Understanding Vaccine Economics with Simulations

Authors: David Bishai and Sasmira Matta

Learning Objectives:

- To understand the Philipson effect or rather how acceptability of a vaccine is determined
- To understand the difference between cost versus benefit
- To understand there is no right answer in determining how to go about decision-making
- To use simulations to better understand vaccine economics

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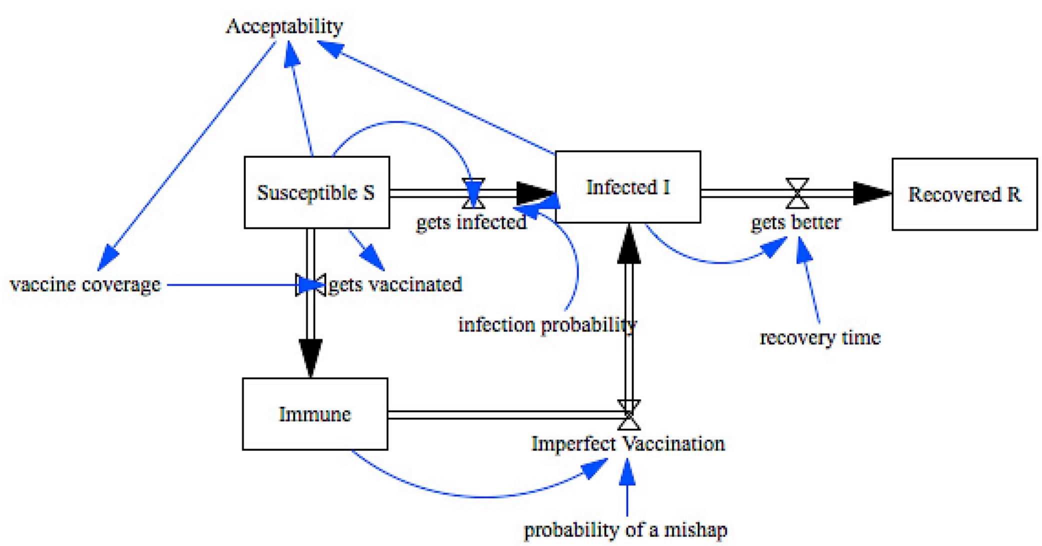
In this exercise you will be using four simulations. One will examine the dynamics in a single country, and the other three will examine the dynamics of neighboring areas. You will be using the Forio software to analyze how the population of infected children and the coverage changes as a result of different scenarios.

Single Country Model:
The following diagram is a causal loop diagram. It represents the dynamics that are occurring in a singular country.

Figure I.



In order to understand this diagram, it is important to understand what is included in the model. This is a modified SIR model, where SIR is an acronym for **Susceptible, Infected, and Recovered**. A SIR model is an epidemiological model that computes the theoretical number of people infected with a contagious illness in a closed population of time [1]. The arrows show the direction of influence for each variable. Since we are also measuring vaccine coverage, this model also tracks the number of children who receive the vaccine.

In the model we have four boxed variables: Susceptible S, Infected I, Recovered R, and Immune. Each of these variables will compute the number of children who fall in to each category at each point in time.

The arrows with the larger heads and rectangular bodies are the flows and they represent the rates. In this model we have four flows: gets infected, gets better, gets vaccinated, and imperfect vaccination. Each of these flows measures the rate at which a child moves from one box to a connecting box.

Ex. If we say that the rate of "gets vaccinated" is 80/1000, this means that for every 1000 children, 80 will get vaccinated at each time step. The other variables that are connected to the diagram by the smaller arrows are other important variables that influence the boxed variables and the rates. The following table summarizes the variables used in the above diagram and the elements they measure.

Table I. Diagram Key

Diagram	Definition
Susceptible S	Measures the number of children that are susceptible to measles
Infected I	Measures the number of children that are infected with measles
Recovered R	Measures the number of kids who recover after having the measles
Immune	Measures the number of children who receive the vaccination
Gets Infected	Rate at which a susceptible child gets sick with measles
Gets Better	Rate at which an infected child recovers from measles
Gets Vaccinated	Rate at which susceptible children get vaccinated
Imperfect Vaccination	Rate at which vaccination is imperfect and does not prevent disease for child
Infection Probability	Likelihood of being infected with measles
Recovery Time	Time it takes for a child to recover from measles
Acceptability	Measures the country's perception of vaccine safety and efficacy
Vaccine Coverage	Proportion of children that are vaccinated
Probability of a Mishap	Probability that the vaccine will not induce immunity

The following simulations have been designed to reinforce different topics in vaccine economics. When answering question focus on changes and shift, and do not get stuck on whether or not differences are significant unless otherwise asked.

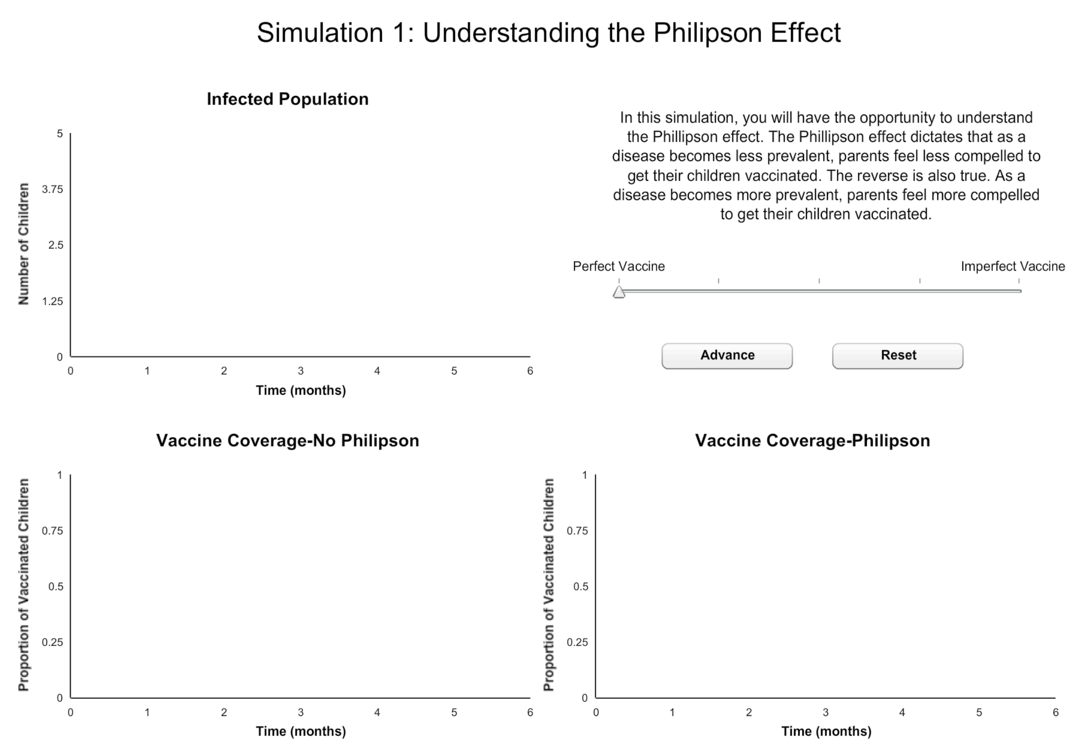
SIMULATION 1: Understanding the Philipson Effect

