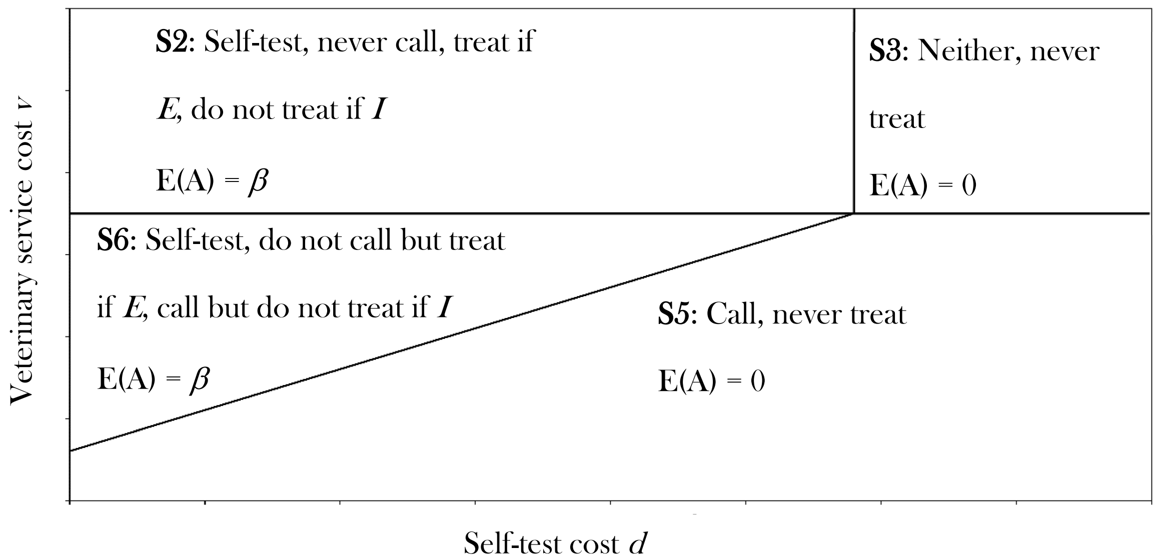

Figure 9 Farmer's optimal strategies in the *d*-*v* plane given upper medium antibiotic cost $\beta(l_3 - l_1) < b < l_3 - l_1$.

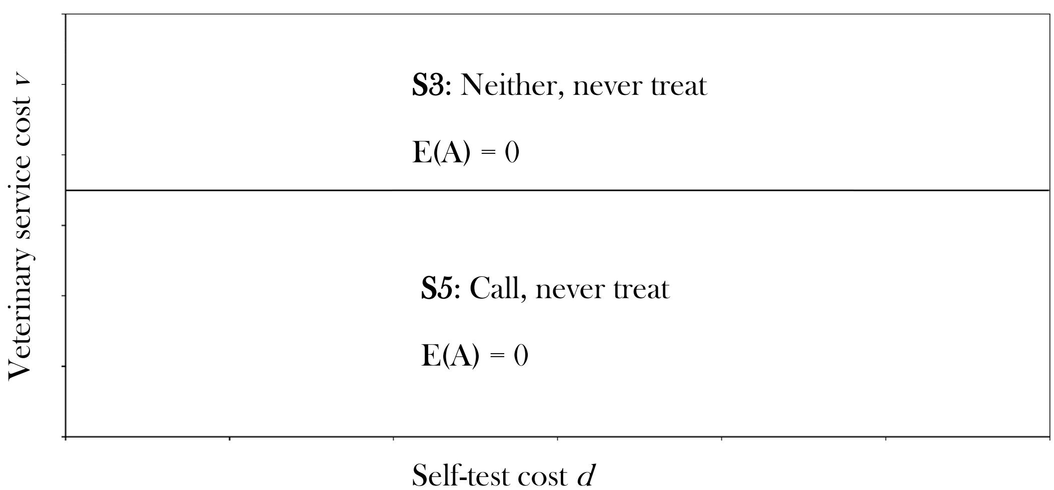

Figure 10 Farmer's optimal strategies in the *d*-*v* plane given high antibiotic cost.

SM 5.4 Comparing privately optimal decisions with socially optimal decisions

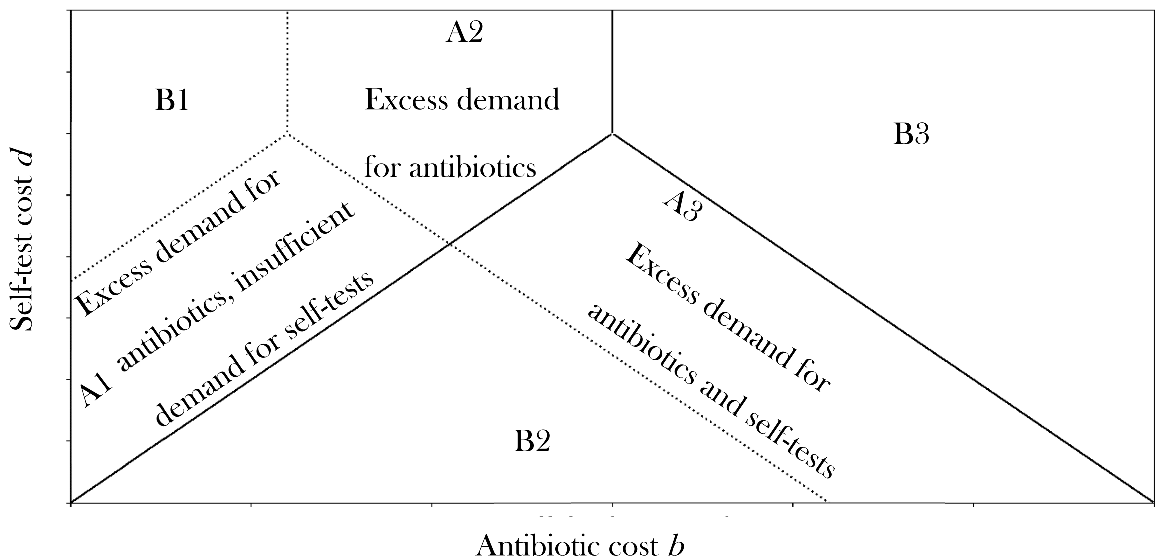

Figure 11 Comparison between farmer's optimal strategies and social optimum in the *b-d* plane given high veterinary service cost $v > l_3 - l_2$

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

Notes: Solid lines indicate boundary conditions across which an unregulated farmer's strategy switches. Dotted lines indicate boundary conditions across which social optimal strategy switches.

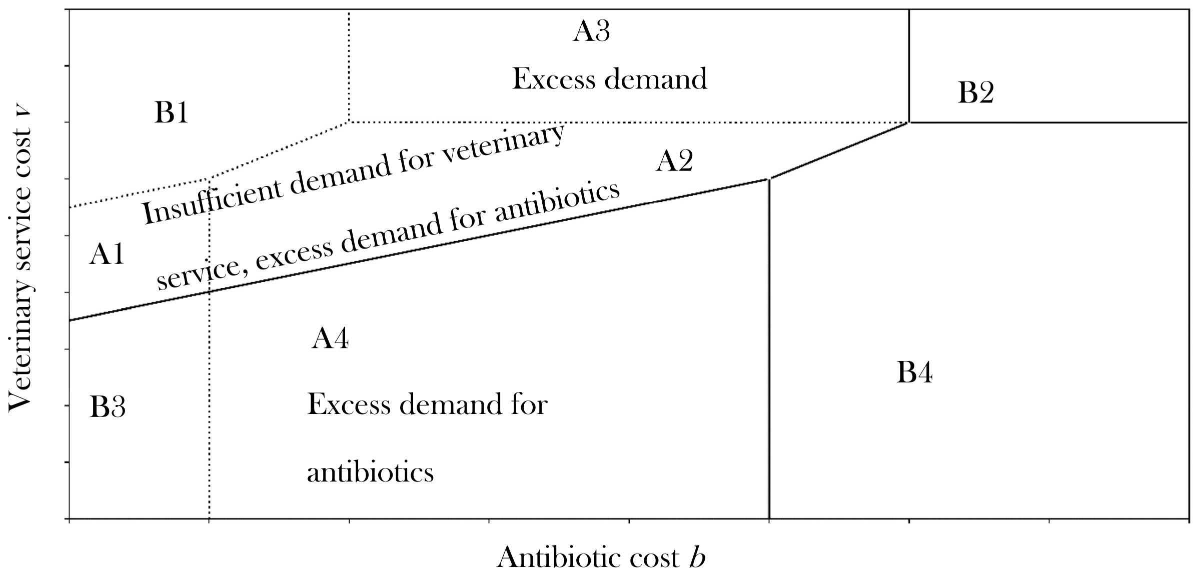

Figure 12 Comparison between farmer's optimal strategies and social optimum in the *b*-*v* plane given high self-test cost $d > \beta(1-\beta)(l_3 - l_1)$

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

Notes: Solid lines indicate boundary conditions between which an unregulated farmer's strategy switches. Dotted lines indicate boundary conditions across which social optimal strategy switches.

SM 5.5 Farmer's optimal strategies under PR in the *b*-*d* plane

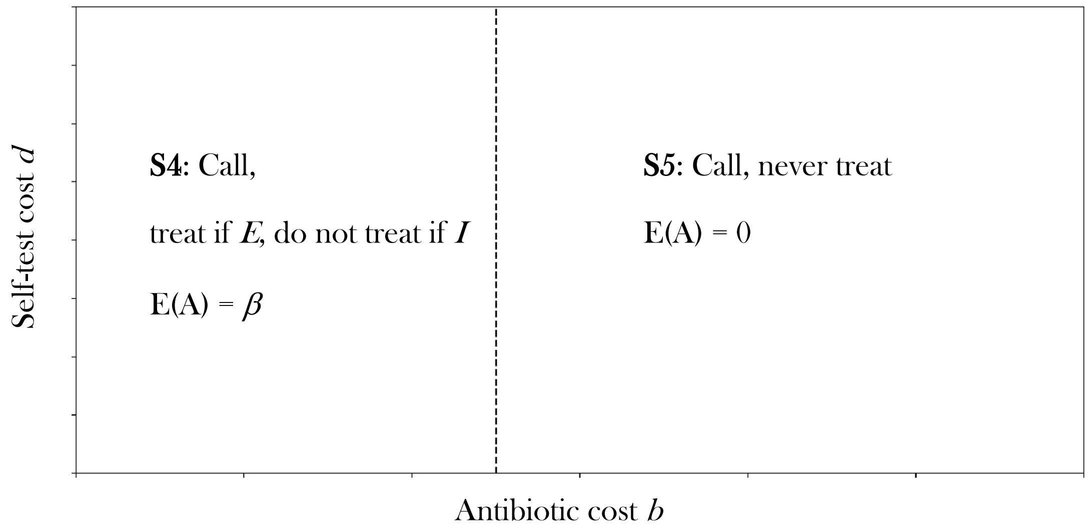

Figure 13 Farmer's optimal strategies under PR in the *b*-*d* plane given low veterinary service cost $v < l_3 - l_2$.

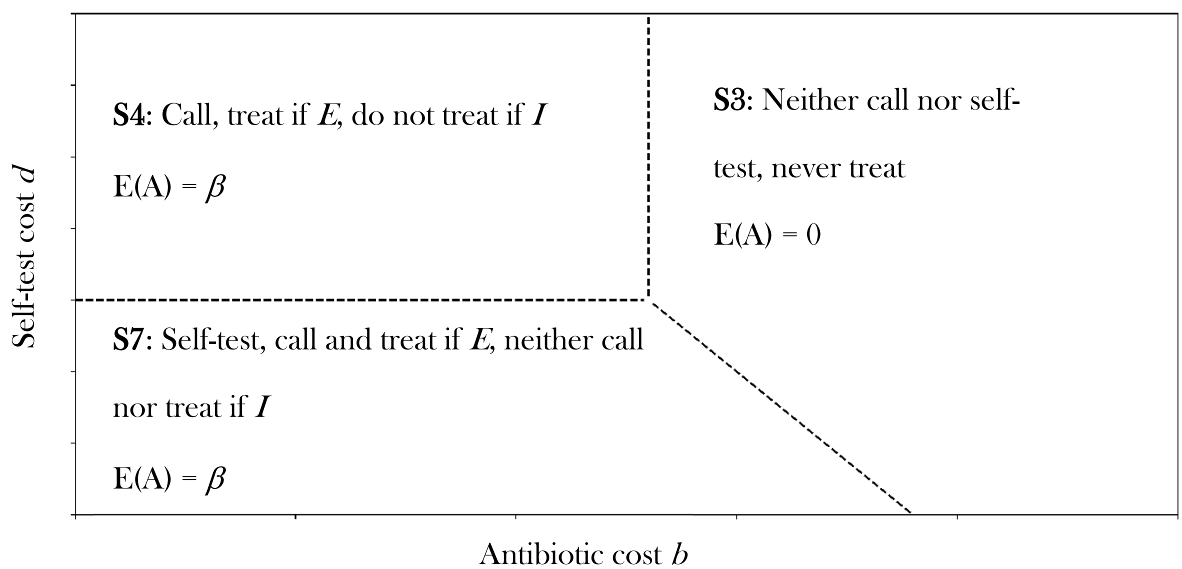

Figure 14 Farmer's optimal strategies under PR in the *b*-*d* plane given lower medium veterinary service cost $l_3 - l_2 < v < l_3 - \beta l_1 - (1-\beta) l_2$.

