

Cycles in the Production of Agricultural Commodities:

The Hog Cycle Exercises

These exercises provide an opportunity to use system dynamics to study the cyclical behavior in the production and prices of hogs. The notes describe a Stella model based on the hog cycle model by Meadows (1970). The notes provide the information needed for you to reconstruct the model in a step-by-step fashion. Simulating the model helps one to understand the underlying causes of the 4-year cycle in hog prices. Students interested in agriculture may then expand and improve the model.

Commodity Cycles

The word *commodity* is used to describe a class of goods which can be produced without qualitative differentiation across a market. Examples include:

- metals such as aluminum, copper and tin
- forest products such as lumber, paper and pulp.
- crops such as bananas, coffee and rice.
- livestock such as cattle, hogs and chickens.

The market for these commodities share a common problem: they all exhibit repeating cycles in prices and production (Sterman 2000, 791). Fluctuations in agricultural prices pose serious difficulties for the farmers and for countries with large commodity exports.

These and other concerns prompted discussion of policies to limit the fluctuations in commodity prices: bilateral agreements, production quotas, buffer stocks and buffer funds. As of 1970, Meadows observed that only four international control schemes were in effect. They applied to coffee, sugar, wheat and tin. They were less than successful in obtaining improved price stability and a better balancing of supply and demand.

Meadows (1970, 82) believed that buffer funds could be the most important of the policy proposals since they could be enacted unilaterally, eliminating some of the implementation problems. He argued that the commodity production cycle model could be expanded to represent buffer funds. The model could also be extended to simulate buffer stocks, quotas and bilateral agreements.

The Hog Cycle

These notes focus on pork, a basic commodity which can be supplied by many different producers without qualitative differentiation. Farmers raise hogs which are slaughtered, and the pork is sold into a commodity market which exhibits swings in prices, with the period of oscillations ranging from three to six years. The oscillatory tendency has persisted over many decades. Indeed, the cycle was known to some observers in the 19th century. For example, Meadows (1970, 37) cited the observation of Samuel Brenner, who, writing back in 1876, declared that

*The advance and decline in the value of hogs to be for twenty years past
... as... certain as the diurnal revolutions of the earth upon its axis.*

(Breimyer 1959, 760)

Corn prices play an important role since corn-feed is one of the largest and most flexible uses of corn. Until the 1960s, the US hog cycle was generally thought to be driven by variations in the price of corn. But some economists began looking inside the hog production system for an endogenous explanation of the cycles that were emerging with a period of around 4 years. Their goal was to look at both internal factors and external factors to gain better understanding.

Meadows' book begins with the development of a generic model of commodity production cycles. The generic model was then parameterized and modified to simulate the cyclical behavior in the production of hogs, cattle and chickens. The dramatic result was that the same generic model provided the fundamental explanation of cycles in all three livestock systems.¹ The hog cycle model was published in 1970 with data drawn from the 1950s and 1960s and parameterized for the US market.² The model was implemented in Dynamo, the software explained on pages 332-333 of the book.

These notes present a Stella version of the model. The Stella model incorporates a few alterations to facilitate student learning. The most important alteration is to establish equilibrium conditions at the start of the simulations. Then, following the example of the real-estate construction model in the book (page 251), we impose an exogenous change to see if it will trigger oscillatory behavior. The exogenous change is imposed in the 12th month of a 240-month simulation, so there will be plenty of time to see the pattern of oscillations. Meadows (1970, 59) showed a sustained cycle with a 45-month period. You will see similar results when you build and simulate the Stella model.

¹Sterman (2000) describes the importance of commodity production cycle in Chapter 20 of *Business Dynamics*. He begins with a description of production cycles that cause problems in industries from "A to Z", from "aircraft to zinc." He reminds us that "markets with negative feedbacks through which price seeks to equilibrate supply and demand often involve long time delays which lead to oscillation." Sterman then presents a generic model of commodity production cycles (citing Meadows' 1970 work as inspiration.) The generic model is then expanded to represent capacity expansion, capacity utilization and the price-setting process. Chapter 20 concludes with an application to the pulp and paper industry and a challenge to readers to adapt the model to livestock commodities such as hogs and cattle.

²The US is ranked 2nd in the world in pork production. China is the pork powerhouse of the world. Chinese farmers are responsible for just over 50% of global pork production. (Their production is around five times larger than US production.) The remaining countries ranked in the top ten for pork production are Brazil, Canada, Russia, Poland, Japan, South Korea, Philippines and Mexico. (These rankings were viewed in November 2011 at the *NationMaster* website: http://www.nationmaster.com/graph/agr_hog_pro-agriculture-hog-production)

The live hog price is a nonlinear function of the relative coverage, as shown in Figure 2. The initial price is \$16.50 per hundredweight, the center point in Figure 2.

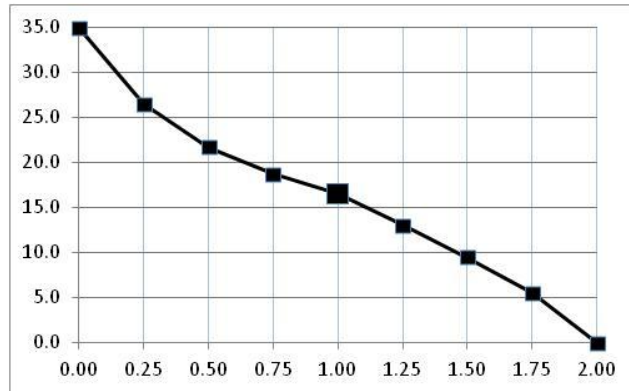


Figure 2. The live hog price depends on relative coverage.

For example, live hogs sell for \$16.50 per hundredweight if inventory provides the desired coverage.

Stella Equation: $\text{live_hog_price} = \text{GRAPH}(\text{relative_coverage})$

(0.00, 35.0), (0.25, 26.5), (0.5, 21.7), (0.75, 18.7), (1.00, 16.5), (1.25, 13.0), (1.50, 9.5), (1.75, 5.5), (2.00, 0.00)

A hundred pounds of hog provides 58 pounds of pork, so the cost of retailers to obtain the pork is \$9.57 per hundredweight. I set the retail marketing margin at \$31.55 per hundredweight, so the retail price of pork is \$60 per hundredweight, i.e., 60 cents/pound.⁴ Per capita consumption is based on the nonlinear curve in Figure 3. With pork selling at 60 cents/pound, each person is assumed to consume 5 pounds per month. The nation's consumption would be 1,000 million pounds/month.

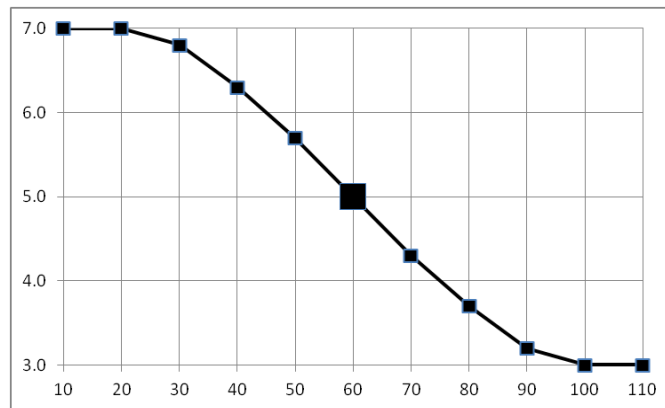


Figure 3. Percapita Consumption depends on the retail price of pork. The center point shows percapita consumption at 5 pounds per month if the retail price is \$60 per hundredweight (i.e., 60 cents/pound).