The Philipson Effect is a theory stating that as a vaccine preventable disease disappears, so too does the demand for vaccines. In other words, as a disease becomes less prevalent, parents are less likely to get their children vaccinated [2]. According to Geoffard and Philipson, the demand for a vaccine is proportional to the benefit of being vaccinated. They point out that if an individual realizes that coverage is very high a rational person would realize that herd immunity is protecting them and that their personal benefit from a vaccination is low. A rational and selfish person would be less and less likely to want a vaccine as the risk of disease goes down to the prior success of the vaccine program.

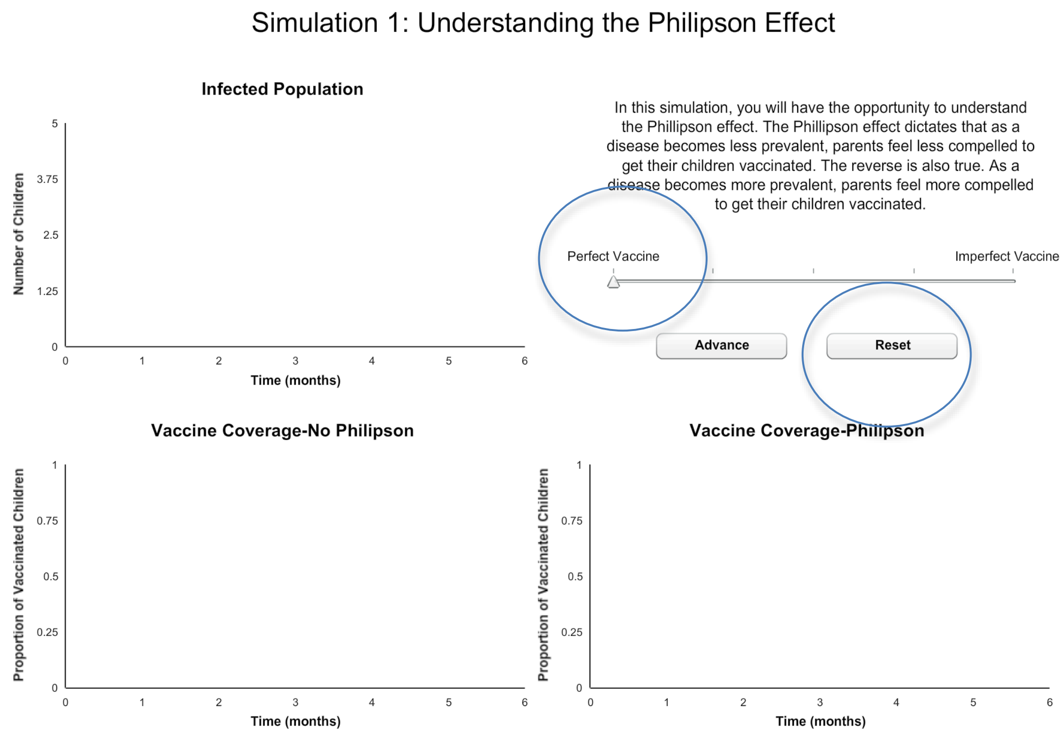
In these exercises, we will consider a vaccine to be perfect if it will definitely immunize a child. Therefore, every child who is vaccinated will definitely be immune to the disease. On the other hand, an imperfect vaccine is a vaccine in which there is a chance that a child will not be immune to a particular disease even if the child receives the vaccine.

In this simulation you will be able to track three things—the infected population, vaccine coverage with the Philipson effect, and vaccine coverage without the Philipson effect. As you run the simulation, focus on how the coverage curves differ.

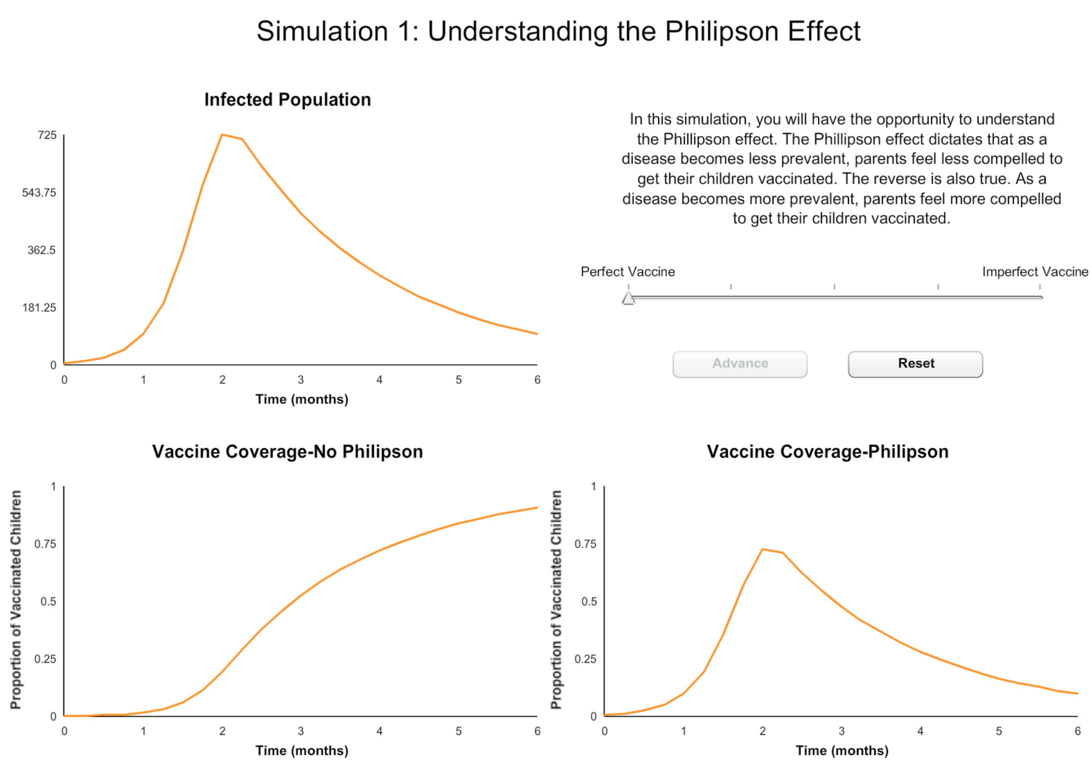
1. Go to the website https://forio.com/simulate/smatta1/single-country
2. You should see the following on your screen