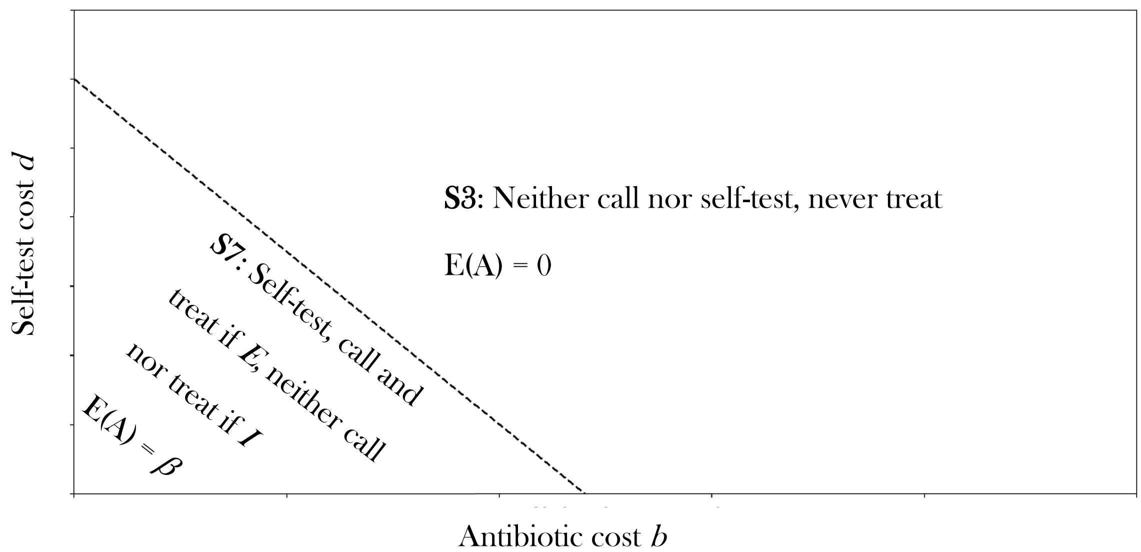

Figure 15 Farmer's optimal strategies under PR in the *b*-*d* plane given upper medium veterinary service cost $l_3 - \beta l_1 - (1-\beta) l_2 < v < l_3 - l_1$.

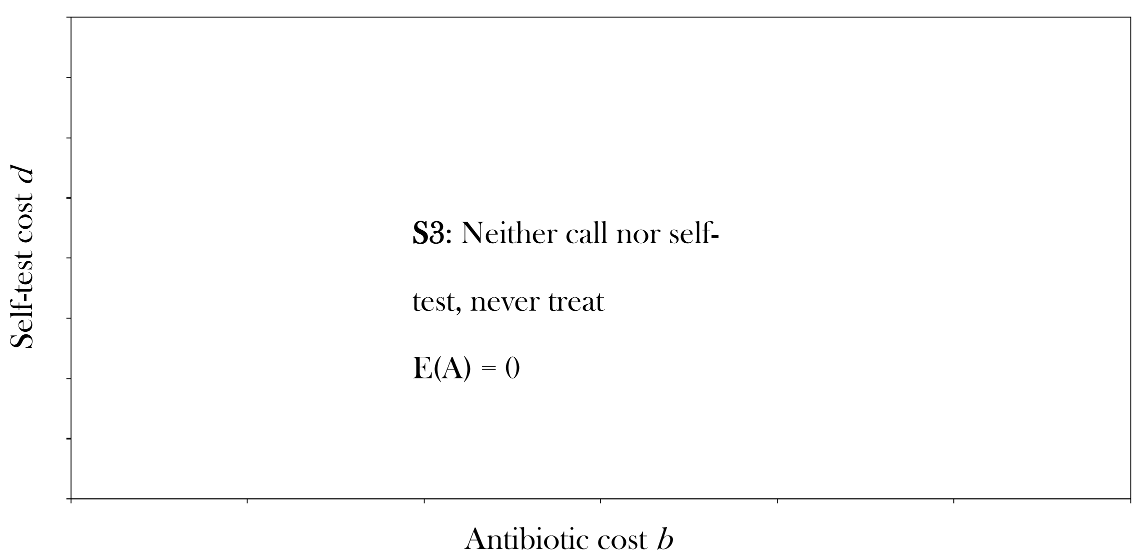

Figure 16 Farmer's optimal strategies under PR in the *b*-*d* plane given high veterinary service cost $v > l_3 - l_1$.

SM 5.6 Farmer's optimal strategies under PR in the *b*-*v* plane

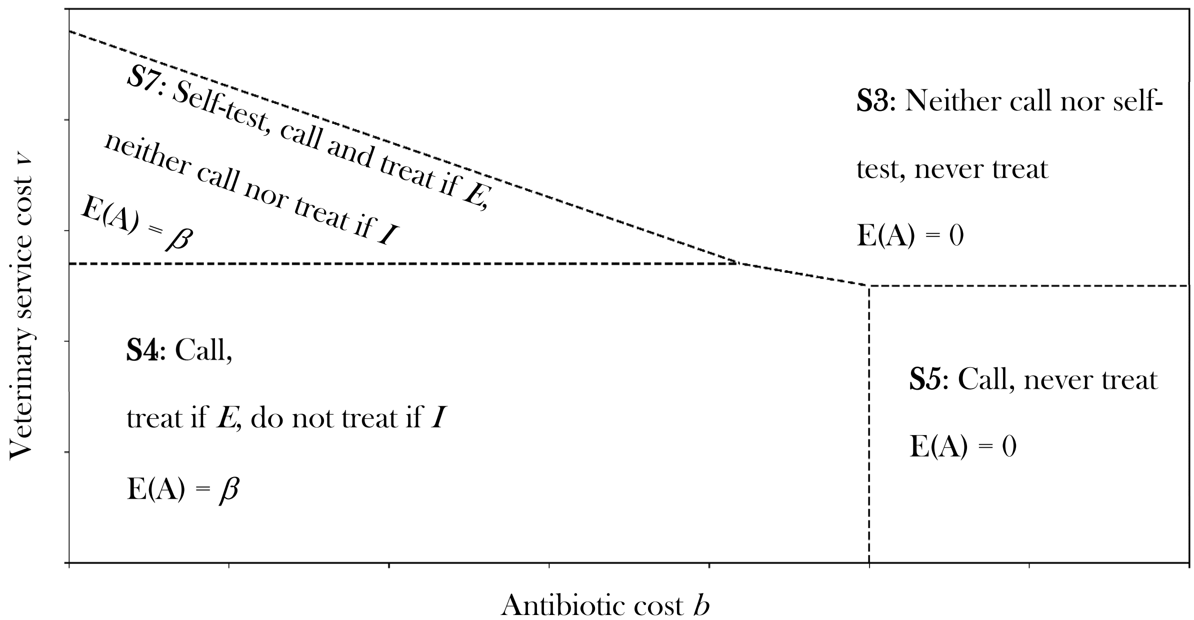

Figure 17 Farmer's optimal strategies under PR in the *b*-*v* plane given low self-test cost $d < \beta(1-\beta)(l_2 - l_1)$.

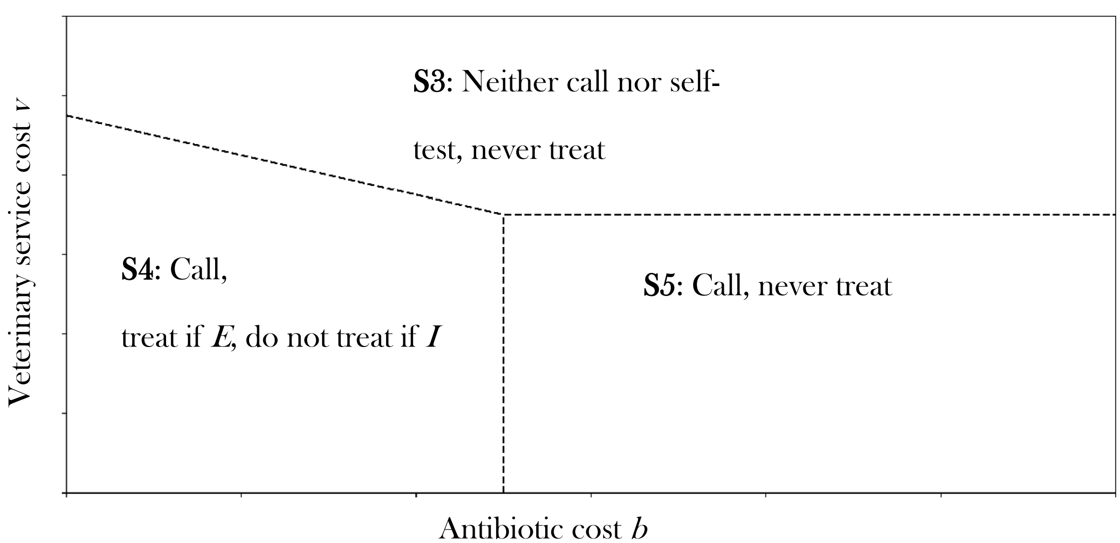

Figure 18 Farmer's optimal strategies under PR in the *b*-*v* plane given high self-test cost $d > \beta(1-\beta)(l_2 - l_1)$.

SM 5.7 Farmer's optimal strategies under PR in the *d*-*v* plane

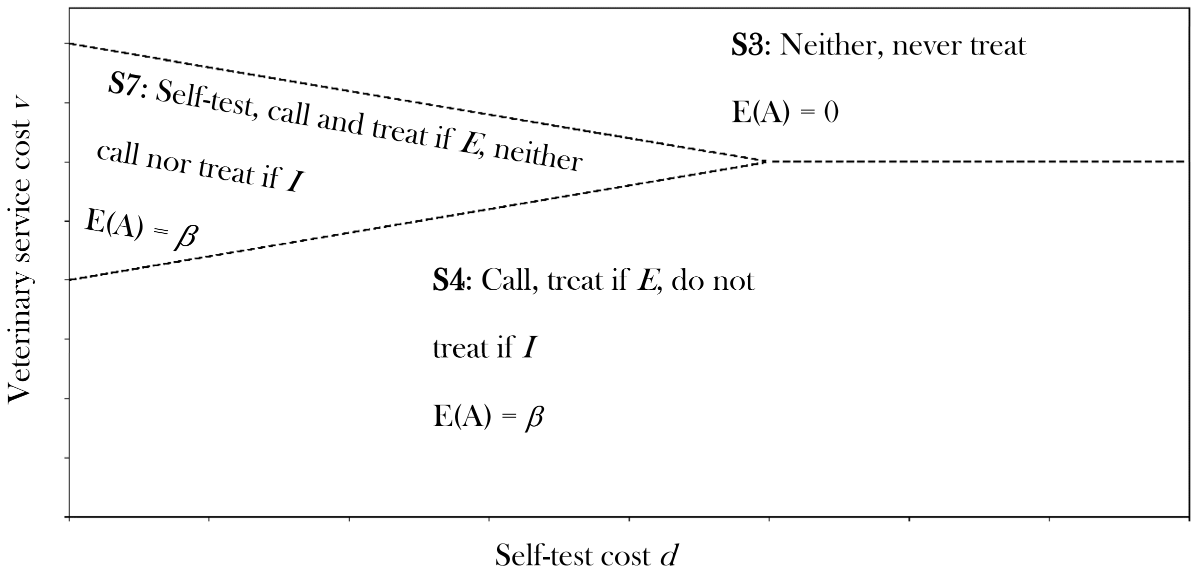

Figure 19 Farmer's optimal strategies under PR in the *d*-*v* plane given low antibiotic cost such that $b < l_2 - l_1$.

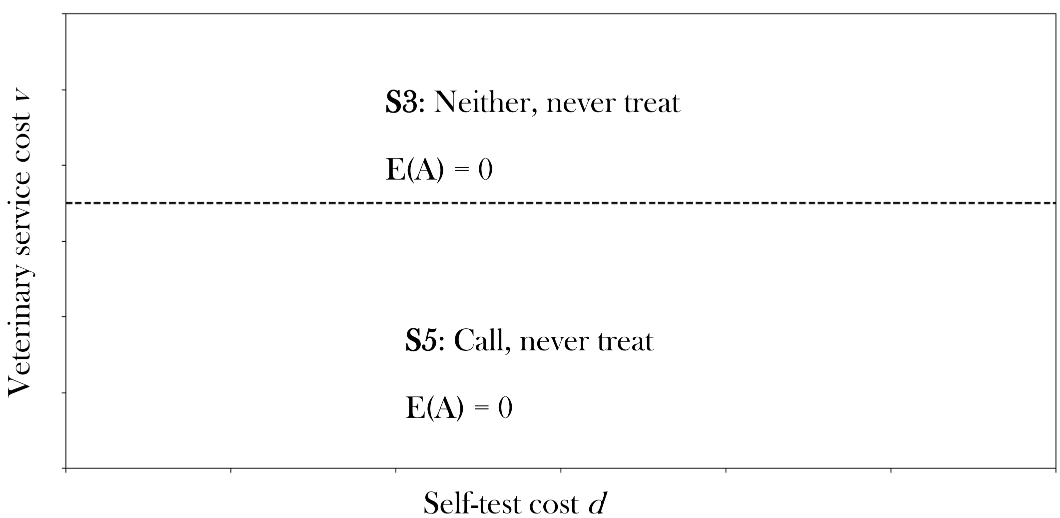

Figure 20 Farmer's optimal strategies under PR in the *d*-*v* plane given high antibiotic cost $b > l_2 - l_1$.