Stella Equation: $\text{per_capita_consumption} = \text{GRAPH}(\text{retail_price})$

(10.0, 7.00), (20.0, 7.00), (30.0, 6.80), (40.0, 6.30), (50.0, 5.70), (60.0, 5.00),
(70.0, 4.30), (80.0, 3.70), (90.0, 3.20), (100, 3.00), (110, 3.00)

⁴The unit "hundredweight" is a common measure of mass in the US livestock industry. Meadows' market margin was \$28 per hundredweight. I use a somewhat higher value to obtain the equilibrium conditions in Figure 1. A starting price of \$60 per hundredweight corresponds to 60 cents/pound of pork. This price may surprise you if you have been to the meat counter recently. But remember that Meadows' model was published in 1970 and developed with data from the 1950s and 1960s.

Figure 4 shows the hog farmers reaction to changes in the hog price. We assume that the farmers smooth the price with a 6 month, first-order averaging delay. They then compare the price of hogs to the cost of corn. Corn prices can be highly variable, and many have looked to the variations in corn costs for the principal explanation of the cycles in hog production. In this example, the cost of corn is fixed at \$1 per bushel. By maintaining a constant cost of corn, we focus our attention on the internal dynamics of the hog farming system. We are looking inside the system for insight on the cycles.

The simulation begins with the hog to corn ratio at 16.50. Meadows assumed that farmers would aim for a desired breeding stock of 8.5 million hogs with this ratio. Hog farming is more profitable if the live hog price is higher (or the cost of corn is lower). If the hog to corn ratio were to increase to 21.5, for example, the desired breeding stock would increase to 10 million hogs. On the other hand, if the hog to corn ratio were to fall to 11.5, the desired breeding stock would decline to 7 million hogs. The breeding stock relationship in Figure 4 will be examined further in the exercises.

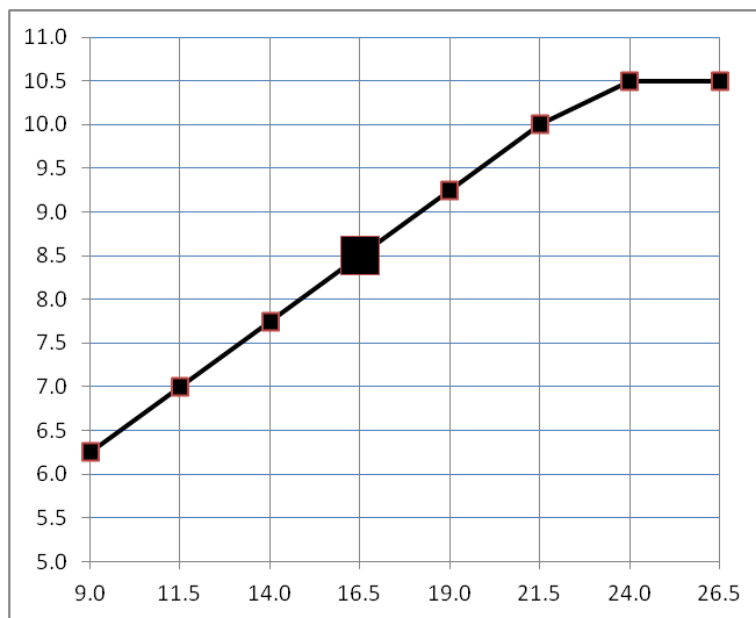


Figure 4. The desired breeding stock depends on the ratio of the live hog price to the corn price. For example, if hogs sell for \$16.50 per hundredweight and corn costs \$1 per bushel, the ratio is 16.5.

In this case, the desired breeding stock is 8.5 million hogs.

Stella Equation: $\text{desired_breeding_stock} = \text{GRAPH}(\text{expected_hog_corn_ratio})$
 (9.00, 6.25), (11.5, 7.00), (14.0, 7.75), (16.5, 8.50), (19.0, 9.25), (21.5, 10.0), (24.0, 10.5)

Figure 1 shows that the breeding stock matches the desired breeding stock at the start of the simulation. Since the deficit is zero, farmers only need to add 0.14 million hogs per year to counteract the slaughter of older sows who have reached the end of their 36-month productive life.⁵ The breeding stock is assumed to produce 0.17 litters per hog per month (i.e., around 2 litters per year). Meadows assumed that 7 pigs could be saved per litter, so the breeding flow is 10 million pigs per month. The piglets need 10 months to develop into a mature hog.

⁵ The Stella model simulates the acquisition of breeding stock somewhat differently than the Dynamo model by Meadows (1970). The Stella model accounts for the slaughtering of sows when making the acquisition and removal decisions. This will ensure that the breeders come closer to meeting their goal, and we have a better opportunity to see equilibrium conditions at the start of the simulation.

A conveyor stock is used to represent the gestation and maturation delay.⁶ The small pigs are called piglets, and there are 88 million piglets at the start of the simulation. They are subject to a weaning loss of 30% which leads to a loss of 3.1 million pigs/month. The other 7.2 million pigs/month survive to join the pigs categorized as mature stock. The mature hogs are retained for a 2-month feeding period before they are slaughtered. With 14.1 million mature hogs, the slaughter is 7.05 million hogs/month. The hogs weigh 240 pounds, and 58% is pork yield (i.e., around 139 pounds per hog). The pork production from the slaughter of these hogs is 981 million pounds/month. Figure 1 shows that the slaughter of the old sows delivers an additional 19 million pounds/month. Total pork production is 1,000 million pounds/month, and we have equilibrium flows for the inventory.

Initial Values of Stock		
Mature Stock	14.1	million pounds of hogs
Breeding Stock	8.5	million pounds of hogs
Piglets	88	million pounds of young pigs
initial hog price	16.50	\$ per hundred weight of hogs
Inventory of Pork	360	million pounds of pork

Table 1. Initial values.

Pork Consumption Parameters		
population	200	million people
expected consumption	1,000	million pounds/month
desired coverage	0.36	months
hog dressing yield	0.58	pounds of pork per pound of hog
marketing margin	31.55	\$/hundredweight of pork

Table 2. Pork consumption parameters.

Hog Production Parameters		
expected corn price	1	\$/bushel
hog price smoothing lag	6	months
litters per hog per month	0.17	litters/hog per month
pigs saved per litter	7	piglets/litter
weaning loss fraction	0.3	dimensionless
gestation & maturation delay	10	months
mature stock feeding period	2	months
live weight of slaughtered hogs	240	pounds/hog
hog dressing yield	0.58	pounds of pork per pound of hog
average productive life of sows	36	months
fraction of sows in breeding stock	0.6	dimensionless
stock adjustment delay	5	months

Table 3. Hog production parameters

⁶ The conveyor is another modification in Meadows' model. He used a 3rd order material delay to represent the processes of gestation and maturation. I believe a conveyor stock is easier for students to understand, and the conveyor may well deliver a more accurate portrayal of the flow into the mature stock. (See page 184 of the book for the response of a conveyor stock, Fig. 14.18, and the response of a third order material delay, Fig. 14.19.)

This completes the tour around the equilibrium conditions in Figure 1. These conditions are described again in Tables 1, 2 and 3. With this information, students should be able to reconstruct the model. The exercises lead you through the reconstruction in a step-by-step manner. You will be testing each piece of the model immediately after construction. Through frequent testing, we hope to have an error-free model when we put the separate pieces together.