3. Click the *reset* button. Start with the slider tool on the *perfect vaccine* setting.



4. Click the *advance* button *six times* so that the simulation runs to completion. This is what you should see on the screen.

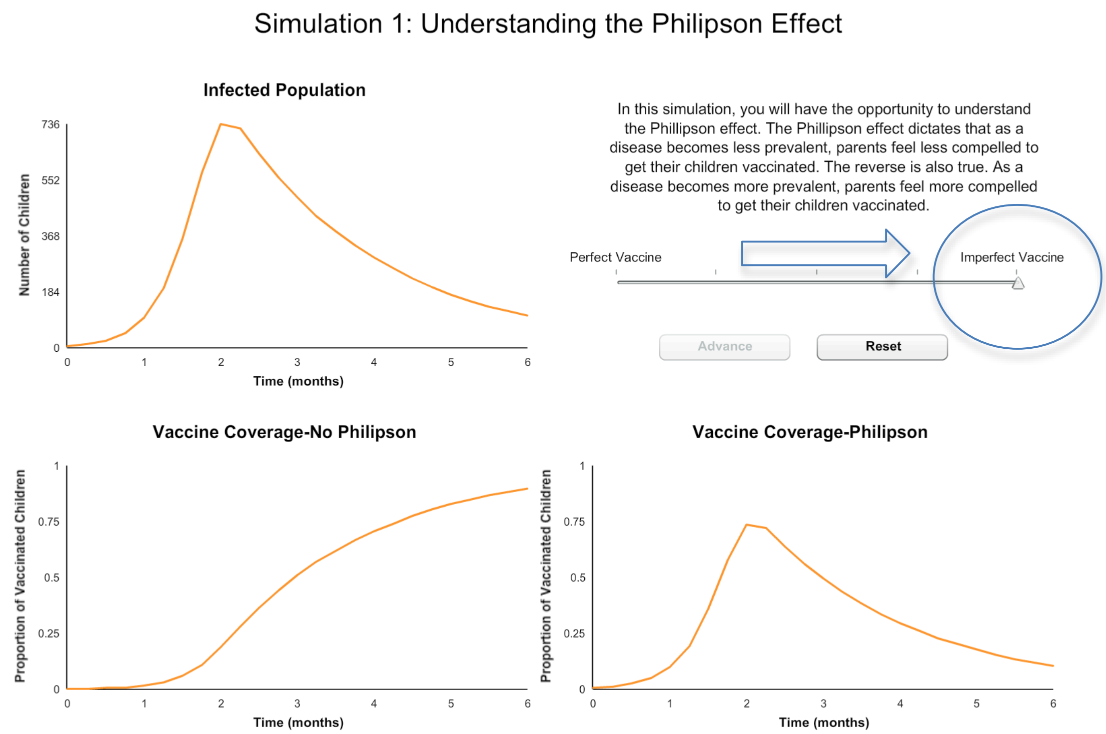


Which vaccine coverage curve resembles the infected population curve? Does this make sense to you? Explain.

The coverage curve that takes the Philipson Effect in to consideration follows the infected population curve. This makes sense because as the Philipson Effect indicates, as the infected population increases, so does the coverage. As the infected population decreases, so does the coverage rate.

On the other hand, the vaccine coverage curve without the Philipson effect has a different curvature, which means that the coverage is changing at a different rate from the infected population curve. This means that the coverage without the Philipson effect is being measured differently.

5. Click the *reset* button. Move the decision slider all the way to the right to the *imperfect vaccination* setting. Now click the *advance* button until the simulation finishes running. After running through the simulation, you should see the following on your screen.



How does the PEAK of the infected curve differ with respect to the previous simulation? Are there more or less children who are infected? Explain.

Under the perfect vaccine setting we see 725 children are infected whereas in the imperfect vaccine setting we see that 736 children are infected. There are more *children infected when the vaccine does not work as well, which makes sense because it does not guarantee full immunity.*

In the simulation you see that when the vaccine is imperfect, about 11 more children will get infected. If parents start seeing that their vaccinated children are in fact getting sick, at what point does this pose a problem? How can you communicate vaccine efficacy to parents?

Participants should use their own experiences to answer this question.

Under which settings—Philipson or No Philipson curves do we achieve more coverage? Why could this be the case?

When we operate without conditions of the Philipson effect, we achieve more coverage. This is the case because when we consider the Philipson effect, parents are choosing whether or not to vaccinate their children based on the disease prevalence. Without the Philipson effect, we assume that the coverage rate is independent of disease prevalence.

Now that we have seen that the Philipson effect has the potential to drastically change the coverage, what do you do? How do you work and communicate with parents and convince them that they should be getting their children vaccinated? How do you prevent them from worrying?

It would be great to talk about this question as a group. Participants might have interesting experiences to share and talk about.