SM 5.8 Comparing farmer's optimal strategies without and with PR in the *b*-*d* plane

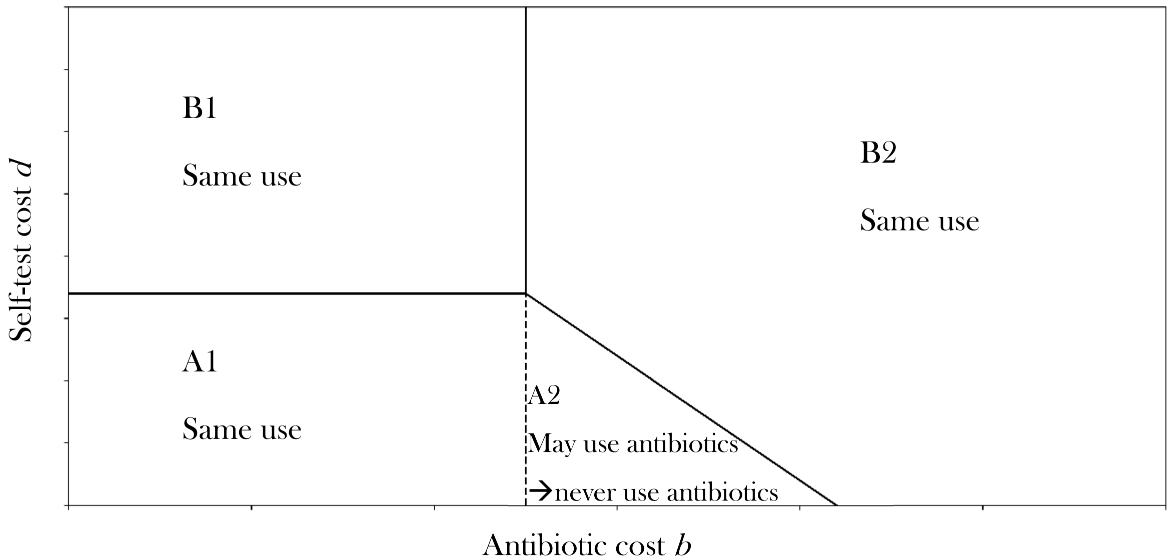

Figure 21 Comparison between farmer's optimal strategies with and without PR in the *b*-*d* plane when veterinary service cost satisfies $v < (1-\beta)(l_3 - l_2)$.

	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 indicate boundary conditions between which an unregulated farmer's optimal strategy switches. Dashed lines indicate boundary conditions between which a PR regulated farmer's optimal strategy switches.

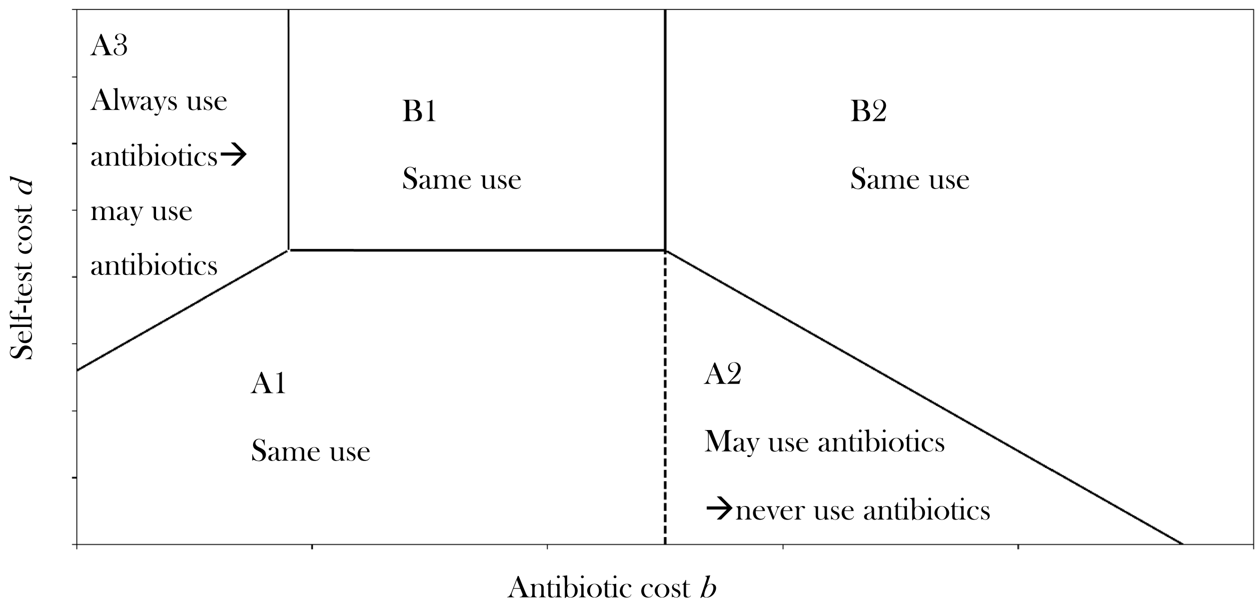

Figure 22 Comparison between farmer's optimal strategies with and without PR in the *b*-*d* plane when veterinary service cost satisfies $(1-\beta)(l_3-l_2)<v<(1-\beta)(l_3-l_1)$.

	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

Note: This figure is to be read as laid out under Figure 21.

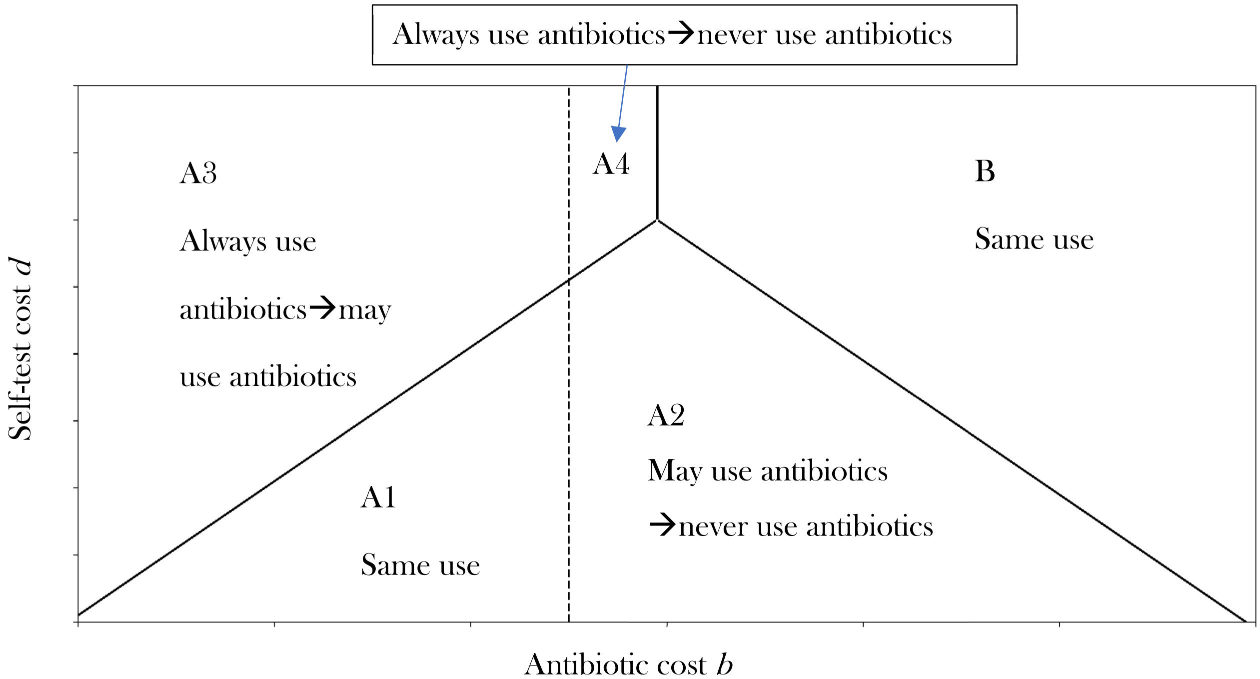

Figure 23 Comparison between farmer's optimal strategies with and without PR in the *b*-*d* plane when veterinary service cost satisfies $(1-\beta)(l_3-l_1)<v<l_3-l_2$.

	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

Note: This figure is to be read as laid out under Figure 21.

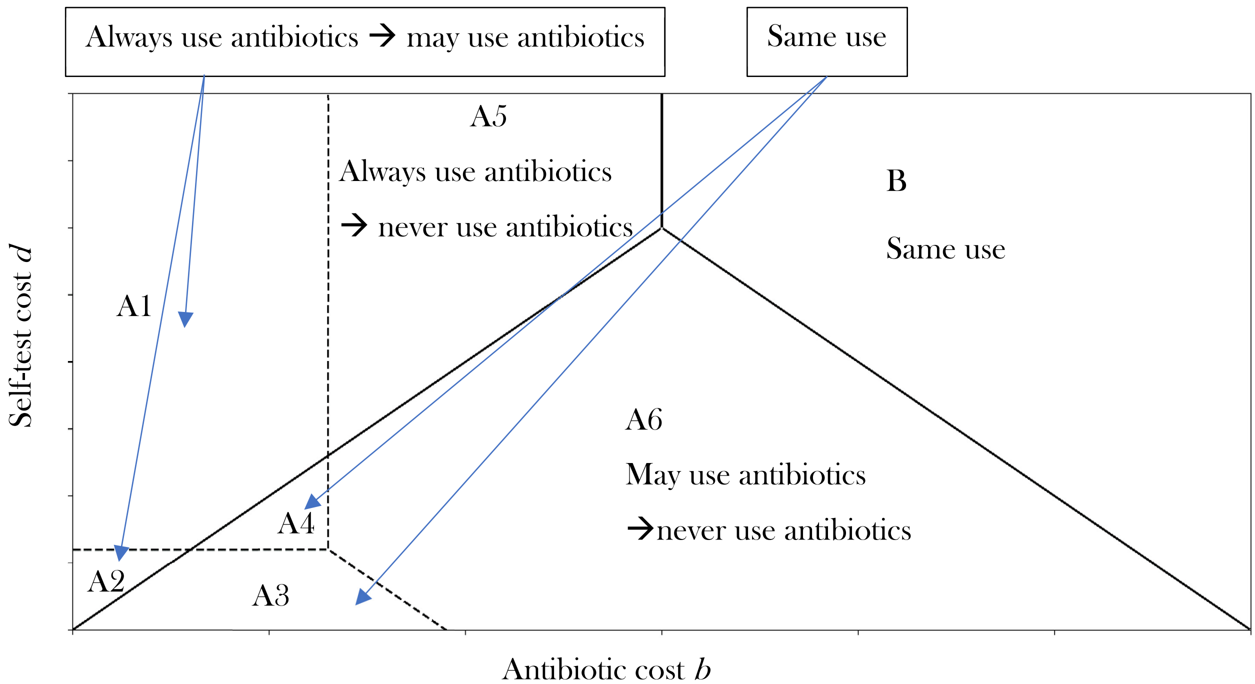

Figure 24 Comparison between farmer's optimal strategies without and with PR in the *b*-*d* plane when veterinary service cost satisfies $l_3 - l_2 < v < l_3 - \beta l_1 - (1-\beta) l_2$.

	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

Note: This figure is to be read as laid out under Figure 21.

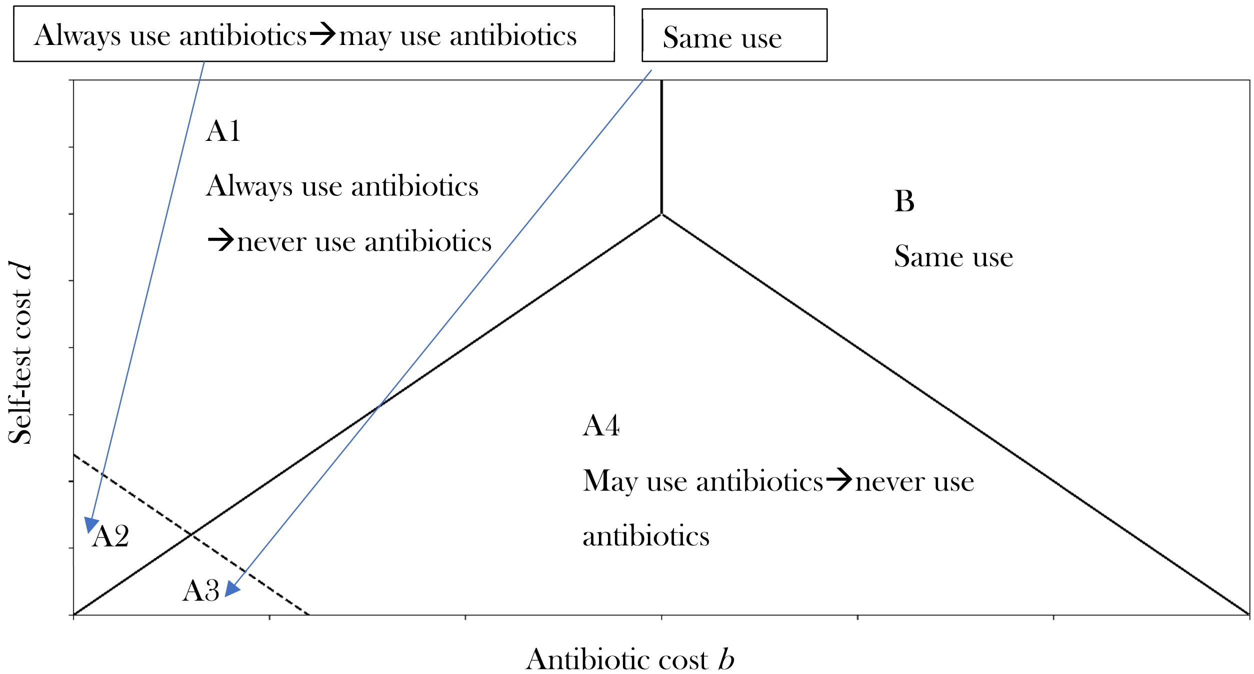

Figure 25 Comparison between farmer's optimal strategies without and with PR in the b-d plane when veterinary service cost satisfies $l_3 - \beta l_1 - (1-\beta) l_2 < v < l_3 - l_1$.

	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

Note: This figure is to be read as laid out under Figure 21.