Exercises

1. Pork consumption sub model:

Build the model shown in Figure 5 with the pork production fixed at 1,000 million pounds/month.

Set DT to 1/16th month and simulate with a pause interval of 12 months.

Build the small interface shown in Figure 6. Run the first 12 months with the slider set to 200 million people.

Then increase the slider to 230 million and simulate the remaining 36 months.

Verify that you get the results in Figure 6.

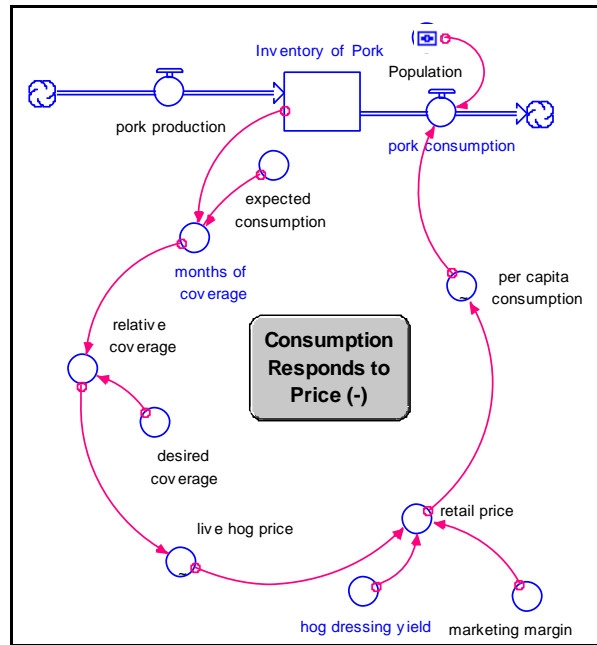


Fig. 5. Consumption of pork.

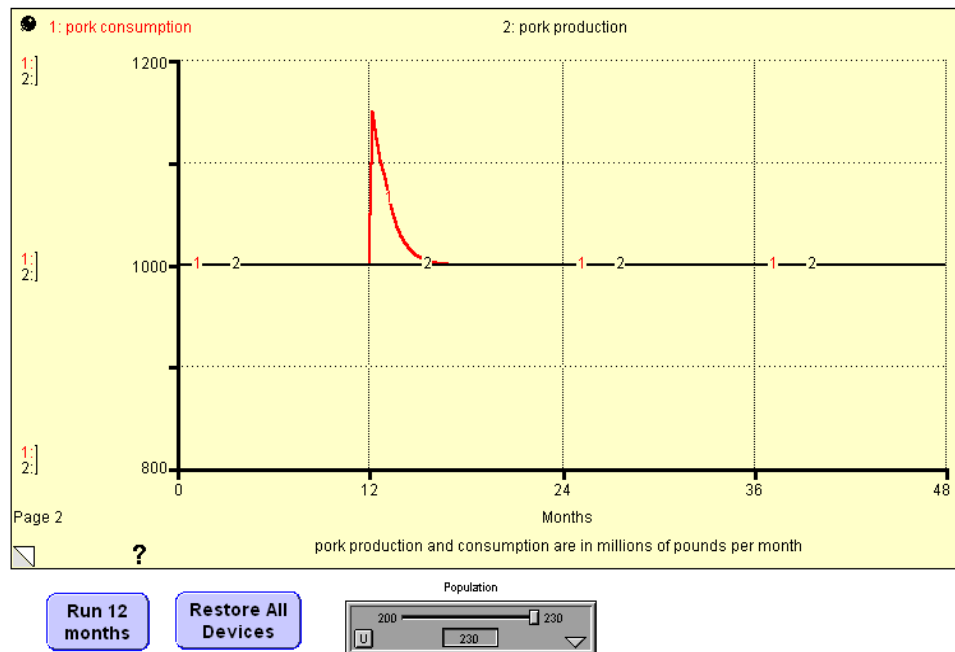


Figure 6. Testing the pork consumption sub model.

2. Simple model of breeding stock acquisition: Build the model in Fig. 7 with the initial value of the breeding stock at 8.5 million hogs. Use a time dependent graphical function (~) to make the desired breeding stock change from 8.5 to 10.5 in the 12th month of the simulation. The breeding stock adjustment delay is 5 months. Simulate the model for 48 months and verify the results in Figure 8.

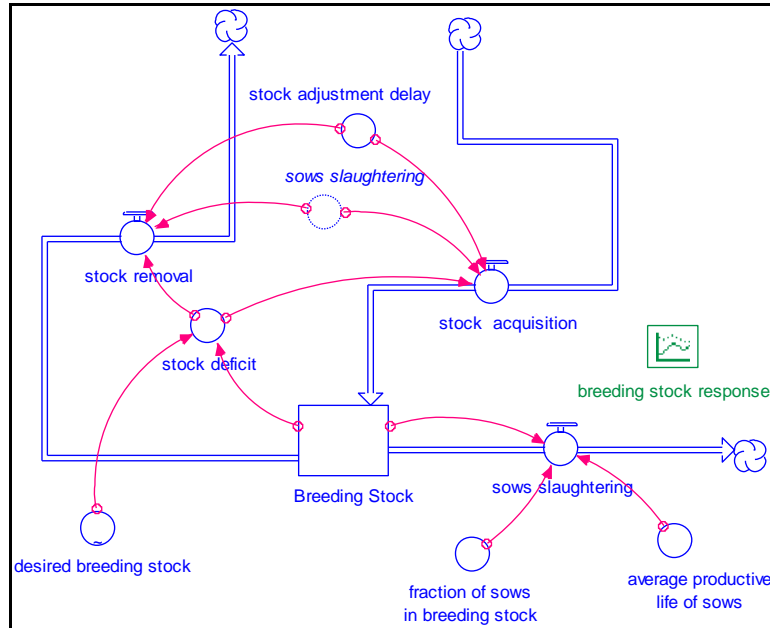


Figure 7. Simple model of breeding stock acquisition. Stella equations for the flows:
 $sows_slaughtering = (Breeding_Stock * fraction_of_sows_in_breeding_stock) / average_productive_life_of_sows$
 $stock_acquisition = (stock_deficit / stock_adjustment_delay) + sows_slaughtering$
 $stock_removal = -(stock_deficit / stock_adjustment_delay) - sows_slaughtering$

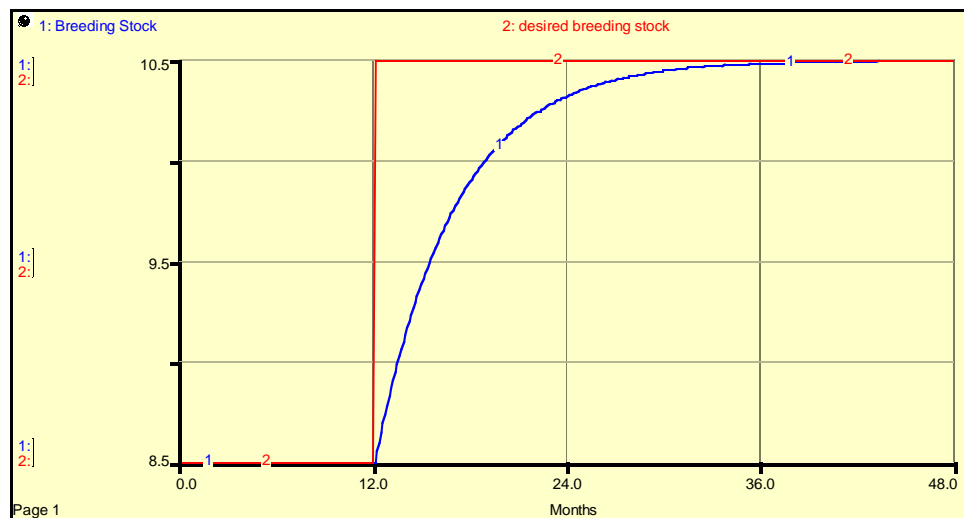


Figure 8. Testing the simple model of breeding stock acquisition with the stock acquisition delay = 5 months. The breeding stock should reach 10.4 million hogs when the time (in months) reaches 27.0. So, after 15 months (3 times the acquisition delay), the breeding stock is quite close to the target.