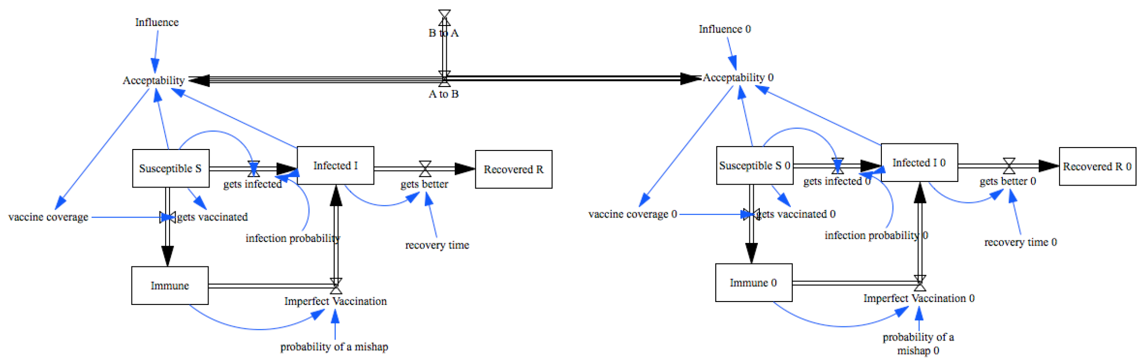
Now that we have walked through the Philipson effect under both perfect and imperfect vaccine conditions, it is now time to move to a two-country scenario.

There was a botched measles campaign in District A where 15 children who received the vaccination died. It was reported that the vaccinations were not stored properly, and that the needles were used multiple times.

You are in charge of the EPI office in District B. District A neighbors District B. You are responsible for improving measles coverage in District B, especially now that parents are weary of getting their children vaccinated after hearing the news.

The next two simulations follow similar dynamics as we have already seen in the singular country causal loop diagram. In fact if you look at the model below, the single country model was copied and pasted twice. On the left hand side we have District A, and on the right hand side we have District B.

Figure II. A More Dynamic Model (Left Side Represents District A and the Right Side Represents District B).



There are two main differences that distinguish the two-district model from the single country model.

I) There is a communication variable which is denoted as Comm for District A and Comm 0 for District B. This variable controls whether or not the communication or the dissemination of information surrounding vaccines is positive or negative.

II) There is an arrow going from District A's Acceptability to District B's Acceptability and vice versa. This demonstrates the transmission of information between the districts—information travels!

What social, cultural, and media events are examples of negative information on vaccine acceptance?

While students will probably have many different answers for this question, it is important that they understand that negative influence will lead to decreased acceptability of vaccines. If a student is stuck the key question to ask is "what can you introduce that will drive acceptability down?"

Possible answers include (but are not limited to the following): Witch doctors advocating for children to not be vaccinated, botched measles campaign in the country, government warning against vaccination of children, etc.

What are social, cultural, and media strategies are examples of positive communication on vaccine acceptance?

Similar to the question above, if a student is stuck, encourage the student to think about what would increase acceptability in a country.

Possible answers include (but are not limited to the following): Government advocates for vaccinations, public figures (like celebrities) advocate for vaccinations, religious leaders advocate for vaccinations, etc.

Now we will explore the two-district model on Forio in three scenarios, which are outlined below. Remember that in each of the following scenarios you are in the EPI program of District B.

SIMULATION 2: Do Not Censor the Media

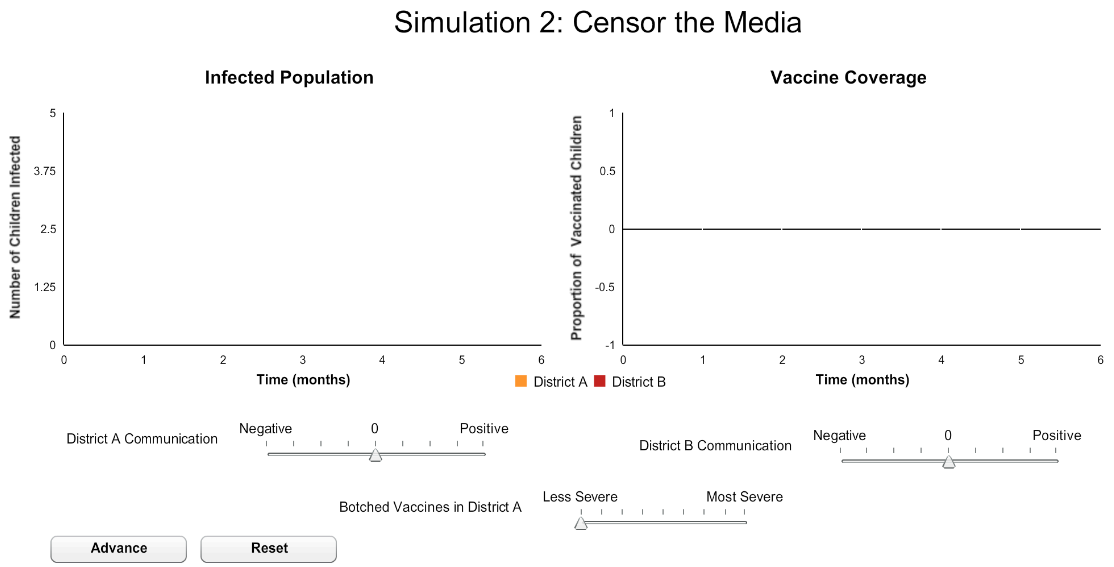
In this simulation, you have decided to censor the media. This means that the bad news about botched measles vaccine in District A cannot reach District B.

In this simulation you can manipulate the communication surrounding vaccines in the districts. The more negative the communication is, the more you can decrease acceptability in the country and vice versa.

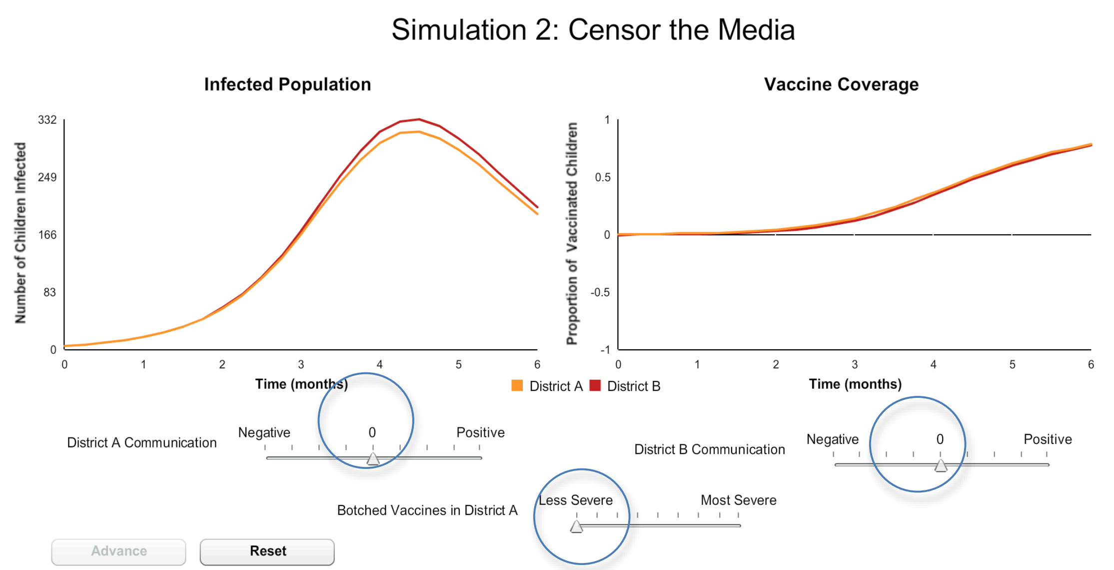
The Botched Vaccines in District A slider can be adjusted to indicate the severity of the botched campaign in District A. The Botched Vaccine in District A will affect the probability of a vaccine mishap. The more severe it is, the more imperfect the vaccine is, and the more problems it will cause.