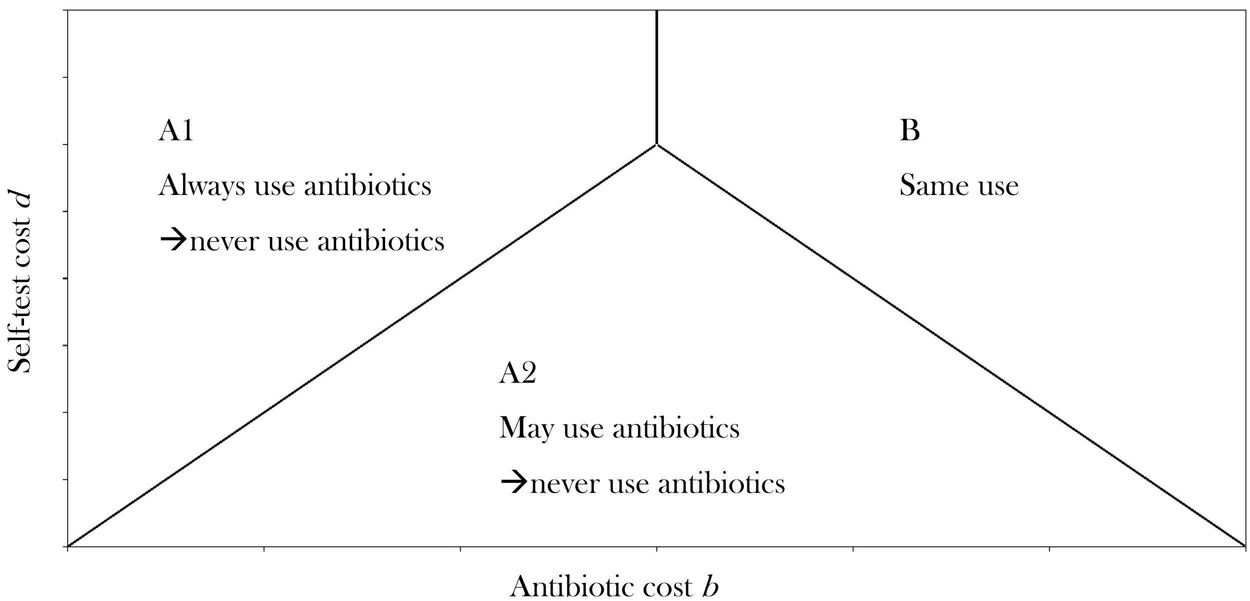

Figure 26 Comparison between farmer's optimal strategies without and with PR in the *b*-*d* plane when veterinary service cost satisfies $v > l_3 - l_1$.

	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

Note: This figure is to be read as laid out under Figure 21.

SM 5.9 Comparing farmer's optimal strategies without and with PR in the *b*-*v* plane

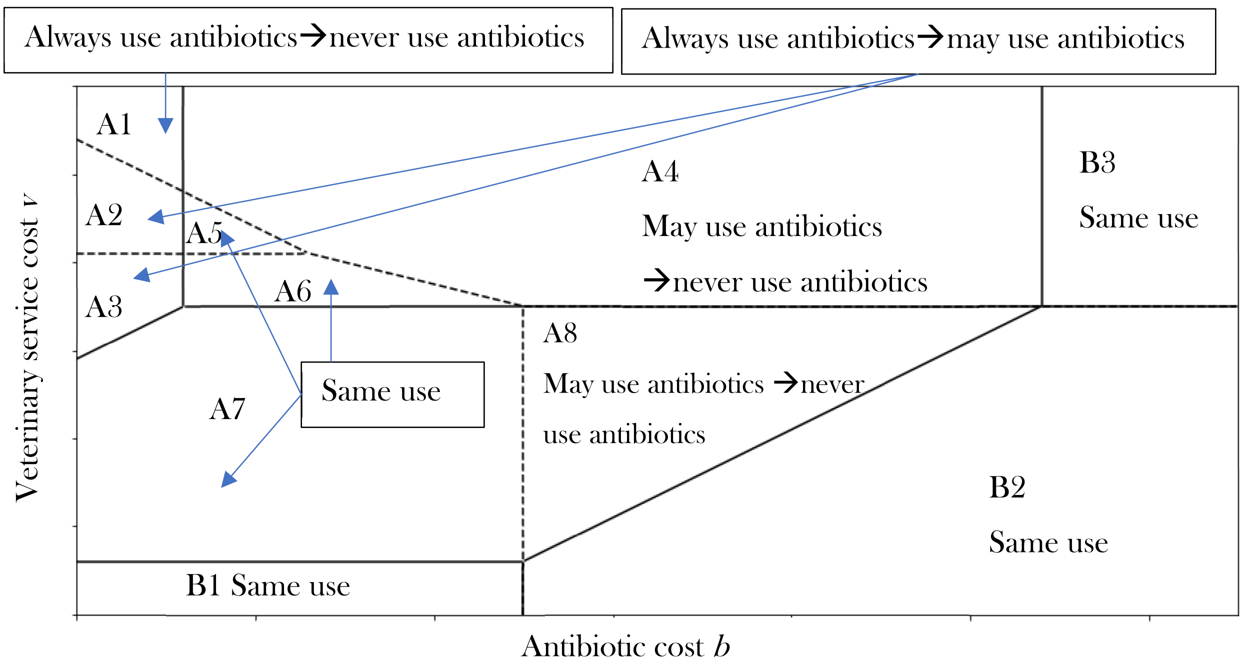

Figure 27 Comparison between farmer's optimal strategies without and with PR in the *b*-*v* plane when self-test cost satisfies $d < \beta(1-\beta)(l_2 - l_1)$.

	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

Note: This figure is to be read as laid out under Figure 21.

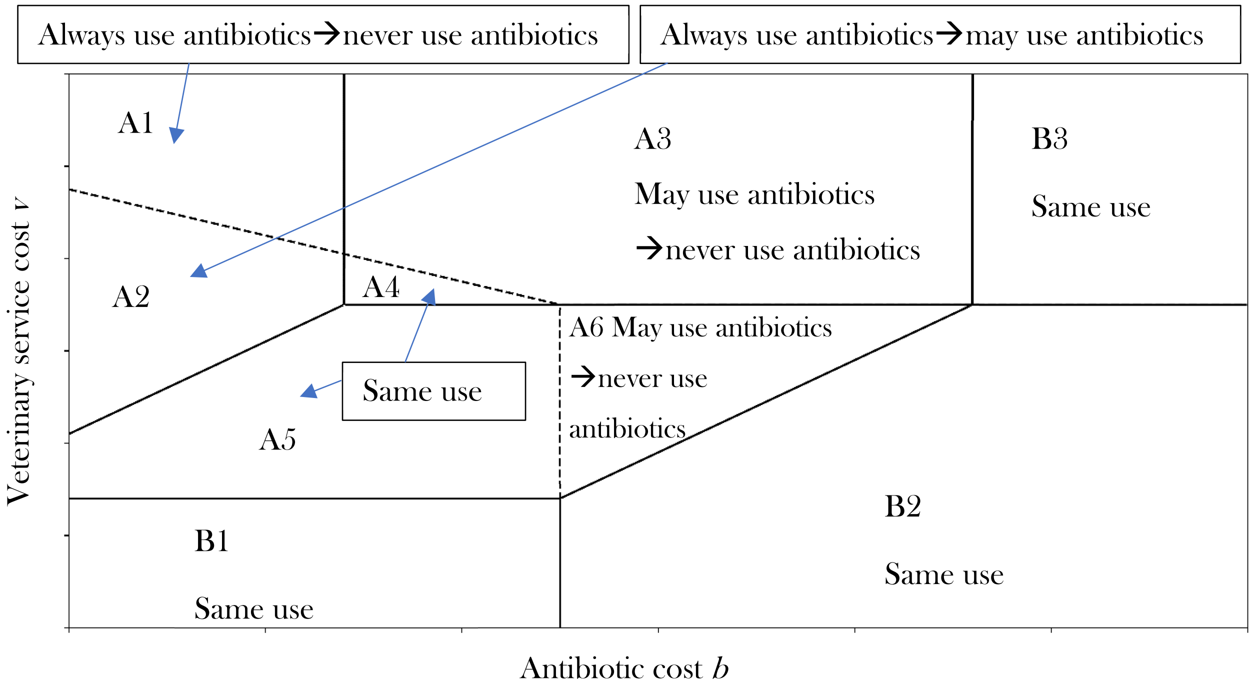

Figure 28 Comparison between farmer's optimal strategies without and with PR in the *b*-*v* plane when self-test cost satisfies $\beta(1-\beta)(l_2-l_1)<d<\beta(1-\beta)(l_3-l_1)$.

	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

Note: This figure is to be read as laid out under Figure 21.

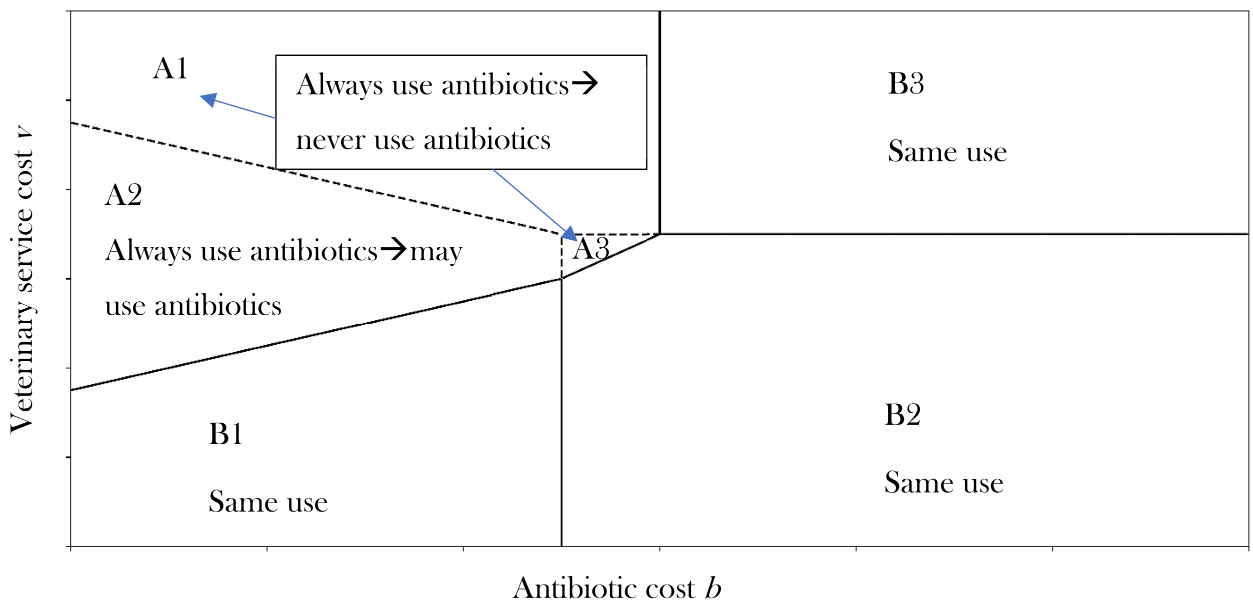

Figure 29 Comparison between farmer's optimal strategies without and with PR in the *b*-*v* plane when self-test cost satisfies $d > \beta(1-\beta)(l_3 - l_1)$.

	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

Note: This figure is to be read as laid out under Figure 21.

SM 5.10 Comparing farmer's optimal strategies without and with PR in the *d*-*v* plane

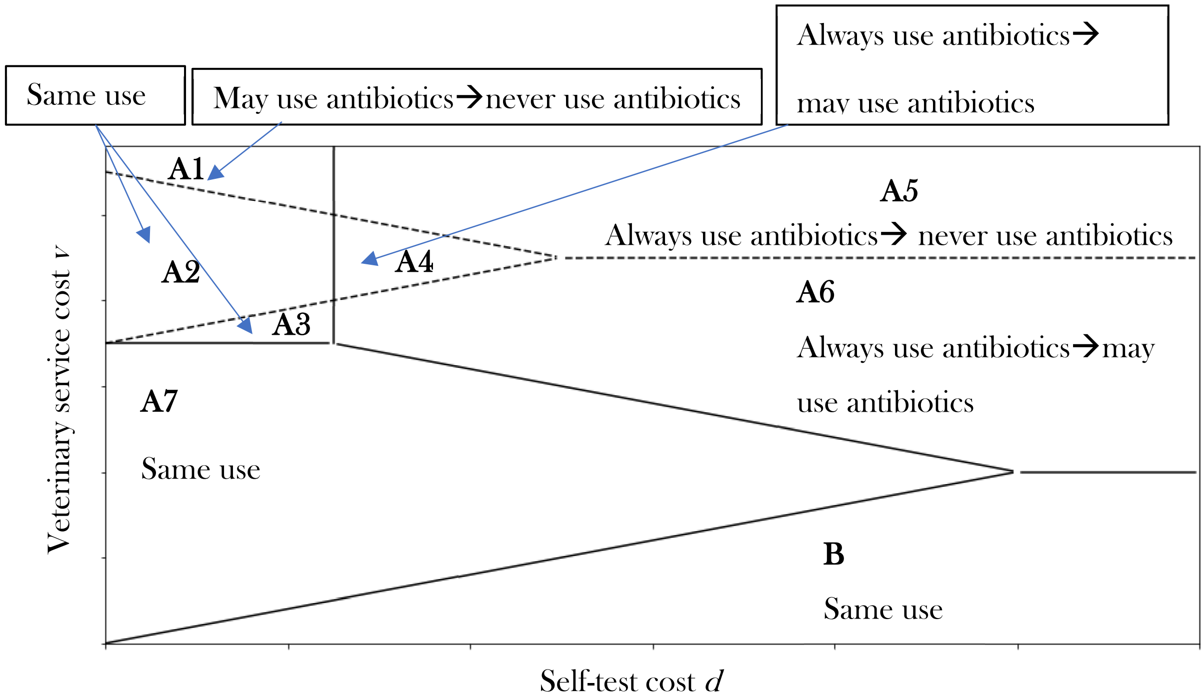

Figure 30 Comparison between farmer's optimal strategies without and with PR in the d-v plane when low antibiotic cost $b < l_2 - l_1$

	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

Note: This figure is to be read as laid out under Figure 21.