3. Supply side of the hog cycle model: The previous model demonstrates the meaning of the 5-month breeding stock acquisition delay. Now, we need to build the model in Fig. 9 to put the breeding stock into proper position within the hog production system. Build this model with the parameters in Fig 1 and Tables 1,2,3. Simulate it for 60 months with $DT = 1/16^{\text{th}}$ month and verify the results in Fig. 10

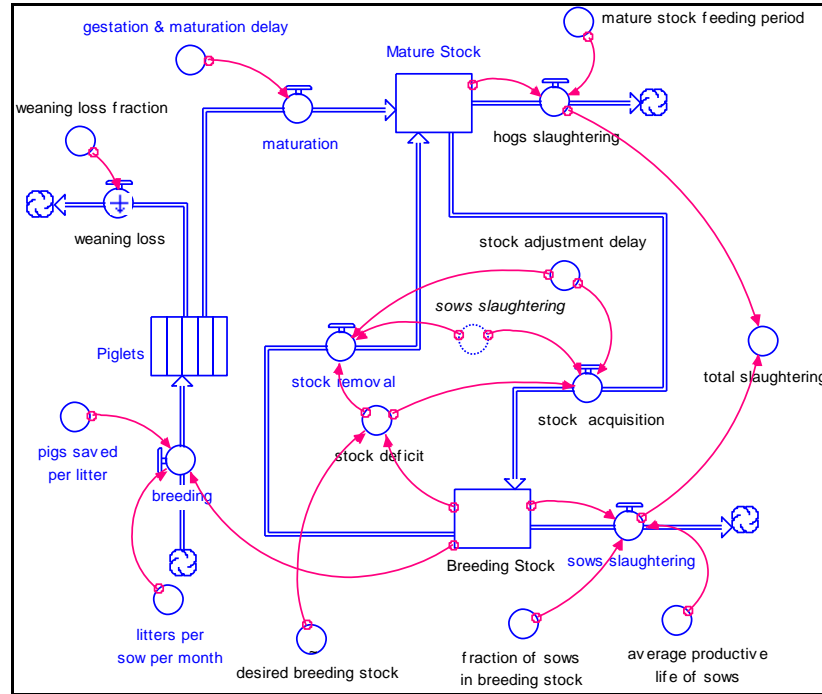


Figure 9. Supply side of the hog cycle model.

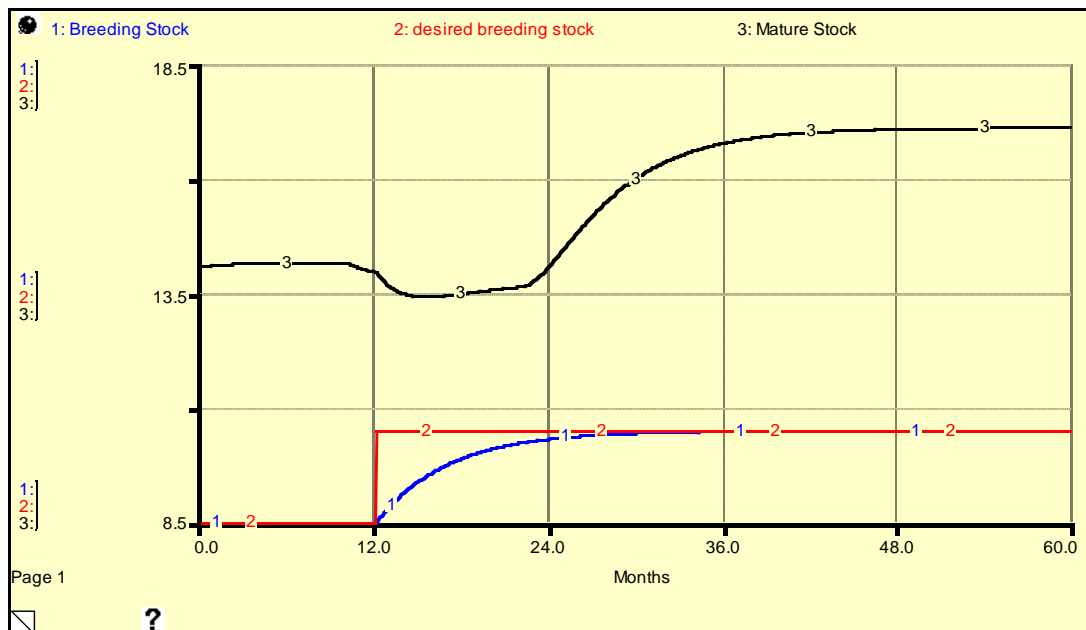


Figure 10. Testing the supply side of the hog cycle model.

The desired breeding stock (~) increases from 8.5 to 10.5 in the 12th month. The breeding stock response is the same as the previous exercise. The mature stock starts at 14.1 and reaches 16.1 by the end of the simulation. But the mature stock experiences a “worse before better” period due to the diversion of mature hogs to build the breeding stock.

4. Feedbacks in the hog cycle model: Complete the causal loop diagram in Figure 11 by labeling each arrow as + or – and by labeling each loop as (+) or (-). You should see three feedback loops:

1. One loop provides rapid feedback to control pork consumption (-).
2. Another loop (with many variables) provides delayed feedback on pork production (-)
3. A smaller loop provides control of breeding stock (-)
4. Another small loop involves hog slaughtering impact on the mature stock (-)
5. The final loop involves the “worse before better” dynamic shown in Fig. 10 (+).