If you hover over the curves, the tool tip will tell you the country that you are looking at and the value at the moment.

1. Go to https://forio.com/simulate/smatta1/south-sudan-and-uganda-1. The following is an image of what you should see on the screen.



2. Set the communication in both countries to 0. Set the Botched Vaccines in District A to the left most Less Severe Setting. Advance the simulation to the end. This is what you should see on the screen.



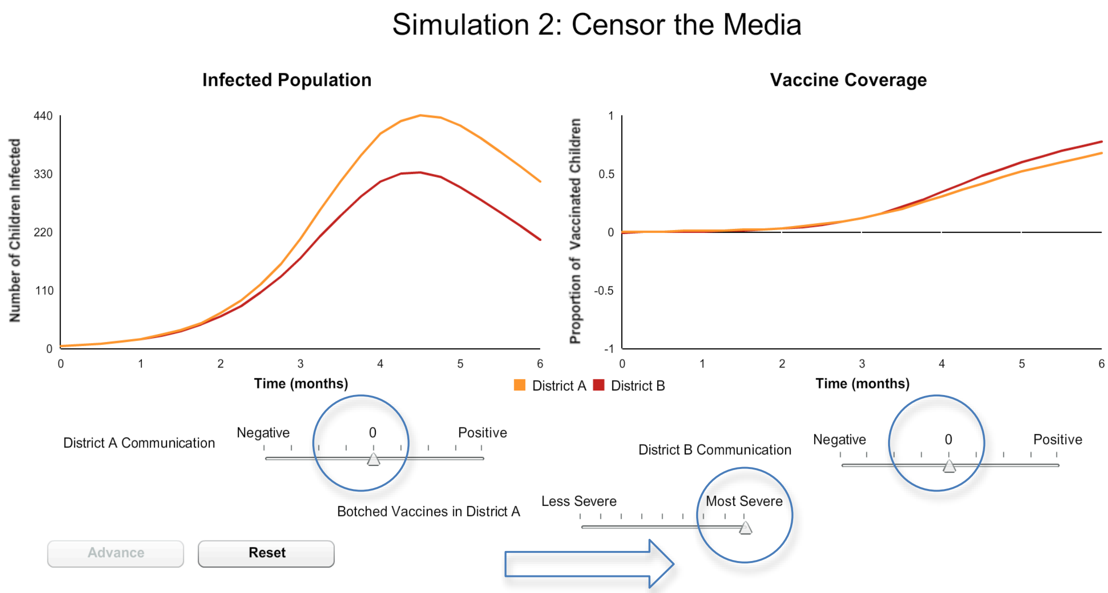
At approximately what time does the peak of the infection occur?

4.5 months

What is the maximum vaccination in coverage in District B at the time of the peak of the infection? (Since the lines are quite close together, you may use the District A's estimate for District B if you are unable to hover over the District B curve).

~.49 coverage

3. Set the Botched Vaccines slider to the right most side or the Most Severe Setting. Keep the influence in both countries at 0. This is what you should see. *Advance* the simulation to the end.



What is the coverage in District B at the peak of the infection?
~.47
Note to Instructors: It is very important that users see that there is a decrease in coverage in District B!

You should be seeing a decrease in coverage. If not just play around with the tool tip until you do. Explain the decrease in coverage. Use the model to help your reasoning.

If the measles campaign in District A is really botched, then it becomes less acceptable to vaccinate children. With acceptability decreasing, fewer children will be vaccinated, and more children in District A will be infected. As the acceptability in District B is influenced by the acceptability in District A, the acceptability will also take a hit in District B. This is why at the peak of infection the coverage is slightly lower. The purpose of this simulation is to understand that the news of a botched measles campaign can affect the willingness of parents to vaccinate their children.

4. Now choose the intensity of the botched vaccines in District A. As you advance the simulation, change the influence in District B.

If you induce positive communication, how will this affect coverage in District B? If you take away induce negative communication, how will this affect coverage in District B?

Users will be able to see that positive influence should bring up the coverage despite what is happening in District A. This is because we can buy acceptability in a sense. We are telling parents ignore what is happening, and focus on the good of vaccines. We can also buy negative acceptability and continue to show parents that vaccines are not good. This would bring the coverage down.

How does changing the influence in District A affect the coverage in District B?

Users will see as they incorporate negative influence in District A, the District B coverage will go down. Users will see that as they incorporate positive influence in District A, the coverage will increase.

With these visualizations, where would you allocate money to improve vaccine coverage in District B? In other words, do you think it is more effective to put money in to influence in District A or in to District B? How would you arrive at the decision?

This is up to the user. Instructors need to stress that we want to put our money in to where we think we will see the largest positive effect.