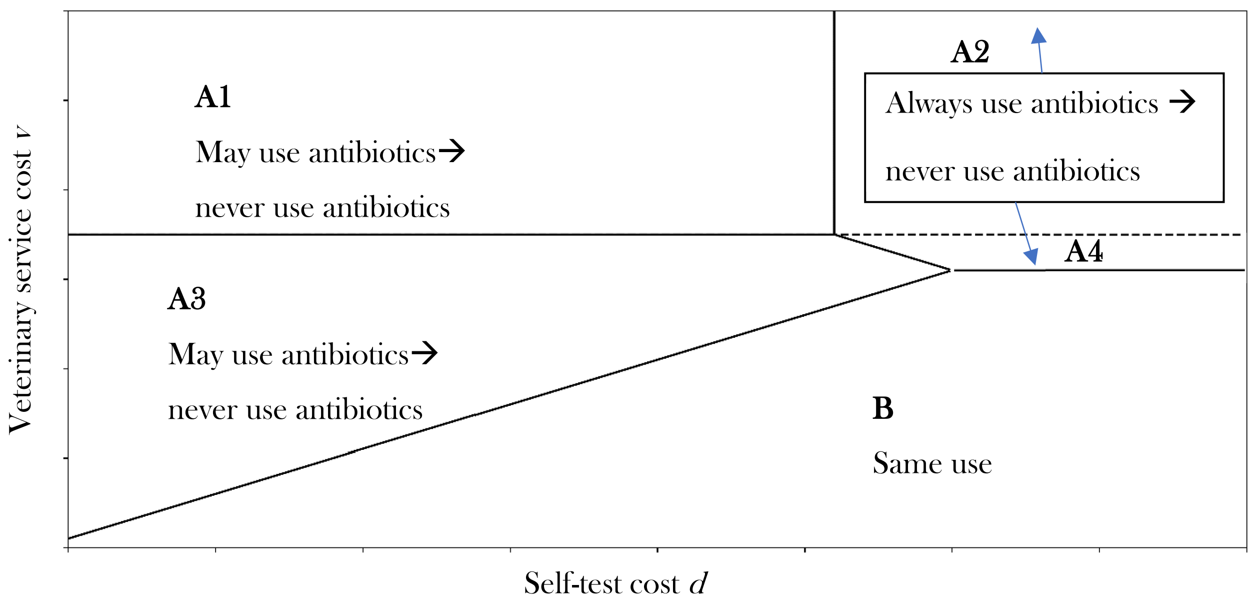

Figure 31 Comparison between farmer's optimal strategies with and without PR in the *d*-*v* plane when antibiotic cost satisfies $l_2 - l_1 < b < l_3 - l_1$.

	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) This figure is to be read as laid out under Figure 21.
(2) When $b > l_3 - l_1$, PR regulation does not change farmer's optimal strategies. Therefore, the comparison figure is not included.

SM 5.11 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 figure 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 32, Figure 33 and Figure 34, respectively, to indicate how the social optimum varies with cost parameters (d, v). We also provide an example comparison in the b-d plane. Based on Figure 14, we assume low and high antibiotic resistance cost and add dotted lines in Figure 35 and Figure 36. Note that dashed lines indicate boundary conditions across which a PR regulated farmer's optimal strategy switches. Dotted lines indicate boundary conditions for social optimal strategy.

We use colors to illustrate an assessment of PR efficiency. In the white area, PR reduces social welfare: the unregulated farmer's strategies realize social optimum while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but PR does not support social optimum. Whether PR pushes private strategies toward social optimum or further away from social optimum depends on context. In light grey areas, PR improves the farmer's strategies and produces social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

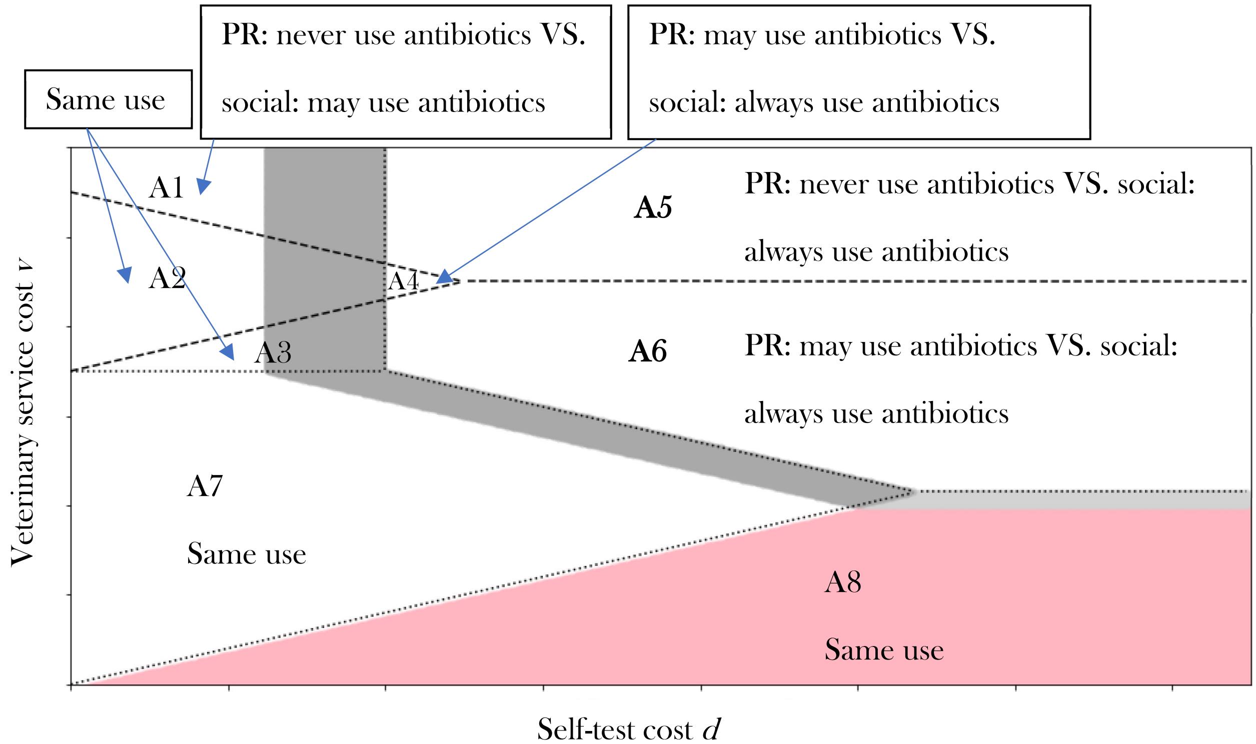

Figure 32 Comparison between farmer's optimal strategies under PR and social optimum assuming antibiotic cost $b < l_2 - l_1$ and low antibiotic resistance cost.

	Under PR	**Social optimum**
A1	Neither call nor self-test, 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 call nor self-test, always treat
A5	Neither call nor self-test, never treat	Neither call nor self-test, always treat
A6	Call, treat if *E*, do not treat if *I*	Neither call nor self-test, 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 boundary conditions across which a PR regulated farmer's optimal strategy switches. Analogously, dotted lines present boundary conditions for a social optimal strategy.

(2) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In light grey area, PR improves the farmer's strategies and produces social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

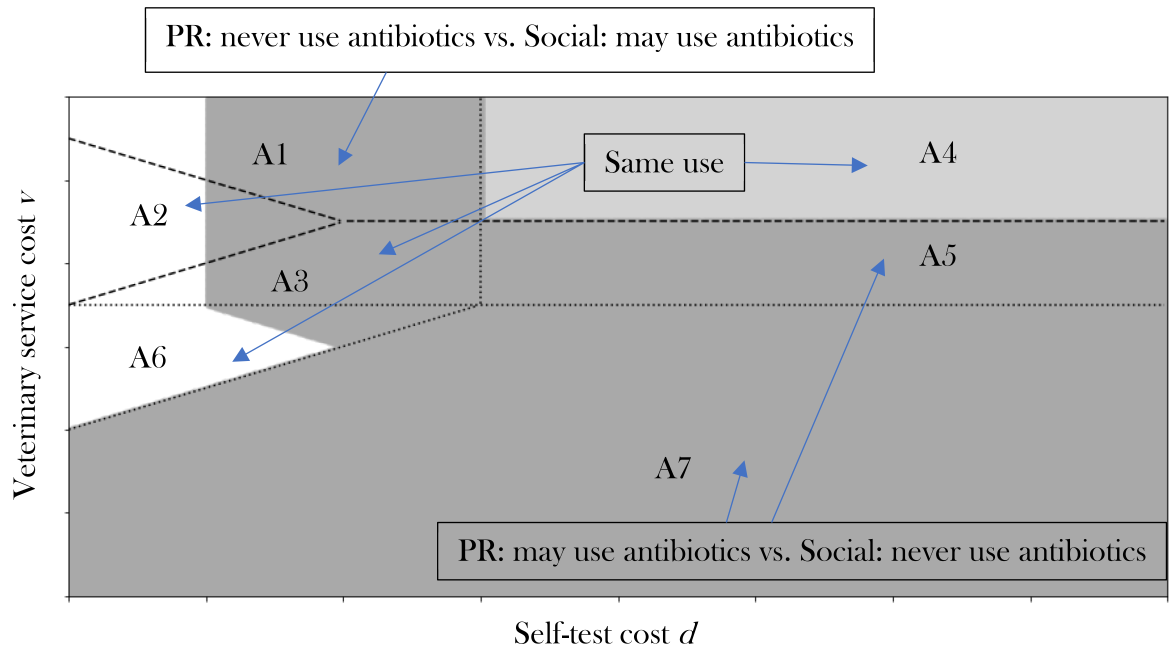

Figure 33 Comparison between farmer's optimal strategies under PR and social optimum assuming antibiotic cost $b < l_2 - l_1$ and medium antibiotic resistance cost

	Under PR	**Social optimum**
A1	Neither call nor self-test, 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 call nor self-test, never treat	**Same**
A5	Call, treat if *E*, do not treat if *I*	Neither call nor self-test, 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 boundary conditions across which a PR regulated farmer's optimal strategy switches. Analogously, dotted lines present boundary conditions for a social optimal strategy.

(2) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In light grey area, PR improves the farmer's strategies and produces social optimum.

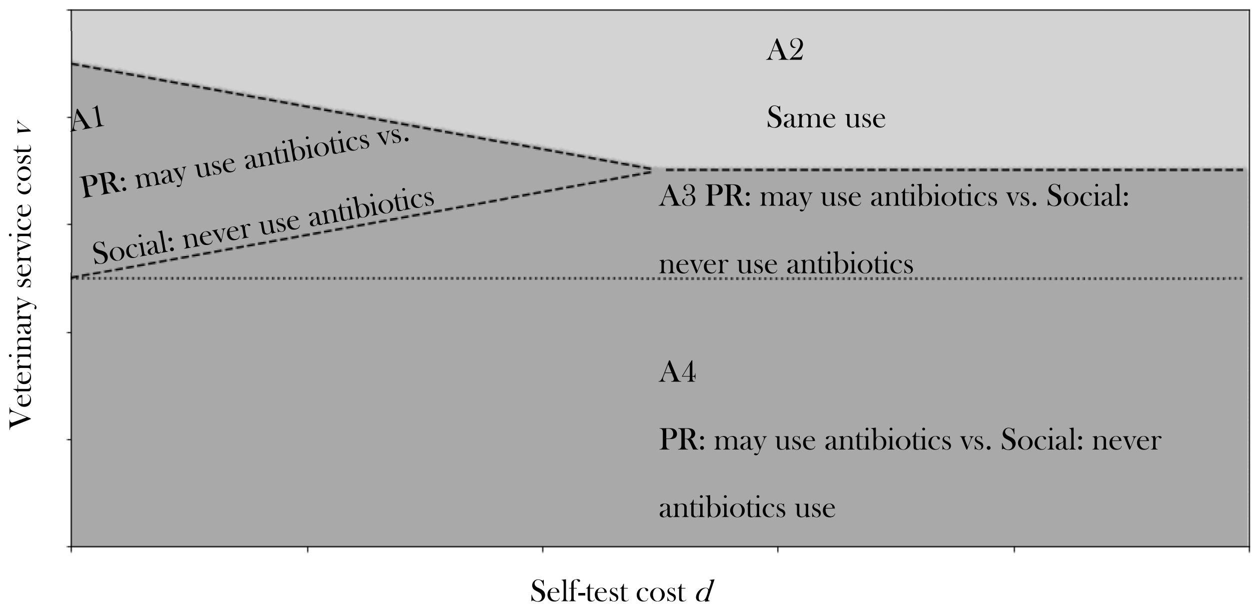

Figure 34 Comparison between farmer's optimal strategies under PR and social optimum assuming antibiotic cost $b < l_2 - l_1$ and high antibiotic resistance cost.

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

Notes: (1) Dashed lines indicate boundary conditions across which a PR regulated farmer's optimal strategy switches. Analogously, dotted lines present boundary conditions for a social optimal strategy.

(2) In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In light grey area, PR improves the farmer's strategies and produces social optimum.