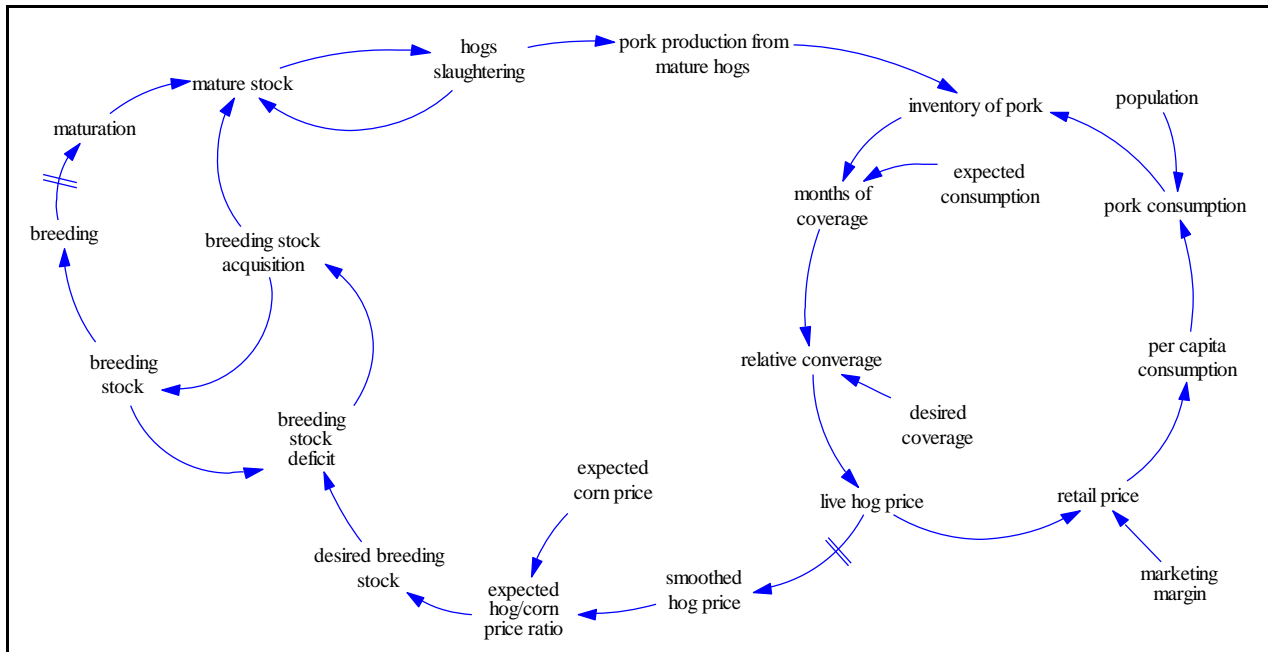


Figure 11. Complete this causal loop diagram of the model shown in Figure 1.

5. Build and verify initial conditions:

Build the model in Figure 1 by combining the demand side model in Figure 5 with the supply side model in Figure 10. Set $DT = 1/16^{\text{th}}$ month and simulate the model for 1 month. Verify that the results correspond to the initial conditions in Figure 1. (Note: the model is not in perfect equilibrium, so your numbers may be slightly different than the numbers in Figure 1.)

6. Control panel for model testing:

Add the slider and other controls shown in Figure 12. Ask for a 240 month simulation with $DT = 1/16^{\text{th}}$ of a month. Use a 12 month pause interval, and change the population from 200 to 230 million after the 12th month. Verify that you see the results in Figures 12A, B, C, D.

7. Period of Oscillations? Let’s use the hog price (shown in red in Fig 12A) to judge the period of oscillations. The peaks in hog prices appear in months 23, 69, 115, 161 and 207. Does the separation between peaks change depending on when you compare them? What is the period of the oscillations?

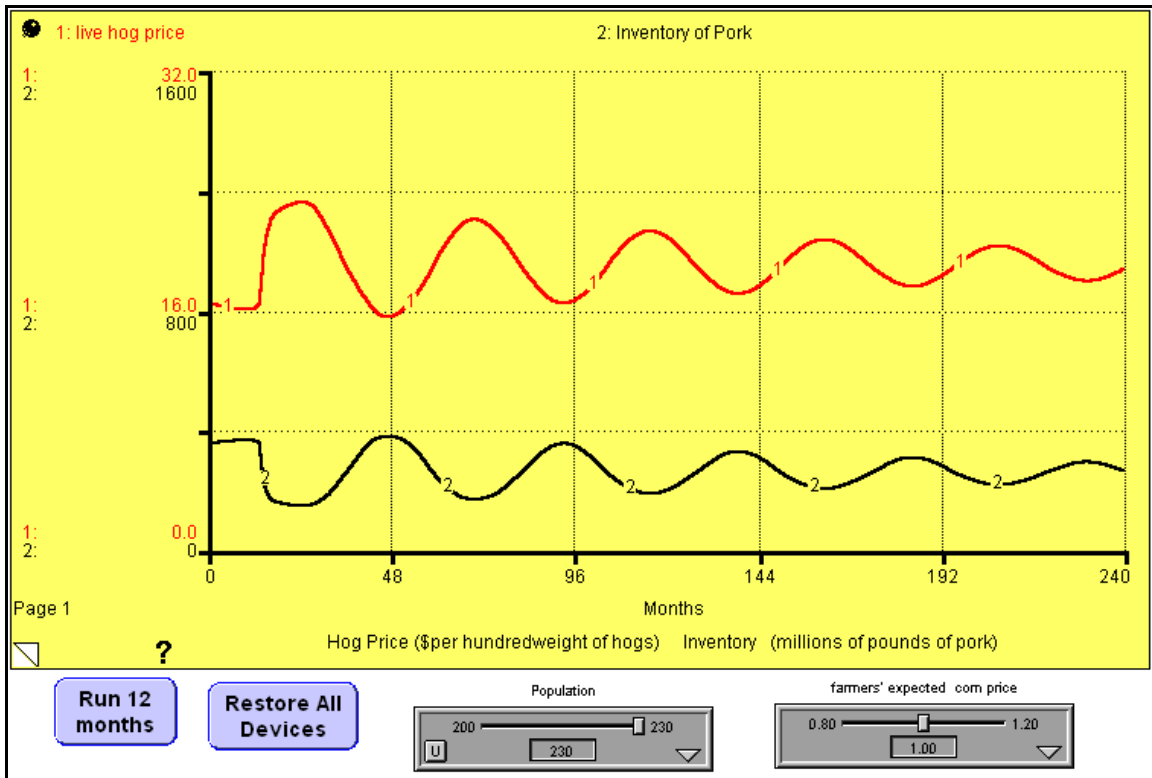


Figure 12A. Hog price and pork inventory in a test of the hog cycle model.