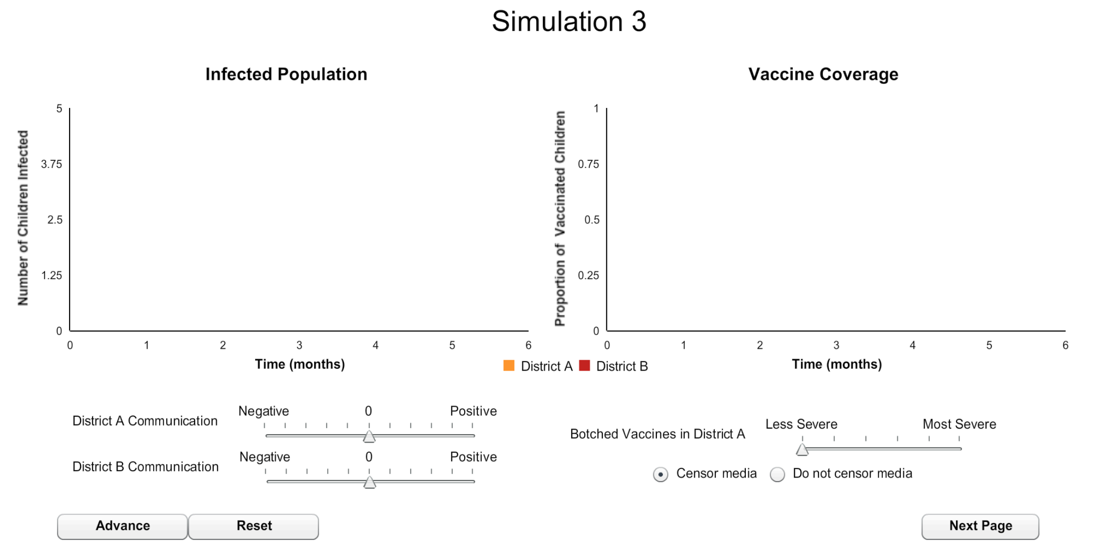
What are your final thoughts on this simulation?

Let users use this space to write down any burning questions or thought that can be discussed later as a group.

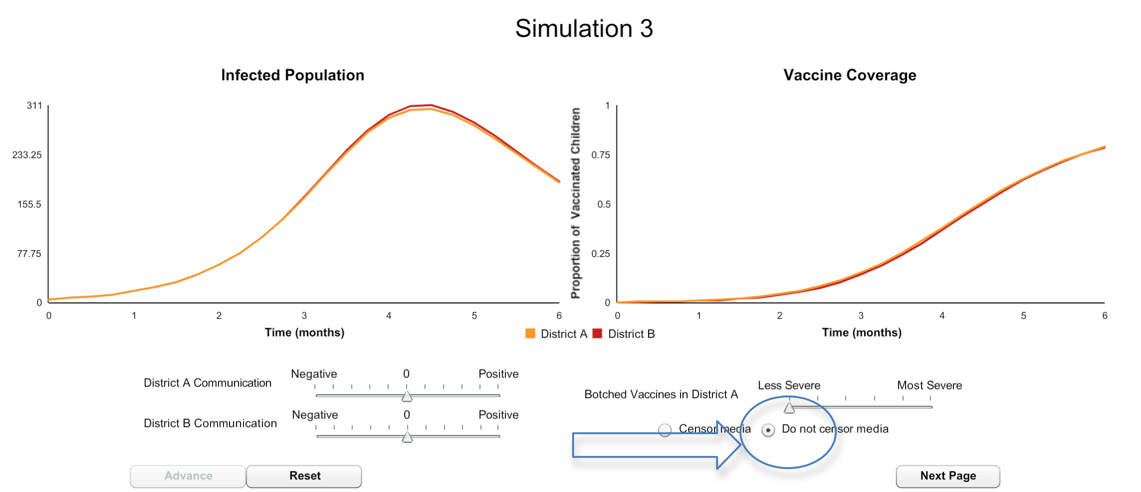
Now let's move to the next simulation!

SIMULATION 3: Censor the Media

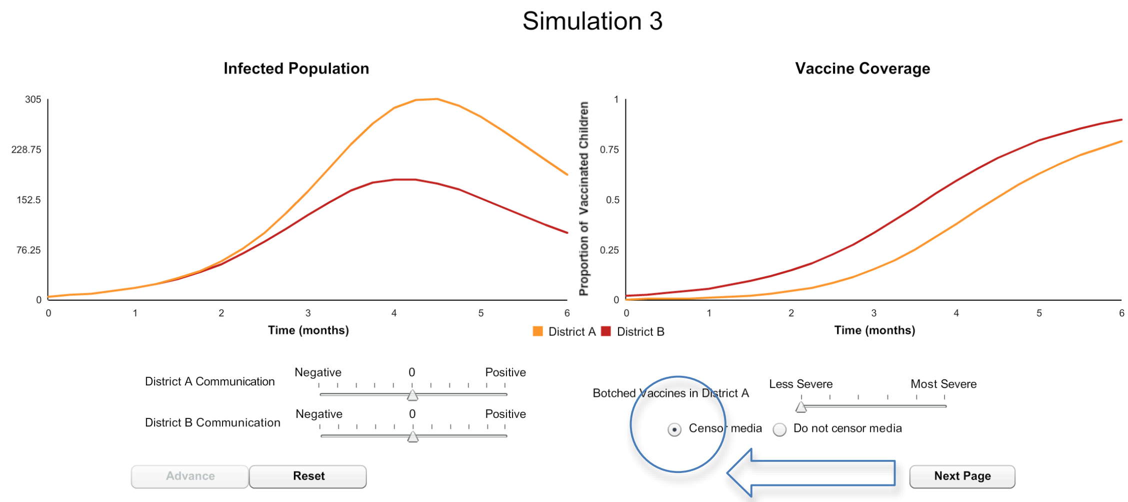
1. Go to https://forio.com/simulate/smatta1/south-sudan-and-uganda. This is what you should see on your screen.



2. Now *reset* the simulation. Click *do not censor media*. Keep the botched vaccine setting at the leftmost *less severe* setting. Keep both communication variables set to 0. *Advance* to the end of the simulation. This is what you should see on the screen when the simulation finishes running.



3. Now maintain the same settings as before (*both communications should be set to zero, less severe botched vaccine campaign in District A)* except this time, *censor media. Advance* to the end of the simulation. This is what you should see on your screen.