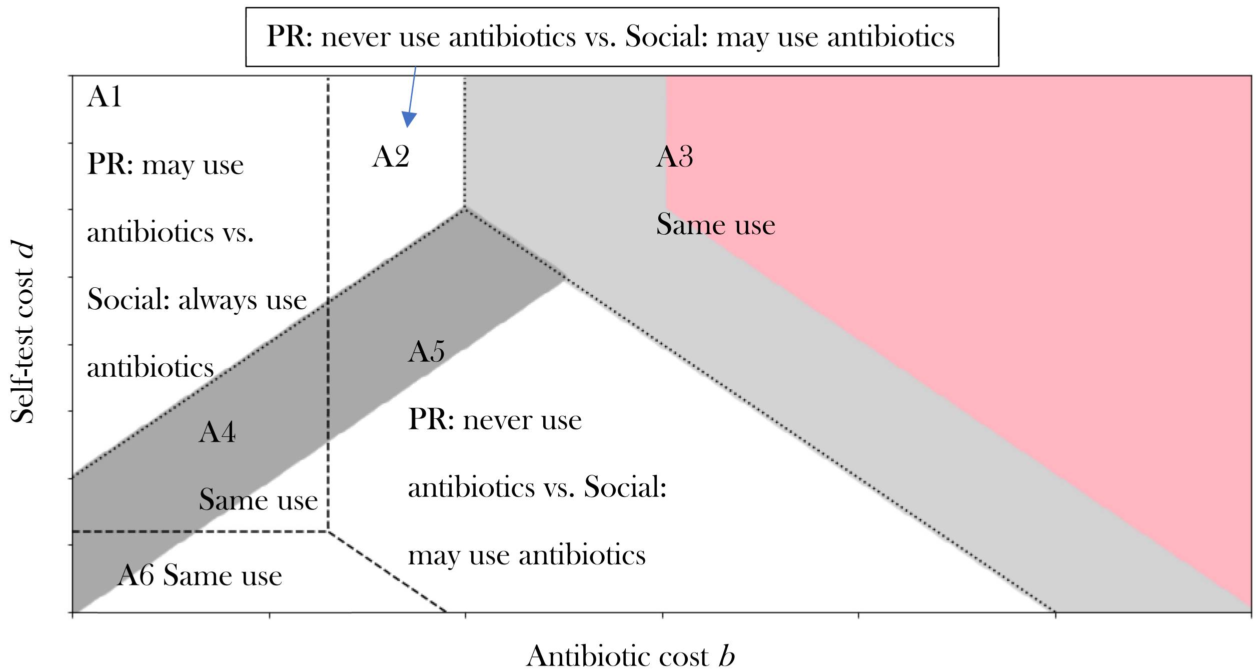

Figure 35 Comparison between farmer's optimal strategies under PR and social optimum assuming veterinary service cost $v > l_3 - l_2$ and low antibiotic resistance cost.

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 boundary conditions across which a PR regulated farmer's optimal strategy switches. Analogously, dotted lines present boundary conditions for a social optimal strategy.

(2) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In light grey area, PR improves the farmer's strategies and produces social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

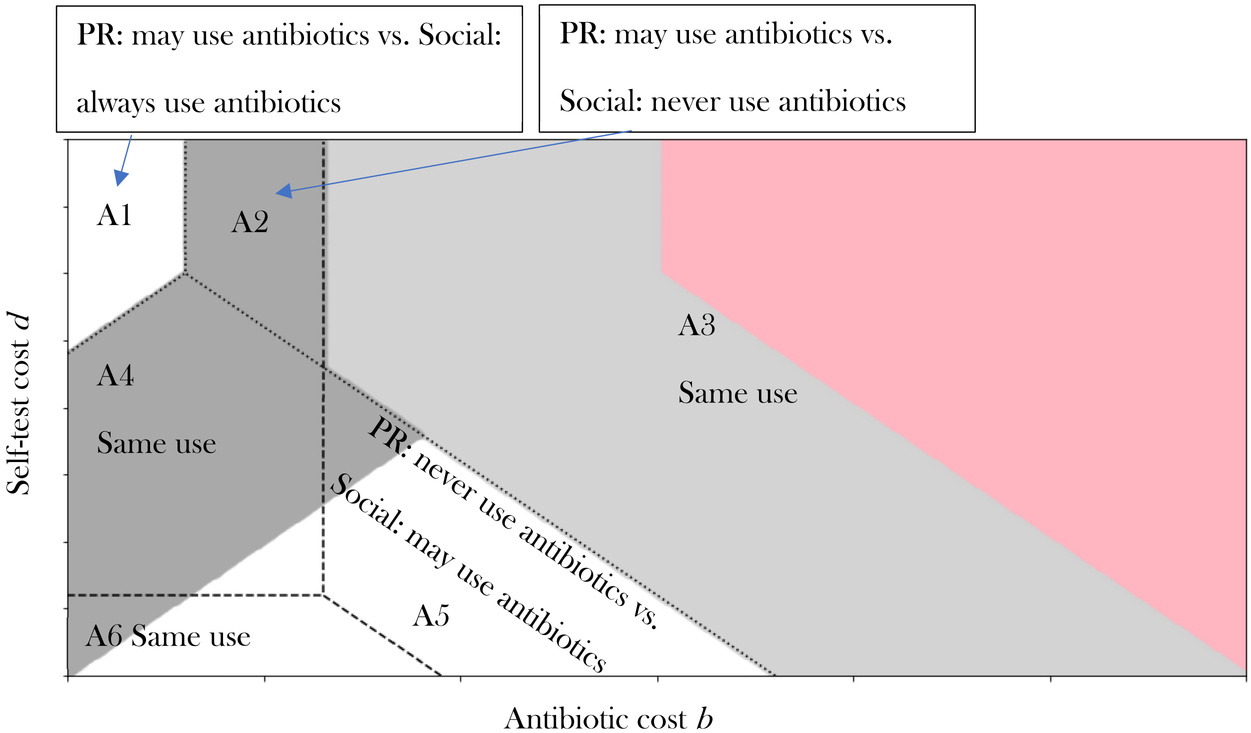

Figure 36 Comparison between farmer's optimal strategies under PR and social optimum assuming veterinary service cost $v > l_3 - l_2$ and high antibiotic resistance cost.

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 boundary conditions across which a PR regulated farmer's optimal strategy switches. Analogously, dotted lines present boundary conditions for a social optimal strategy.

(2) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In light grey area, PR improves the farmer's strategies and produces social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

SM 5.12 Heterogeneity across farmer's characteristics

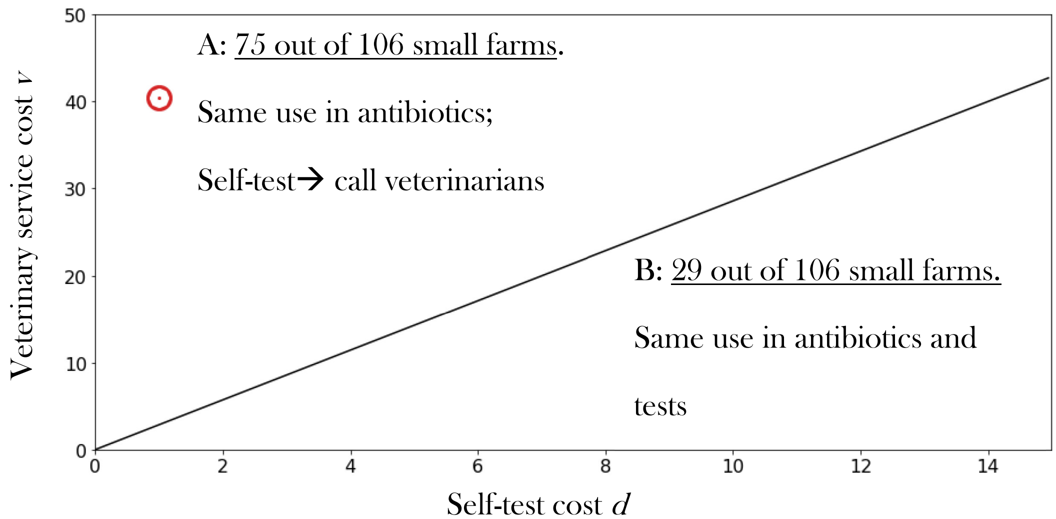

Figure 37 Comparison between small farm's optimal strategies without and with PR given parameter values listed in Table 4-1.

Notes: (1) The comprehensive graphical representation of small, medium and large farms closely resembles Figure 5. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Solid lines indicate boundary conditions across which an unregulated farmer's optimal strategy switches. In this figure, a PR regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

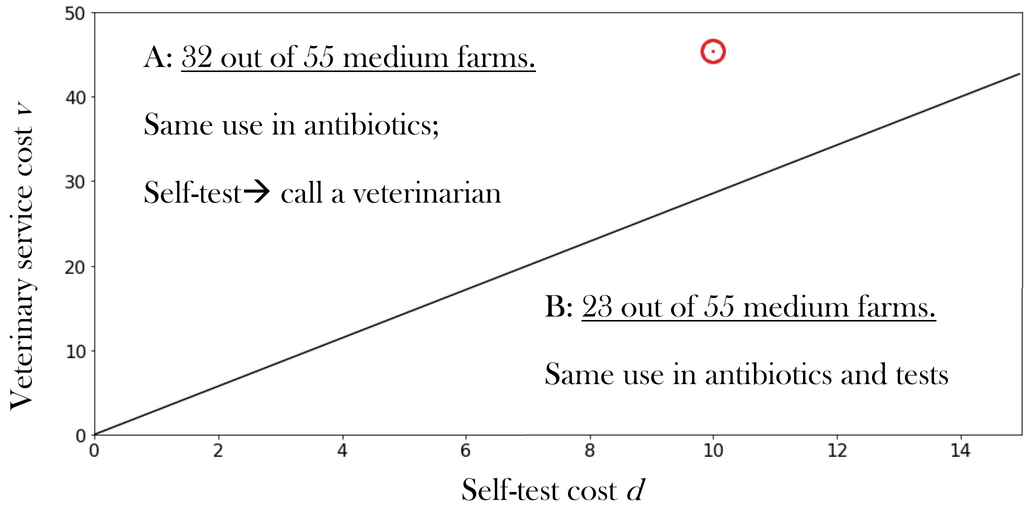

Figure 38 Comparison between medium farm's optimal strategies without and with PR given parameter values listed in Table 4-1.
Note: This figure is to be read as laid out under Figure 37.

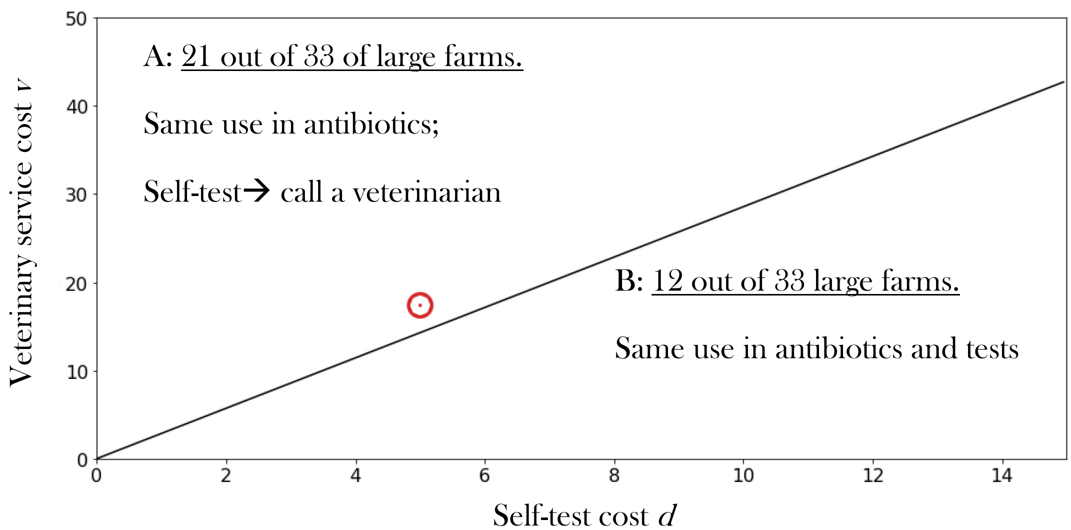

Figure 39 Comparison between large farm's optimal strategies without and with PR given parameter values listed in Table 4-1.
Note: This figure is to be read as laid out under Figure 37.

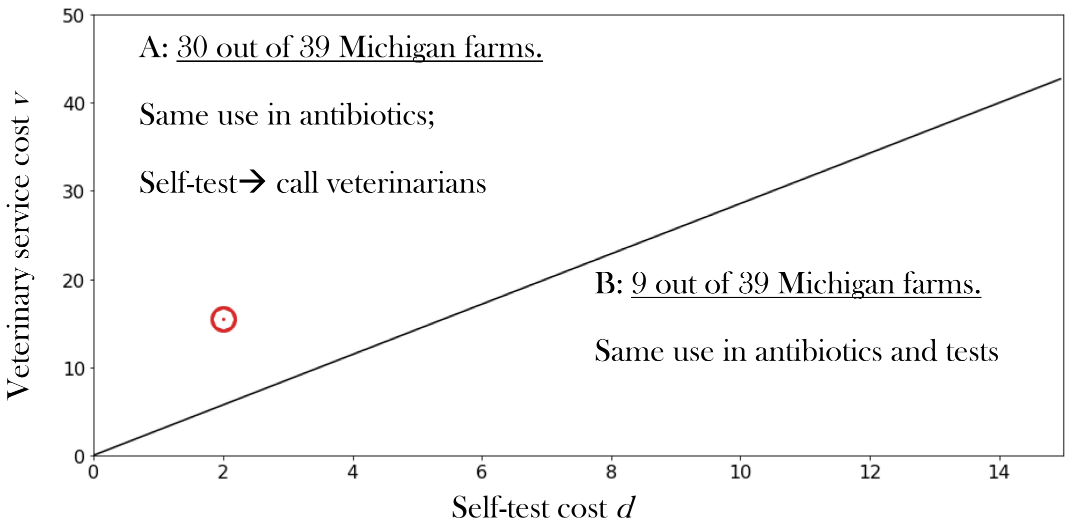

Figure 40 Comparison between Michigan farm's optimal strategies without and with PR given parameter values listed in Table 4-2.
Notes: (1) The comprehensive graphical representation of Michigan, Minnesota and Wisconsin farms closely resembles Figure 5. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Solid lines indicate boundary conditions across which an unregulated farmer's optimal strategy switches. In this figure, a PR regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

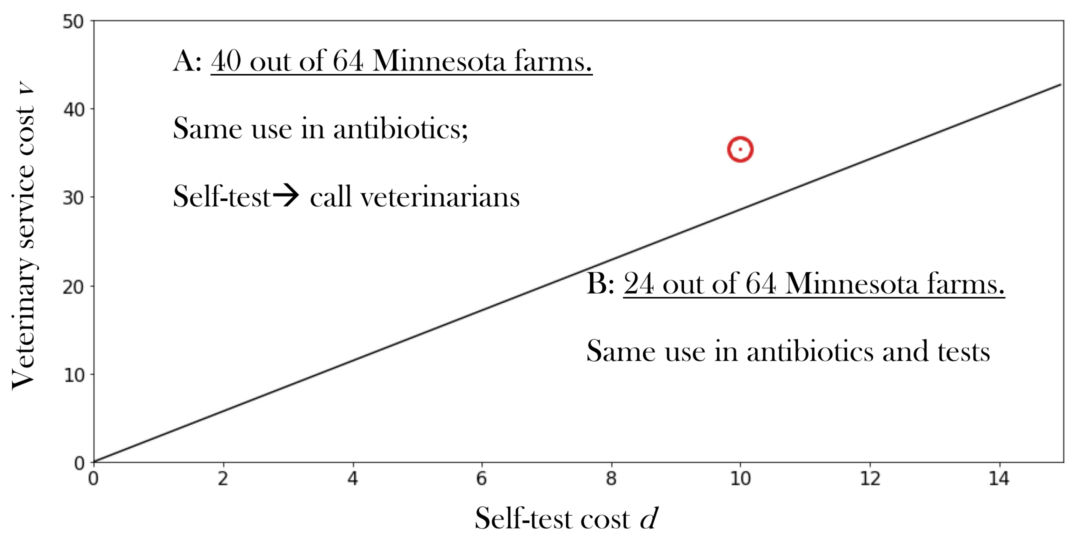

Figure 41 Comparison between Minnesota farm's optimal strategies without and with PR given parameter values listed in Table 4-2.
Note: This figure is to be read as laid out under Figure 40.