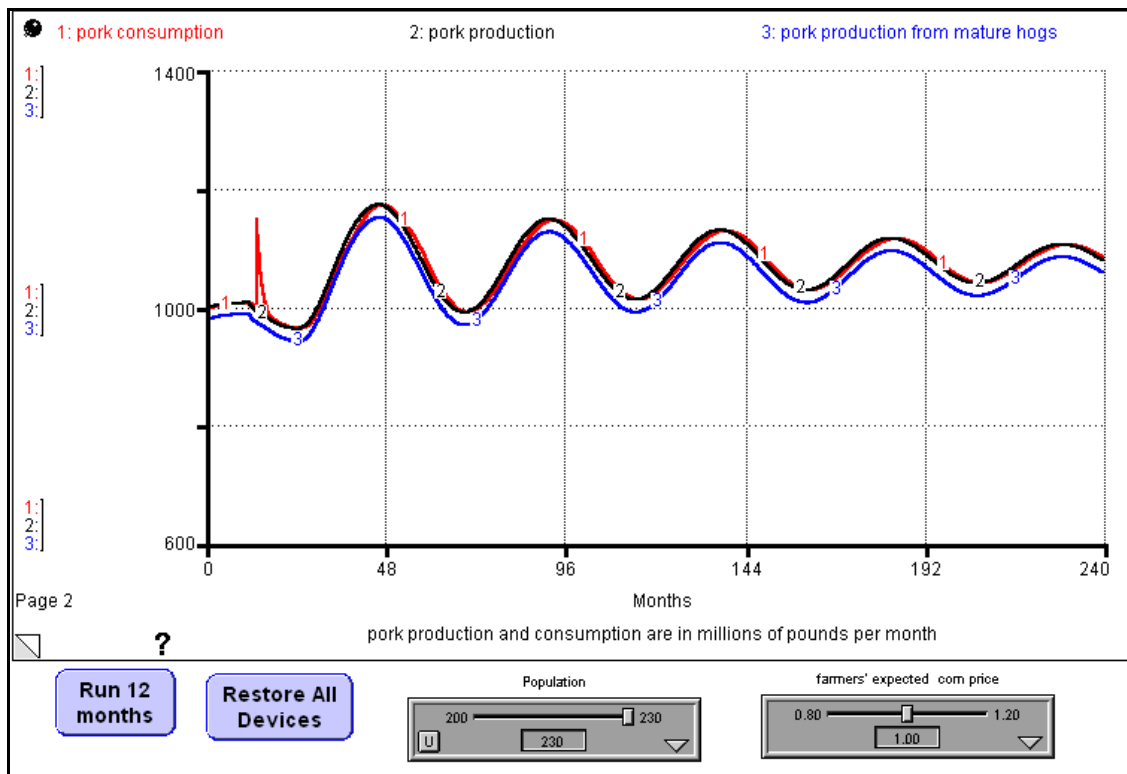


Figure 12B. Pork production and pork consumption in a test of the hog cycle model.

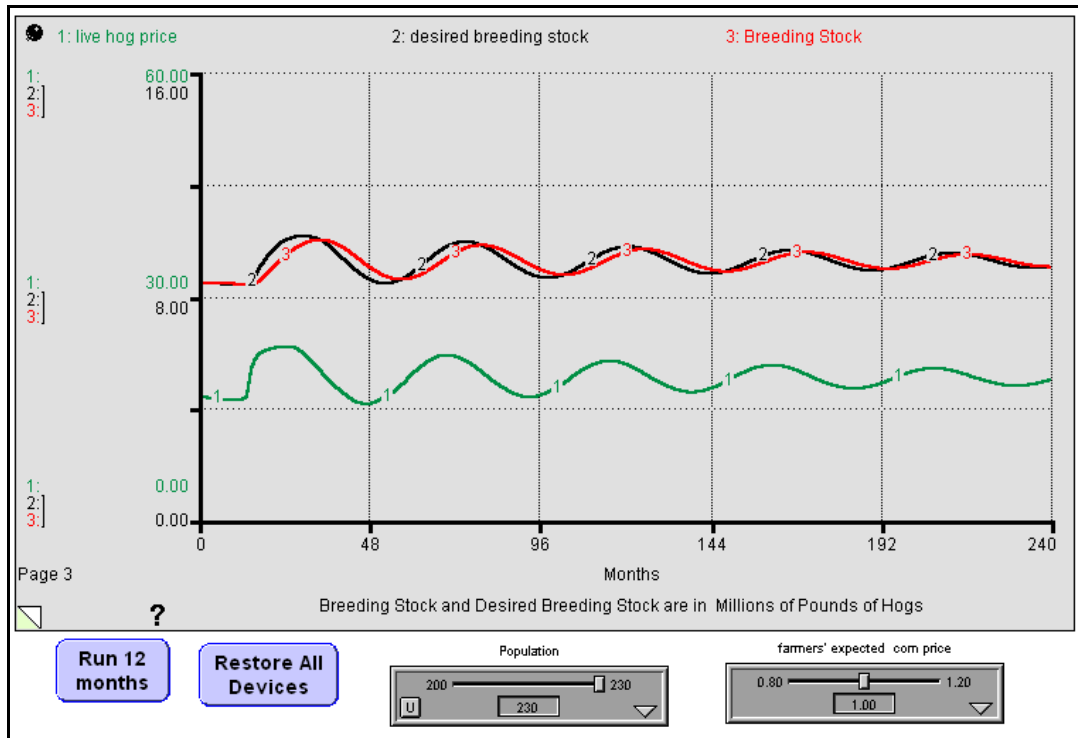


Figure 12C. Live hog price and breeding stock in a test of the hog cycle model.

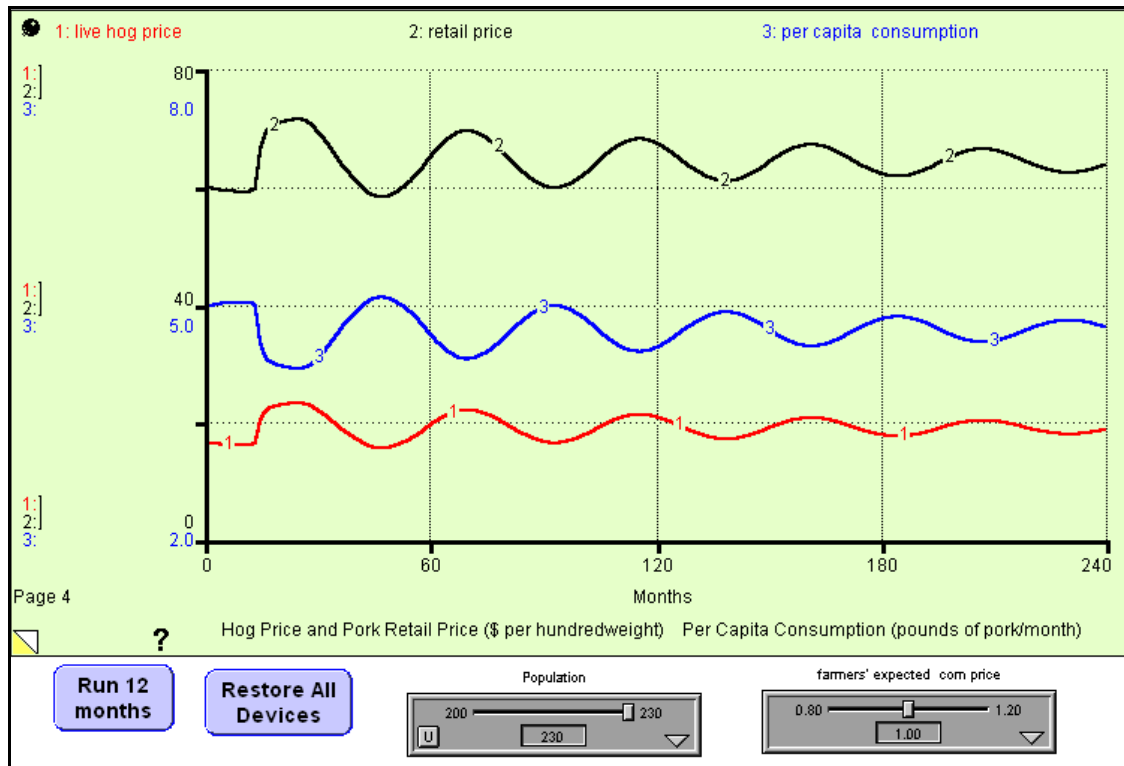


Figure 12D. Live hog price, retail price and percapita pork consumption.

8. Do we need a smaller DT?

The Figure 12 results were generated with $DT = 16^{\text{th}}$ of a month. Change DT to $1/32^{\text{nd}}$ of a month and repeat the simulation. Does the new simulation look essentially the same? For example, do you get the same estimate of the period of the oscillations?