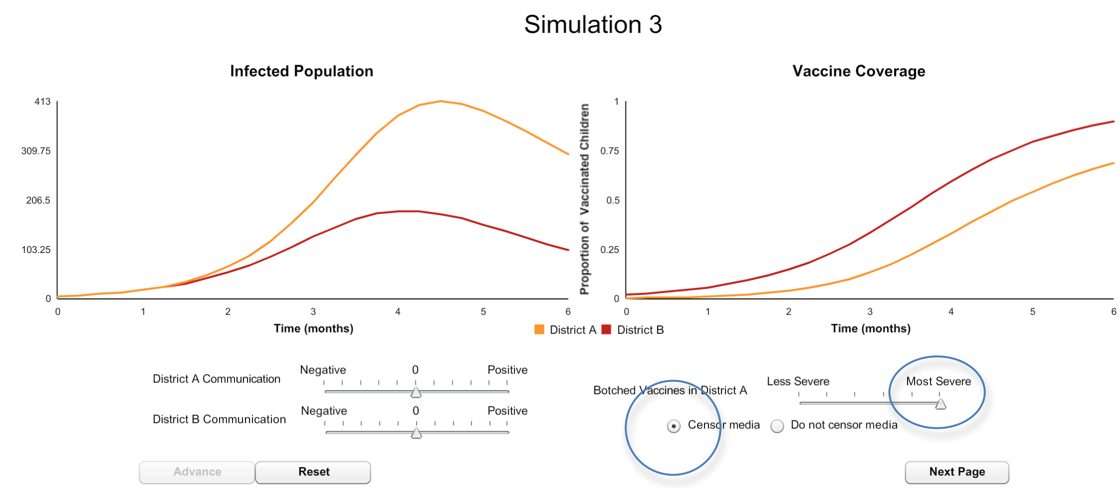


Notice that the curves are father apart when we censor. Why is this the case? Be sure to explain how the infected population curves AND the vaccine coverage curves change. Be sure to explain why this also makes sense.

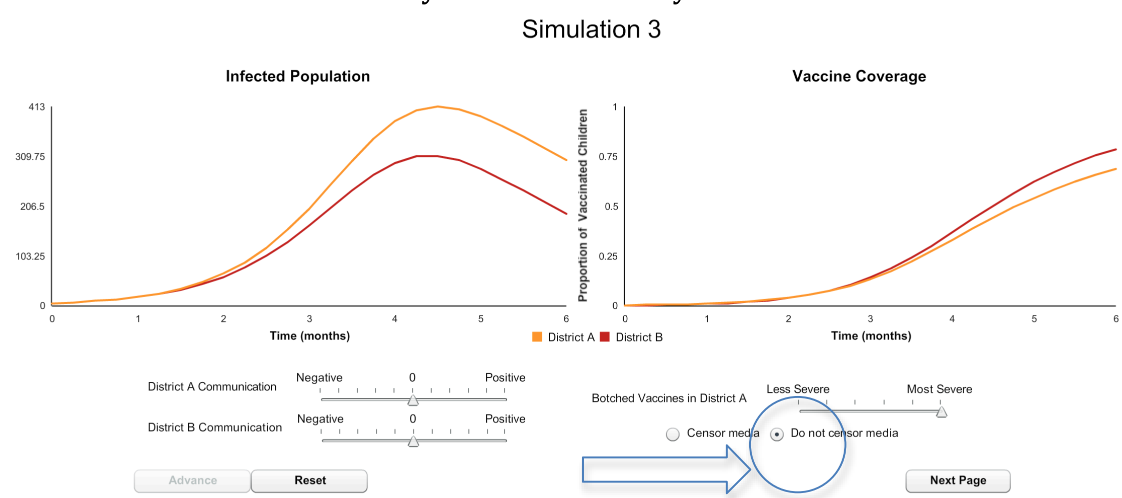
There is more space in between the infected population curves when we censor the media as opposed to when we do not. This makes sense because when we censor the media, we are cutting District B off from what is happening in District A. Because they are unaware of the botched measles campaign in District A, they will not be as opposed to receiving vaccinations and so we will not see as large of a peak in the infected children curve.

As for the vaccine coverage curve, when we censor the media, again District B unaware of what is happening in South Sudan. As such, the coverage in District B will be higher than it is in District A because the news of the botched measles campaign is not reaching District B so they will not experience a change in the vaccination coverage. The District A coverage though, will fall. Because of this change, we see a gap between the two curves.

4. *Reset* the simulation. Now increase the severity to the right most side setting, *most severe.* The *communication* should be set to 0 for both districts. *Censor the media. Advance* the simulation to the end. You should see the following on your screen.



5. Reset the simulation. Now keep the settings the same as above except *do not censor* the media. This is what you should see on your screen.



Compare the two sets of curves when the severity of the botched vaccines in District A is the most severe. How does the severity of the botched measles campaign affect the distance between the curves?

The gaps again, exist between these curves is because of censoring. The rationale is the same as the previous question. As the botched measles campaign becomes more severe, the disparity between the coverage in District A and District B is lessened. This makes sense because while the censoring is limited to the media, migrants for example are moving in to District B and there is still information spreading.

6. Now increase or decrease the communication & chance the censor settings as you advance through different simulations. What do you notice?

- *If the media is censored:*
    - *Buying positive influence only further boosts the coverage*
    - *Negative influence will decrease coverage independently of the botched measles campaign in South Sudan*
- *If the media is not censored:*
    - *Buying positive influence will help boost coverage after it has been affected by the news in South Sudan*
    - *Negative influence will further bring the coverage down*

Final Questions and Thoughts:
Is censoring the media worthwhile? Does it have a great effect?

Instructor's Note:
Help the participant think about the cost vs. the benefit of censoring the media. Ask the participant: what matters? In other words, how influential is the media in Uganda? Is that the best way to combat negative information surrounding vaccinations?

According to the simulations how can we achieve the greatest coverage when the botched measles campaign in District A is very severe? If you have unlimited resources? If you have limited resources?

This simulation shows that we need to cut off the media because otherwise the bad news will spook the Ugandans and affect coverage.

With limited resources you can only affect the positive influence to a limited capacity whereas with unlimited resources you can in sense purchase acceptability or rather purchase people's willingness to accept and utilize the vaccine.

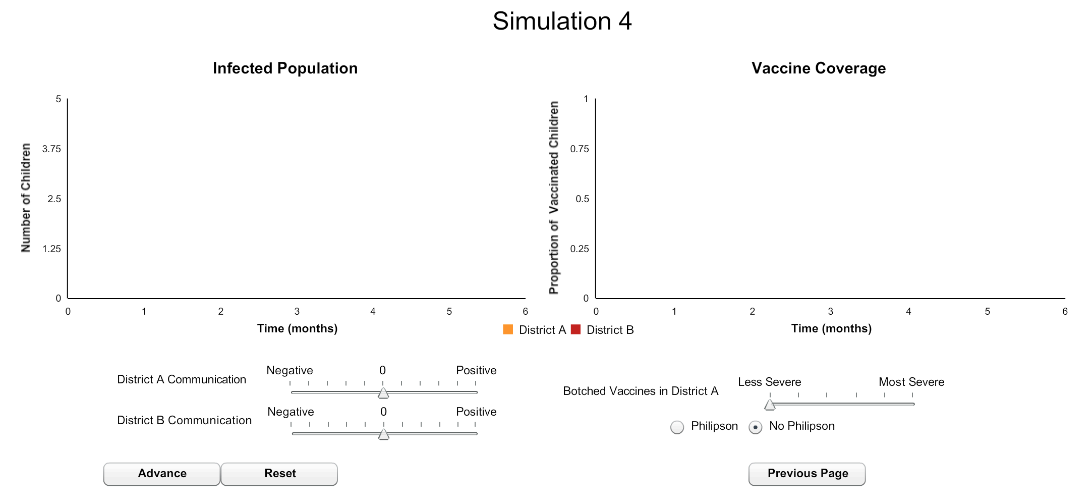
How do you think those in District B would react if they learned that the media was censored?