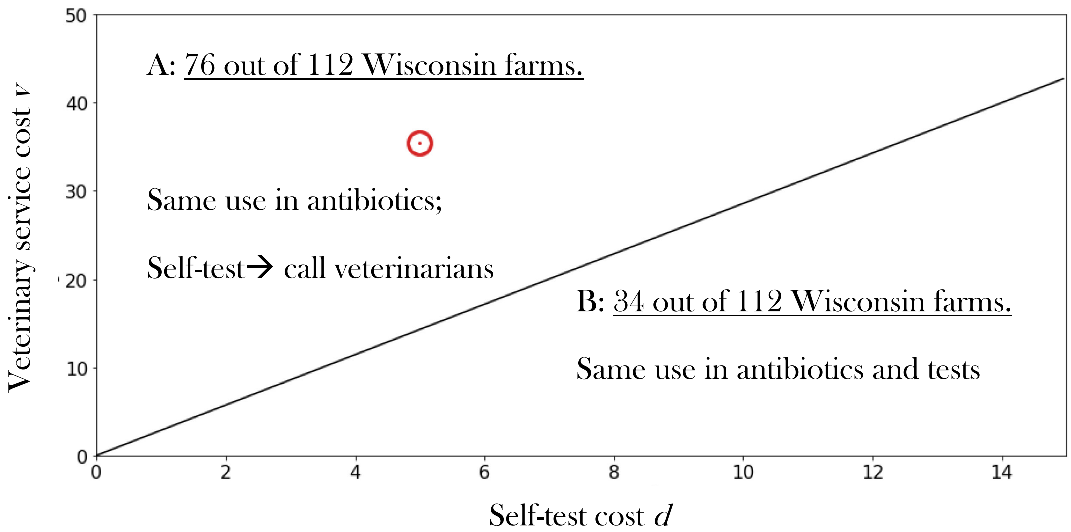

Figure 42 Comparison between Wisconsin farm's optimal strategies without and with PR given parameter values listed in Table 4-2.
Note: This figure is to be read as laid out under Figure 40.

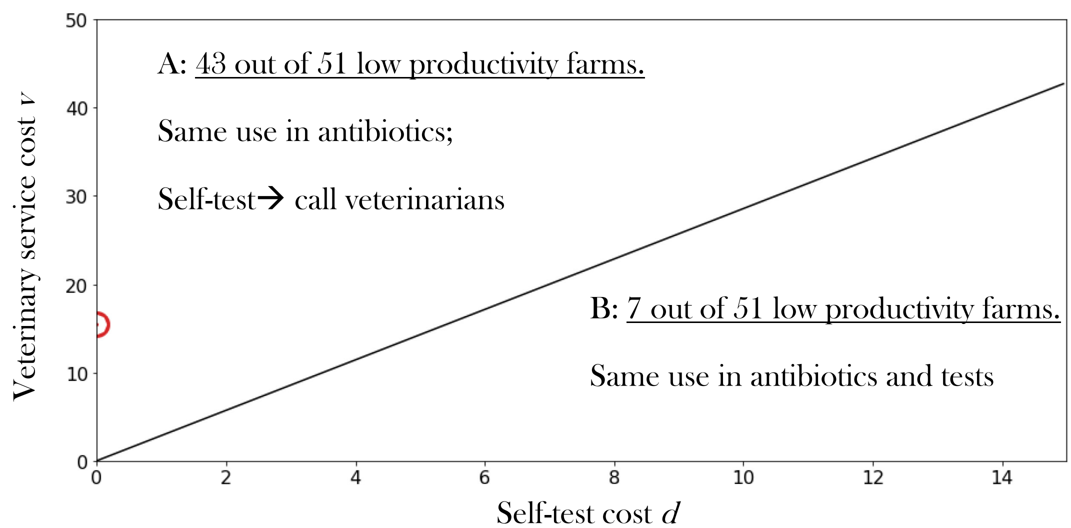

Figure 43 Comparison between low productivity farm's optimal strategies without and with PR given parameter values listed in Table 4-3.
Notes: (1) The comprehensive graphical representation of low, medium and high productivity farms closely resembles Figure 5. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Solid lines indicate boundary conditions across which an unregulated farmer's optimal strategy switches. In this figure, a PR regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

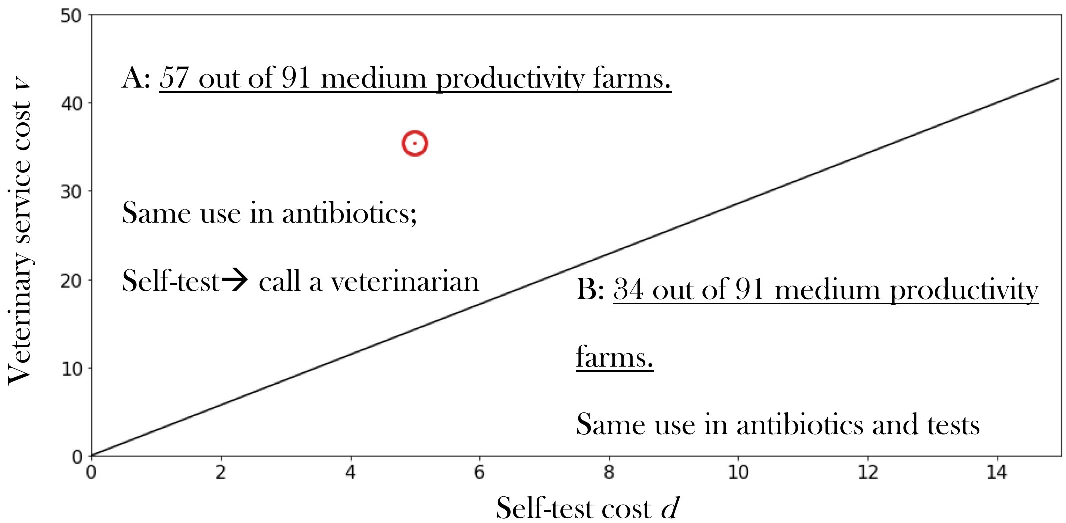

Figure 44 Comparison between medium productivity farm's optimal strategies without and with PR given parameter values listed in Table 4-3.
Note: This figure is to be read as laid out under Figure 43.

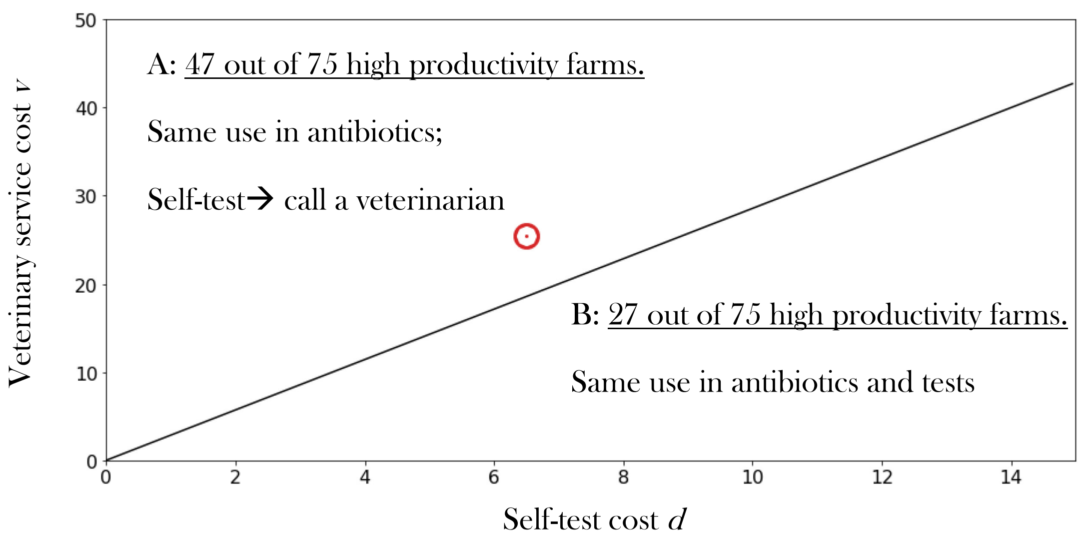

Figure 45 Comparison between high productivity farm's optimal strategies without and with PR given parameter values listed in Table 4-3.
Note: This figure is to be read as laid out under Figure 43.

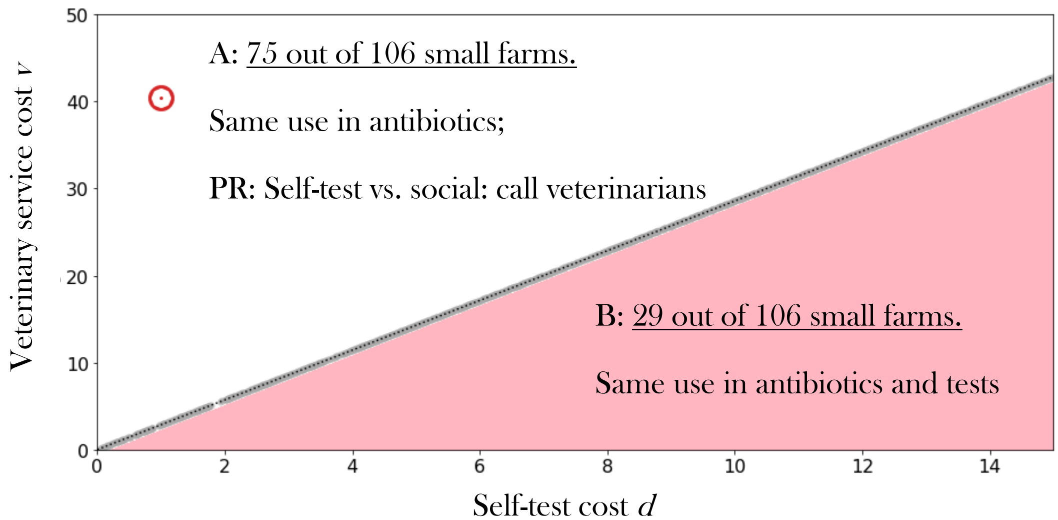

Figure 46 Comparison between small farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-1.

Notes: (1) The comprehensive graphical representation of small, medium and large farms closely resembles Figure 6. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Dotted lines represent boundary conditions across which the social optimal strategy switches. In this figure a PR regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

(3) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

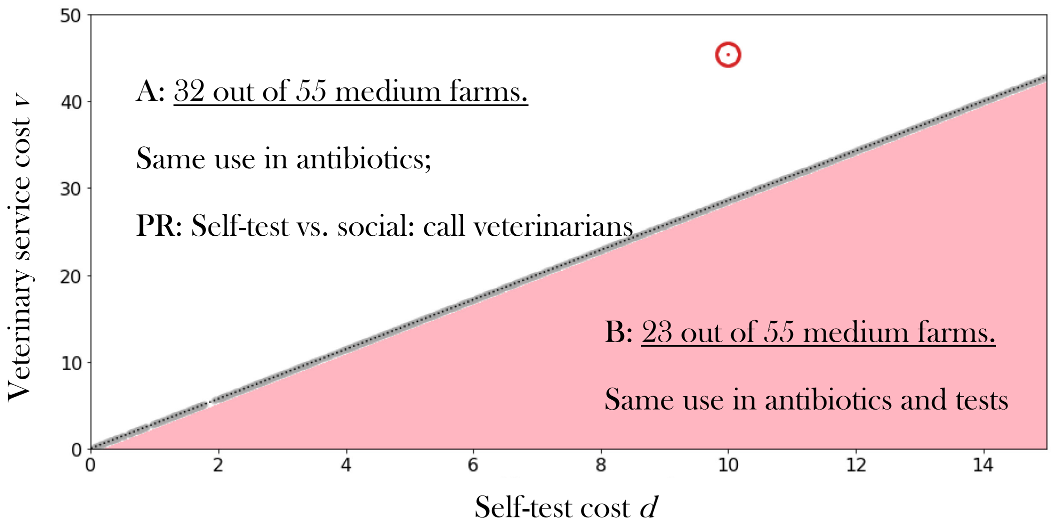

Figure 47 Comparison between medium farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-1.
Note: This figure is to be read as laid out under Figure 46

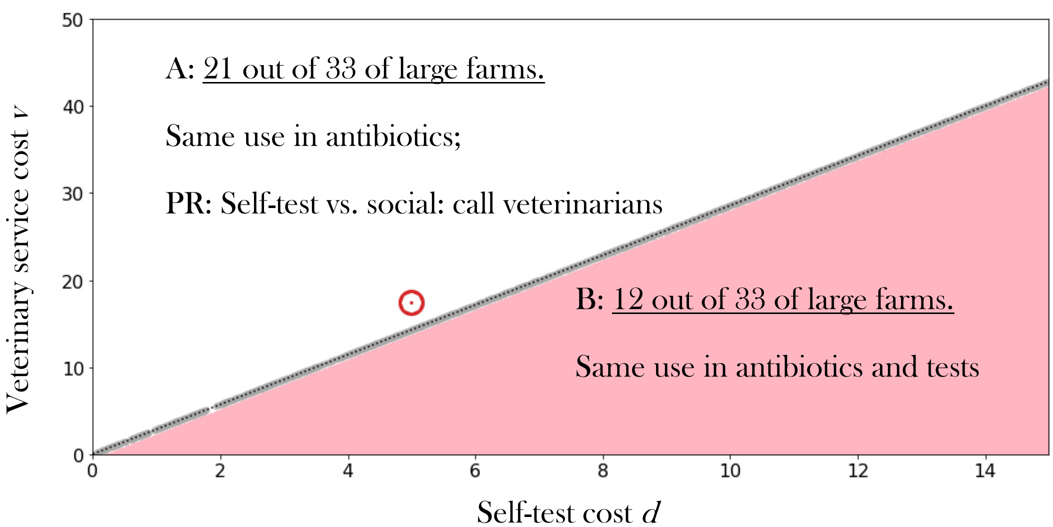

Figure 48 Comparison between large farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-1.
Note: This figure is to be read as laid out under Figure 46.