9. Sensitivity to the Desired Coverage:

The previous results are based on a desired coverage of 0.36 months and an initial inventory of 360 million pounds of pork. Suppose it were possible to store pork at lower costs. Presumably, this would lead to an increase in the desired coverage. And perhaps the extra pork in inventory would soften the cycles? Let's see if the model confirms this hypothesis. Add a "comparative graph" of the live hog price, scaled from 16 to 24, as shown in Figure 13. Then verify the price results by conducting four simulations with 200 million people for the first 12 months and 230 million after the 12th month.

- | | |
|---------------------------------|-----------------------------------|
| Run 1: desired coverage = 0.36, | initial inventory of pork = 360 |
| Run 2: desired coverage = 0.72, | initial inventory of pork = 720 |
| Run 3: desired coverage = 1.08, | initial inventory of pork = 1,080 |
| Run 4: desired coverage = 1.44 | initial inventory of pork = 1,440 |

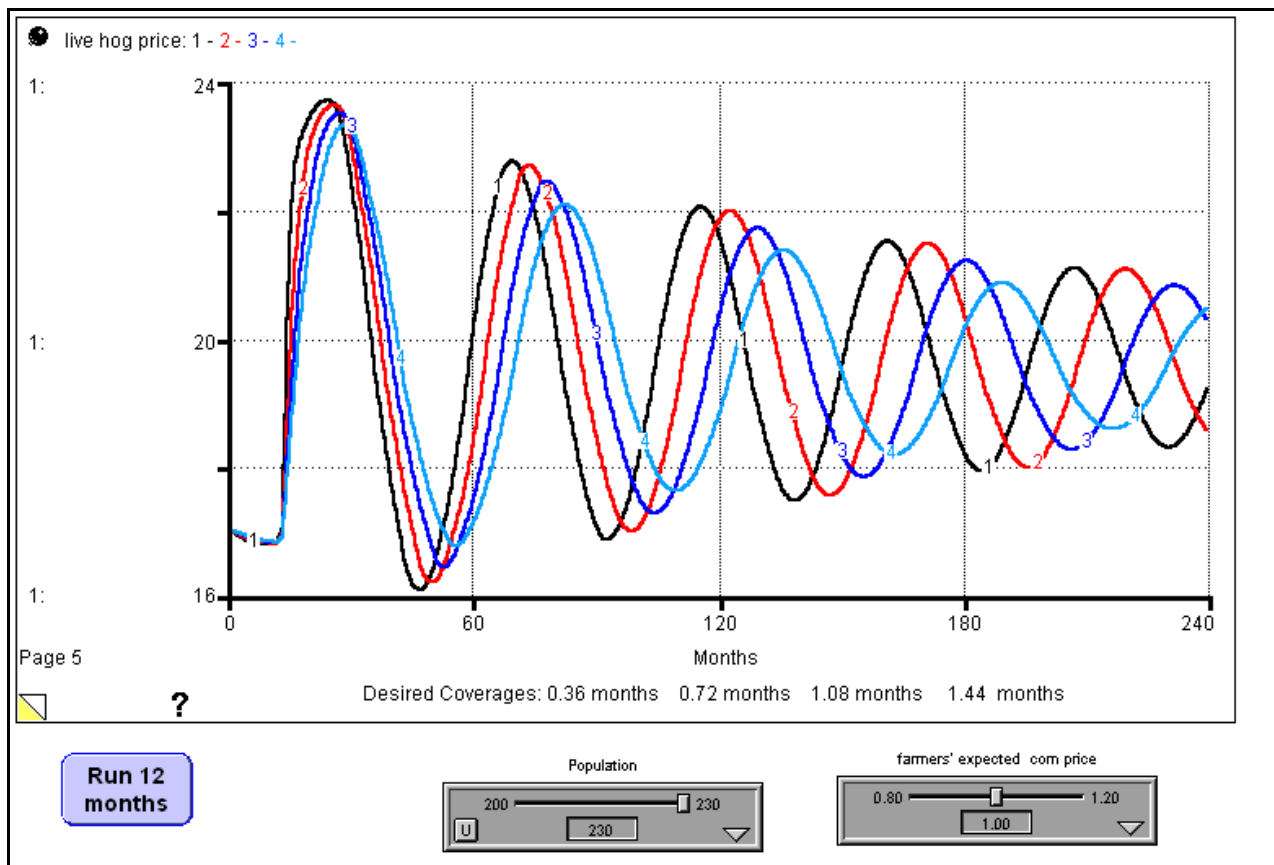


Figure 13. Simulations with greater desired coverage show longer periods, i.e., run 1:46 months, run 2:50 months, run 3:52 months, run 4:54 months.

10. Sensitivity to the Breeding Stock Decisions:

Add a *curve selector* for the breeding stock decision, as shown in Figure 14. Then use the three DBS variables to give the three curves shown in Figure 15. Each of curves calls for 8.5 million hogs when the hog price is \$16.50 per hundredweight. This means that we can run the model with the initial conditions shown in Figure 1.

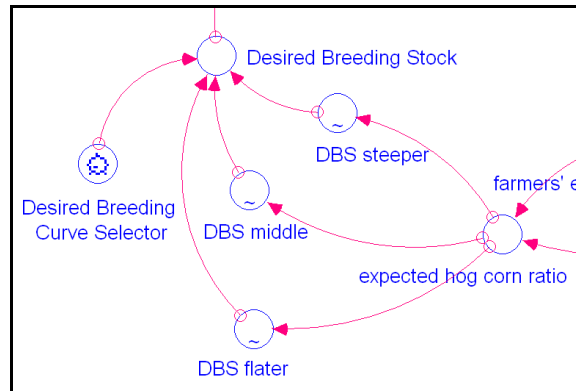


Figure 14. Extra variables for easy changes in the DBS curve. Stella equations:

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Desired_Breeding_Stock = IF(Desired_Breeding__Curve_Selector=1) THEN (DBS_flater)
ELSE (IF(Desired_Breeding__Curve_Selector=2) THEN DBS_middle ELSE DBS_steeper)
DBS_flater = GRAPH(expected_hog_corn_ratio)
(9.00, 7.00), (11.5, 7.50), (14.0, 8.00), (16.5, 8.50), (19.0, 9.00), (21.5, 9.50), (24.0, 10.0), (26.5, 10.5)
DBS_middle = GRAPH(expected_hog_corn_ratio)
(9.00, 6.25), (11.5, 7.00), (14.0, 7.75), (16.5, 8.50), (19.0, 9.25), (21.5, 10.0), (24.0, 10.5), (26.5, 10.5)
DBS_steeper = GRAPH(expected_hog_corn_ratio)
(9.00, 5.50), (11.5, 6.50), (14.0, 7.50), (16.5, 8.50), (19.0, 9.50), (21.5, 10.5), (24.0, 10.5), (26.5, 10.5)

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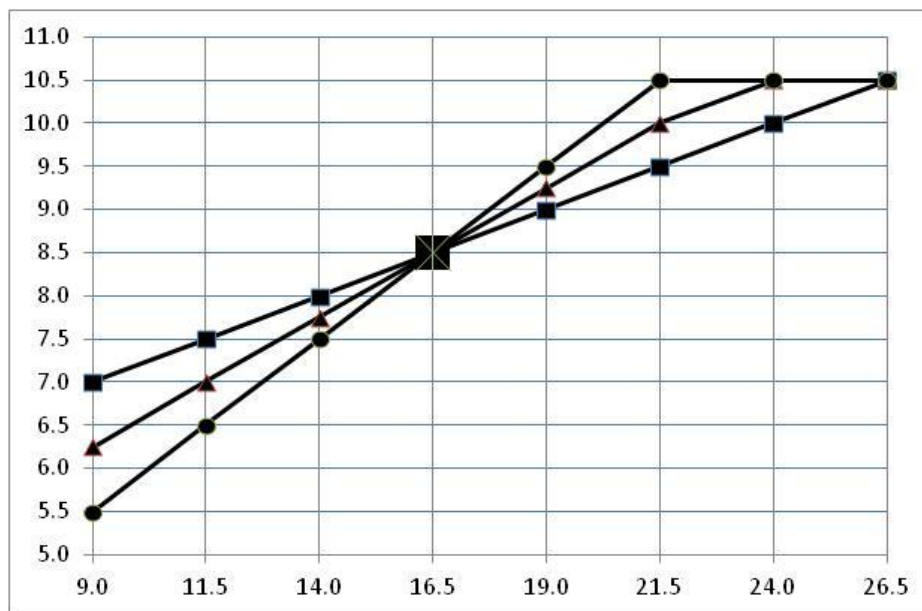


Figure 15. Three versions of the desired breeding stock curve.