Instructor's Note: Have participants talk about this so they can learn differing perspectives regarding censoring.

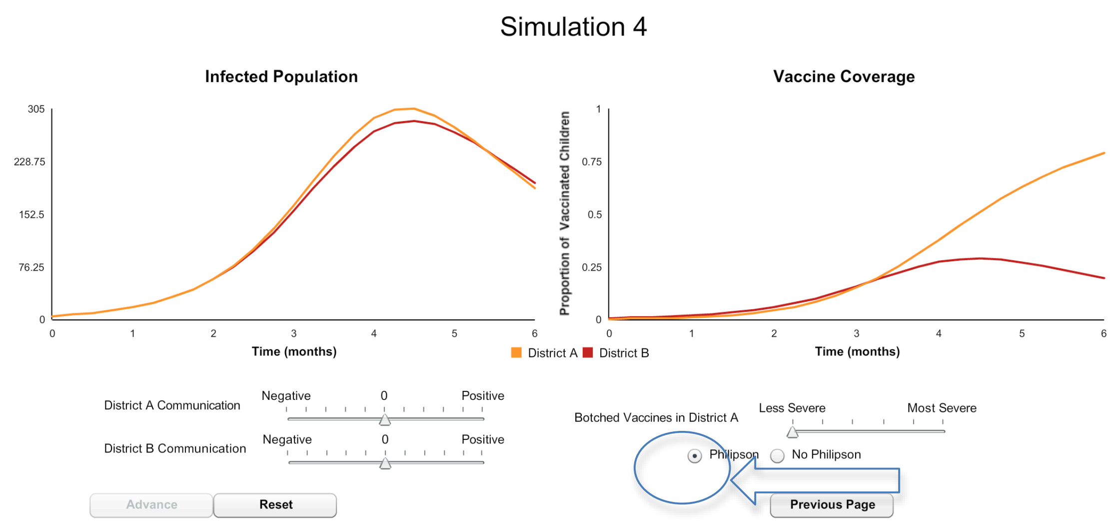
7. Now click Next Page and proceed to the next simulation.

SIMULATION 4: Philipson in the Districts

1. After clicking the *next page* button, this is what you should see on your screen.



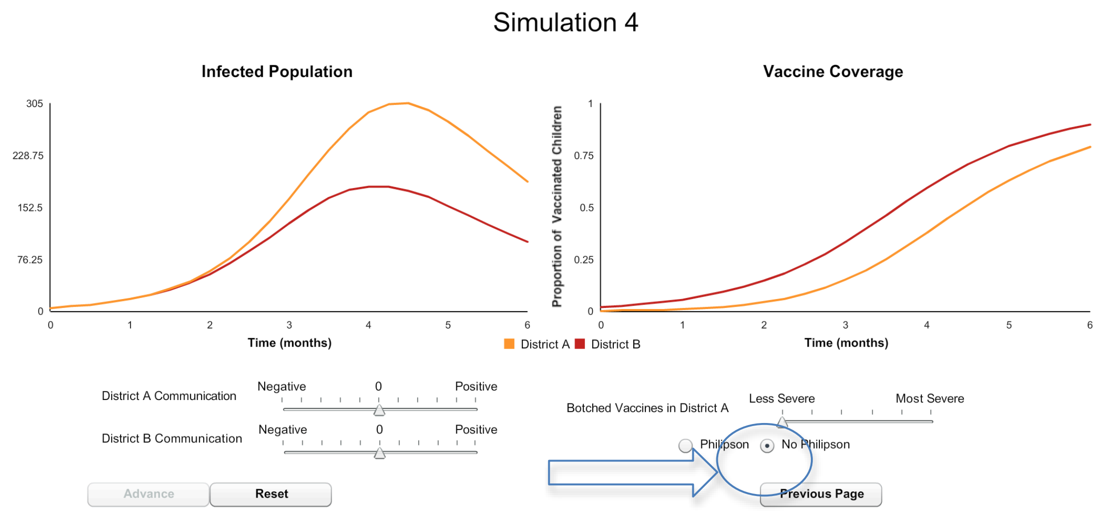
2. Click the reset button. Select Philipson. Advance to the end of the simulation. This is what you should see on the screen.



Pop quiz: Describe the Philipson effect in your own words.

The Philipson effect is present when parents' likelihood of getting their children vaccinated is directly proportional to the prevalence of the disease itself. Without the Phillipson effect, the parents' willingness is not based on the prevalence of the disease, but rather the understanding that receiving a vaccine is a positive social good.

3. Reset the simulation. Click No Phillipson. Advance the simulation to the end. This is what you should see on the screen.



Describe the differences that you see in vaccine coverage as you turn the Philipson effect on and off.

When considering the Philipson effect, the coverage curves move in unison with the infected curves. The more kids that are infected, the more coverage we will see. When there is not Philipson effect we see that the infected population is not the sole driver of vaccine coverage.

4. Play around with this simulation and adjust the botched vaccine severity and the communication levels.

Describe what you see?

Users will see that even when buying positive influence or negative influence, under the presence of the Philipson effect, the coverage is not influenced by the acceptability or the parents' willingness to vaccinate their children.

What are your final conclusions? What would you like to see moving forward? Use this space to discuss any new and/or final thought you have.

Works Cited

1. Weisstein, E.W. *SIR Model*. Available from: http://mathworld.wolfram.com/SIRModel.html.
2. Geoffard, P.-Y. and T. Philipson, *Disease Eradication: Private versus Public Vaccination.* The American Economic Review, 1997. **87**(1): p. 222-230.