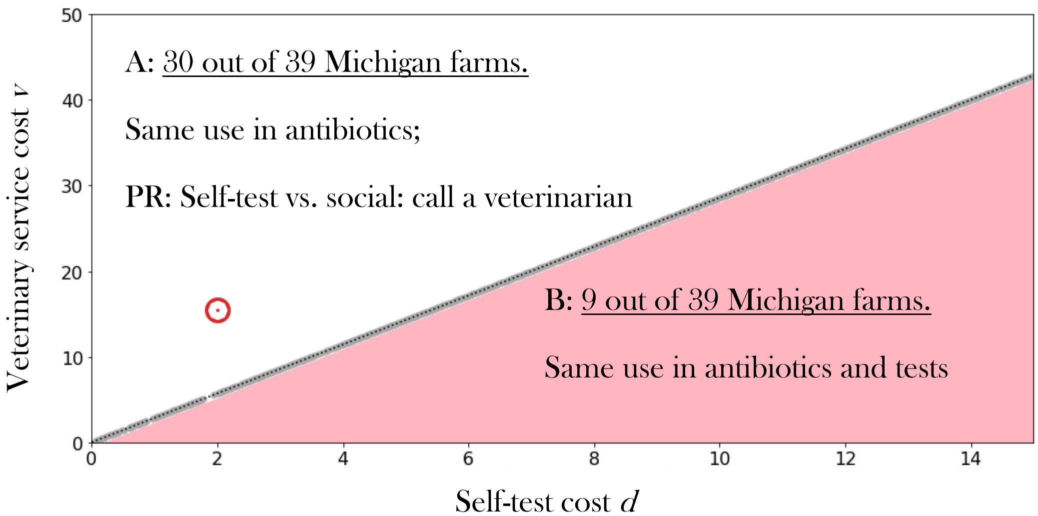

Figure 49 Comparison between Michigan farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-2.

Notes: (1) The comprehensive graphical representation of Michigan, Minnesota and Wisconsin farms closely resembles Figure 6. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Dotted lines represent boundary conditions across which the social optimal strategy switches. In this figure a PR regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

(3) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

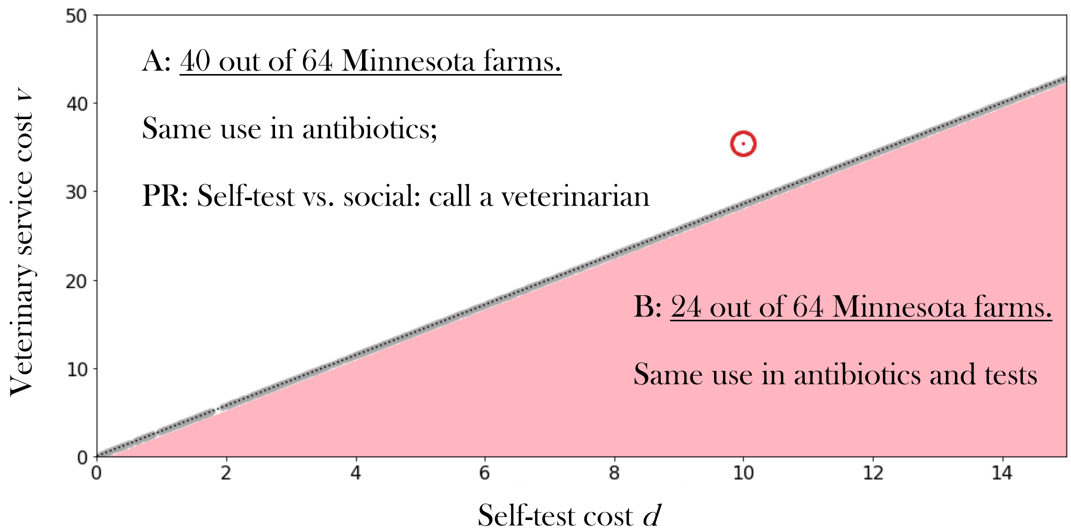

Figure 50 Comparison between Minnesota farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-2.
Note: This figure is to be read as laid out under Figure 49.

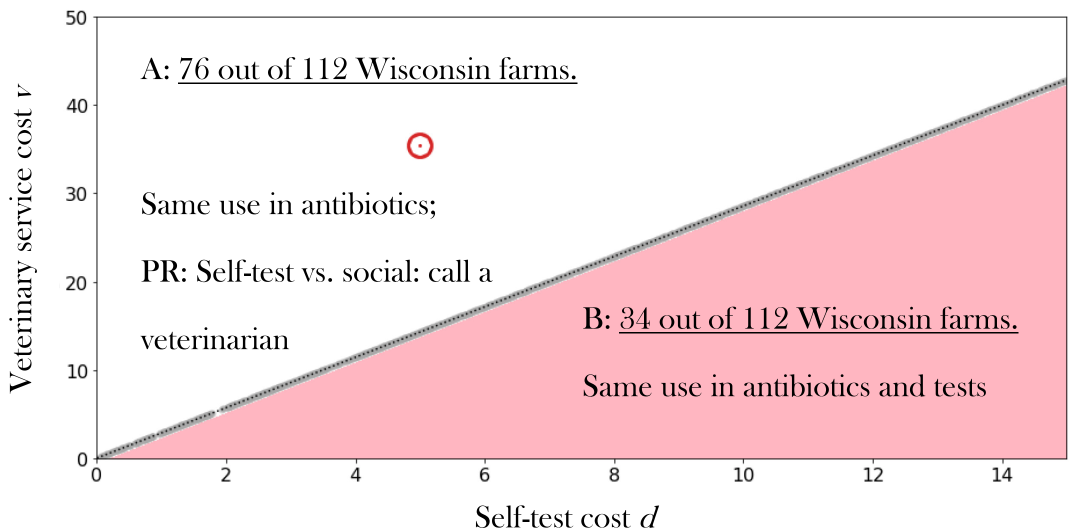

Figure 51 Comparison between Wisconsin farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-2.
Note: This figure is to be read as laid out under Figure 49.

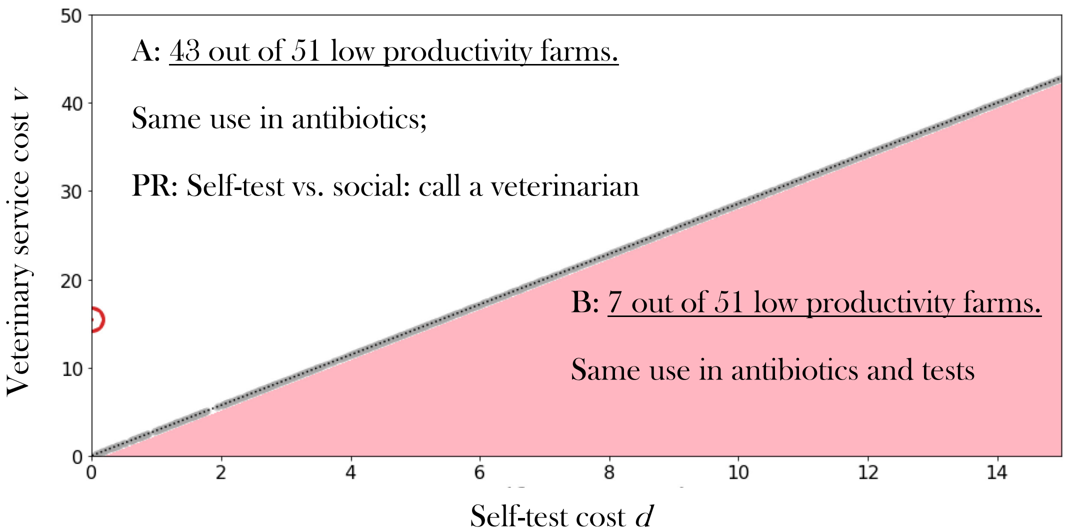

Figure 52 Comparison between low productivity farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-3.
Notes: (1) The comprehensive graphical representation of low productivity farms closely resembles Figure 6. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Dotted lines represent boundary conditions across which the social optimal strategy switches. In this figure a PR regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

(3) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum. In the pink area, the farmer's strategies without and with PR both realize social optimum.

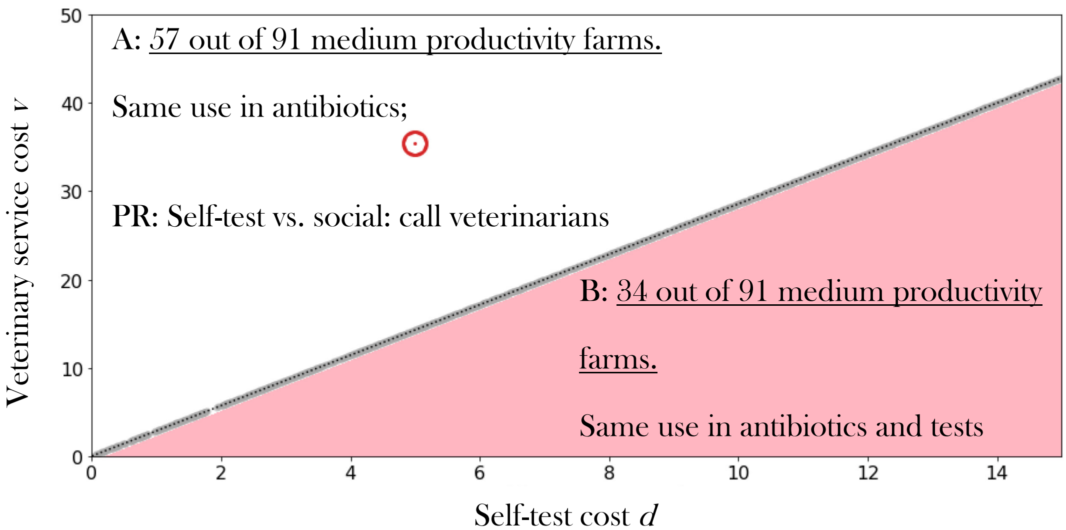

Figure 53 Comparison between medium productivity farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-3.
Note: This figure is to be read as laid out under Figure 52

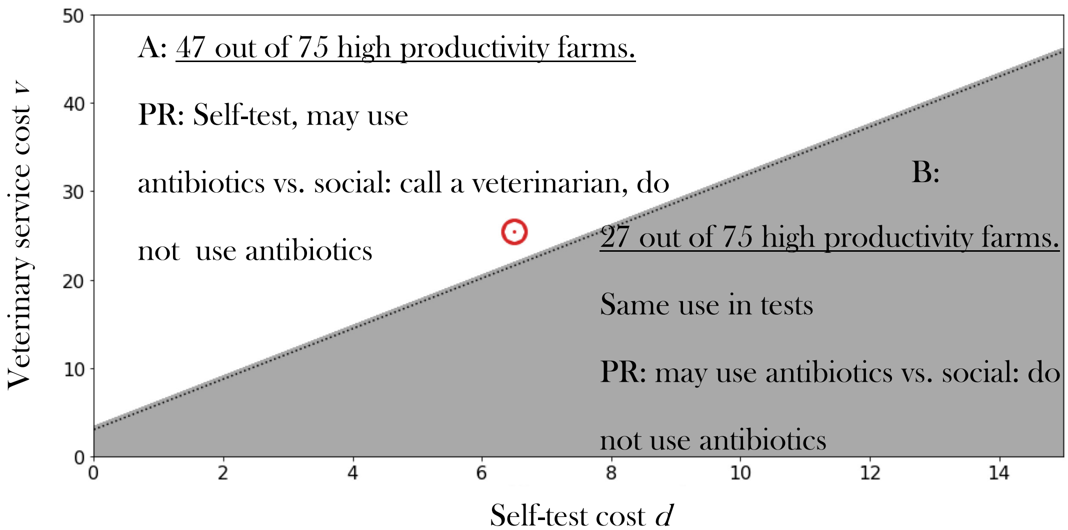

Figure 54 Comparison between high productivity farm's optimal strategies under PR and social optimum given parameter values listed in Table 4-3.

Notes: (1) The comprehensive graphical representation of high productivity farms closely resembles Figure 6. We enlarge a portion of the figure such that we can focus on the data point highlighted in red. The red data point represents the current optimal strategy for the corresponding type of dairy farms. Dotted lines represent boundary conditions across which the social optimal strategy switches. In this figure PR a regulated farmer's optimal strategy is to call a veterinarian and then use antibiotics according to prescriptions.

(2) The numbers of farms in areas A and B may do not add up to the total farm number. This is because a few farms for which the optimal strategies differ from those in areas A and B are not included in the presentation.

(3) In the white areas, the unregulated farmer's strategies correspond to the socially optimal level while PR changes the wedge between actual strategies and socially optimal strategies. In dark grey areas, PR may change sub-optimal private strategies but does not induce social optimum.