Add a “knob input device” to allow one to dial up DBS curve 1, 2 or 3. Enter information about the three curves in the comment window, then press the ? on the knob. Your information should pop into view. Create a comparison graph for the live hog price, scaled from 0 to 32, as shown in Figure 16.

Run the model three times, selecting curve 1, then curve 2, then curve 3. Use the slider to change the population from 200 million to 230 million in the 12th month in each simulation. Verify that get the results in Figure 16. Notice in particular the damped behavior of the hog price in the first simulation with the flatter DBS curve.

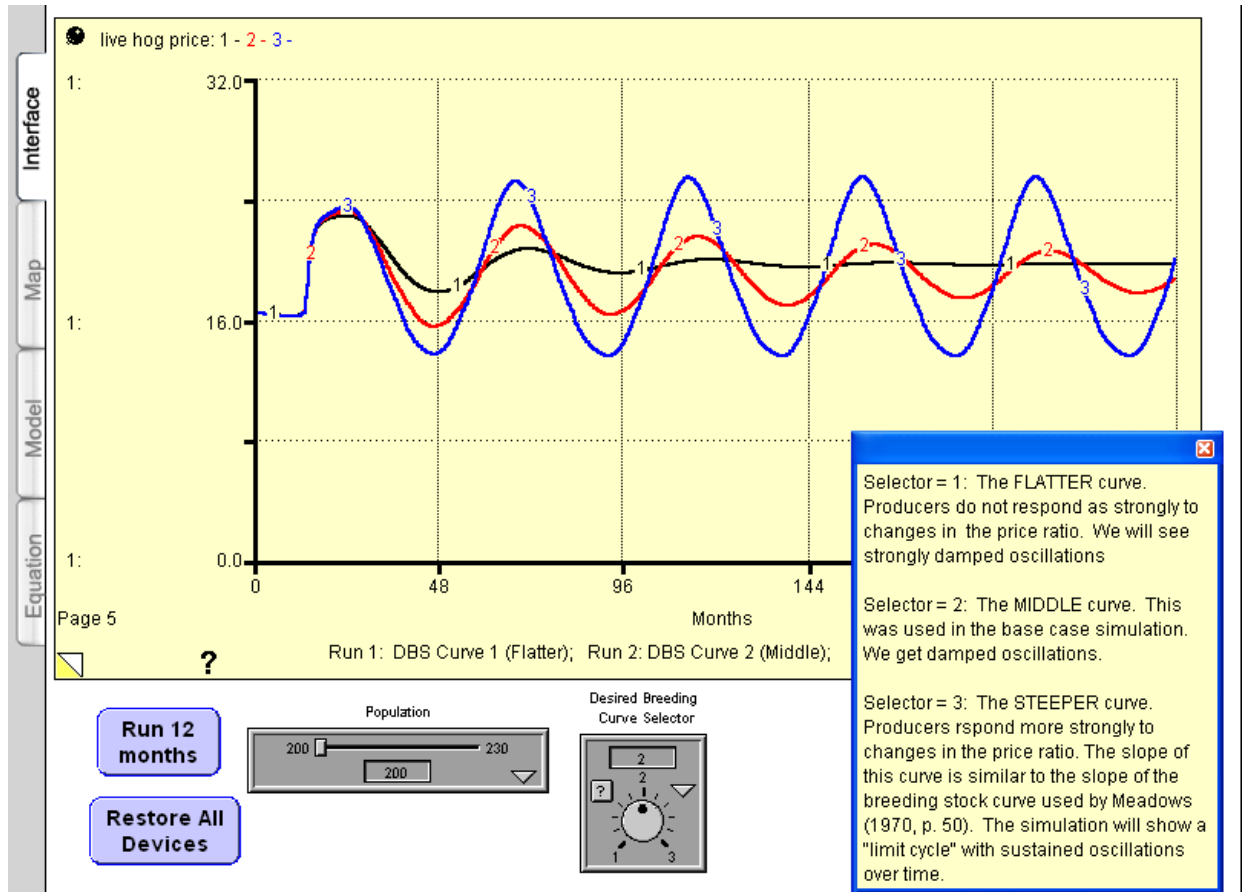


Figure 16. Comparison of simulations with different versions of the desired breeding stock curve.

11. Concluding Discussion Question:

You are asked to work with hog farmers and pork processors to make changes that would reduce the tendency for the large swings in the hog cycle. You convene a meeting with hog farmers and pork processors coming together to share their views.

- Suppose the hog farmers address the pork processors by saying the cycles could be damped if the processors would carry more pork in inventory.
- And suppose the pork processors address the farmers by saying that the cycles could be damped if the hog farmers would not react so strongly to changes in the live hog price.

Explain what insight can be added to the discussion by using the hog cycle model. For example, do the model results confirm the hog farmers' position? Or do the model results confirm the pork processors' position? Does the model show that they are both wrong? Or that they are both right? And if they are both right, which position seems to hold more promise for dampening the hog cycle?

Future Exercises

This is the 1st version of the hog cycle exercises. Future versions could include exercises to make the hog cycle more realistic in today's market. And there may be new exercises to deal with buffer funds. And perhaps we will include exercises to adapt the model to other commodities.

The new versions may also include exercises for students interested in promotion of small-scale hog operations that strive for higher quality pork production and local distribution. These farmers would not be in the "commodity" business since they are aiming for a qualitatively different product than the pork produced by large-scale operations.⁷ The simulation of small-scale, local farmers could be quite different than the model shown in these notes. For example:

- For market share calculations, the new model might make use of the multi-nomial logit model, the "work horse" of discrete choice modeling (see page 214 in the book). Quality pork would sell at much higher prices, but those prices may be immune from the hog cycle dynamics. A small fraction of dedicated consumers might purchase the quality pork despite the price premium. They would then tell their friends and spread the news about the quality product.
- To simulate the word-of-mouth effect, future students might make use of a modified version of the SIR epidemic model on page 89. The SIR stocks for the spread of an epidemic could be changed to PIR stocks for the growing interest in small-scale pork:
 - P could stand for the potential, but unformed part of the population
 - I could be the interested population, people who heard about quality pork from a friend;
 - R could be the regular customers for local farmers selling the quality pork.

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⁷ Hog farming in the US has become increasingly concentrated in large operations. For example, 88% of the pig crop in 2008 came from operations with more than 5,000 head (NASS 2009).