Guided Study Program in System Dynamics

System Dynamics in Education Project
System Dynamics Group
MIT Sloan School of Management[1]

Solutions to Assignment #18
Thursday, March 18, 1999

Reading Assignment:

Please read the following:

- Principles of Systems,[2] *by Jay W. Forrester, Chapter 4*

Please refer to Road Maps 9: A Guide to Learning System Dynamics (D-4509) and read the following paper from Road Maps 9:

- *The Credit Card Model, by Manas Ratha (D-4683)*

Please refer to Road Maps 6: A Guide to Learning System Dynamics (D-4506-4) and read the following paper from Road Maps 6:

- *Systems thinking: critical thinking skills for the 1990s and beyond, by Barry Richmond (D-4565)*

Please refer to Road Maps 8: A Guide to Learning System Dynamics (D-4508-1) and read the following paper from Road Maps 8:

- *Mistakes & Misunderstandings: Use of Generic Structures and Reality of Stocks and Flows, by Lucia Breierova (D-4646)*

Exercises:

1. Principles of Systems

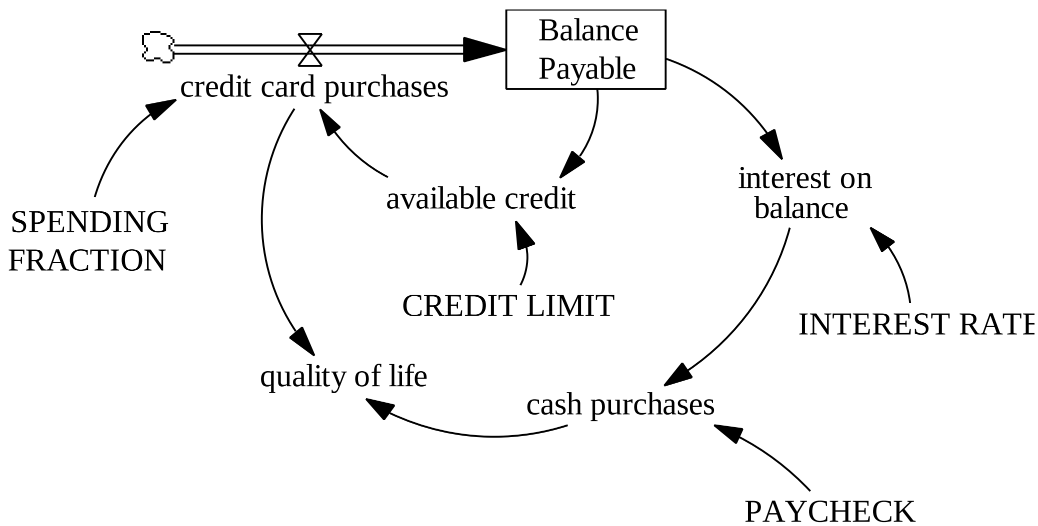
Please read chapter 4 of Principles of Systems and do the workbook exercises for these sections (located at the end of the book). The material in this chapter is very important and you should make sure you understand it. Please let us know if you have any questions. You do not need to submit anything for this reading assignment.

[2] Forrester, Jay W., 1968. *Principles of Systems*, (2nd. ed.). Waltham, MA: Pegasus Communications. 391 pp.

2. The Credit Card Model:

A. Build the model as you progress with the paper. Formulate the model and simulate it to make sure it is producing the expected behavior. In your assignment solutions document, please include the model diagram, documented equations, and graphs of model behavior.

Model diagram:



Model equations:

available credit = CREDIT LIMIT – Balance Payable

Units: dollar

"Available credit" is the difference between the "CREDIT LIMIT" and "Balance Payable." The "available credit" is the maximum amount of money Joe can charge to his credit card at the time.

Balance Payable = INTEG (credit card purchases, 0)

Units: dollar

The "Balance Payable" is the amount of money Joe owes to International Express.

cash purchases = PAYCHECK – interest on balance

Units: dollar/Month

The purchases made each month with the money left from the "PAYCHECK" after paying the "interest on balance."

credit card purchases = available credit * SPENDING FRACTION

Units: dollar/Month

"Credit card purchases" is the amount Joe charges on his credit card each month, and is a fixed fraction, the "SPENDING FRACTION" of the "available credit."

CREDIT LIMIT = STEP(6000,6)

Units: dollar

The maximum amount Joe can charge on his credit card. It is the maximum value of the "Balance Payable."

interest on balance = Balance Payable * INTEREST RATE

Units: dollar/Month

The interest charged on Joe's "Balance Payable" by International Express.

INTEREST RATE = 0.015

Units: 1/Month

The fraction of the "Balance Payable" charged as interest per month.

PAYCHECK = 2000

Units: dollar/Month

The "PAYCHECK" is the amount of money Joe earns each month.

quality of life = cash purchases + credit card purchases

Units: dollar/Month

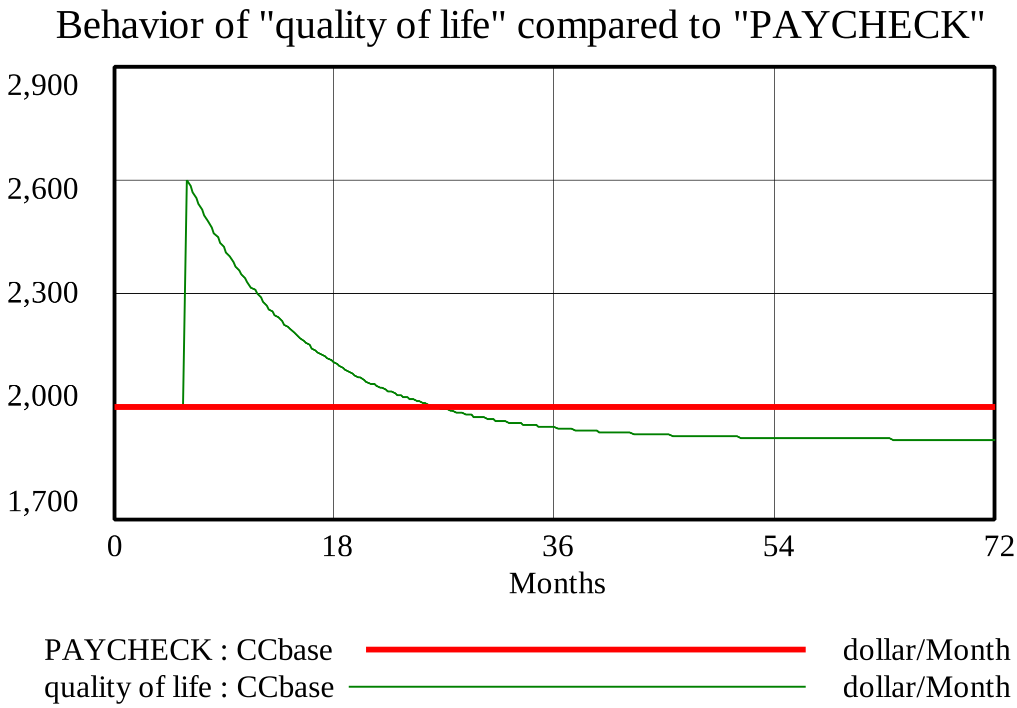
The "quality of life" is the total amount of money Joe can spend at any time.

SPENDING FRACTION = 0.1

Units: 1/Month

The "SPENDING FRACTION" is the fraction of the "available credit" Joe spends on "credit card purchases" each month.

Model behavior:

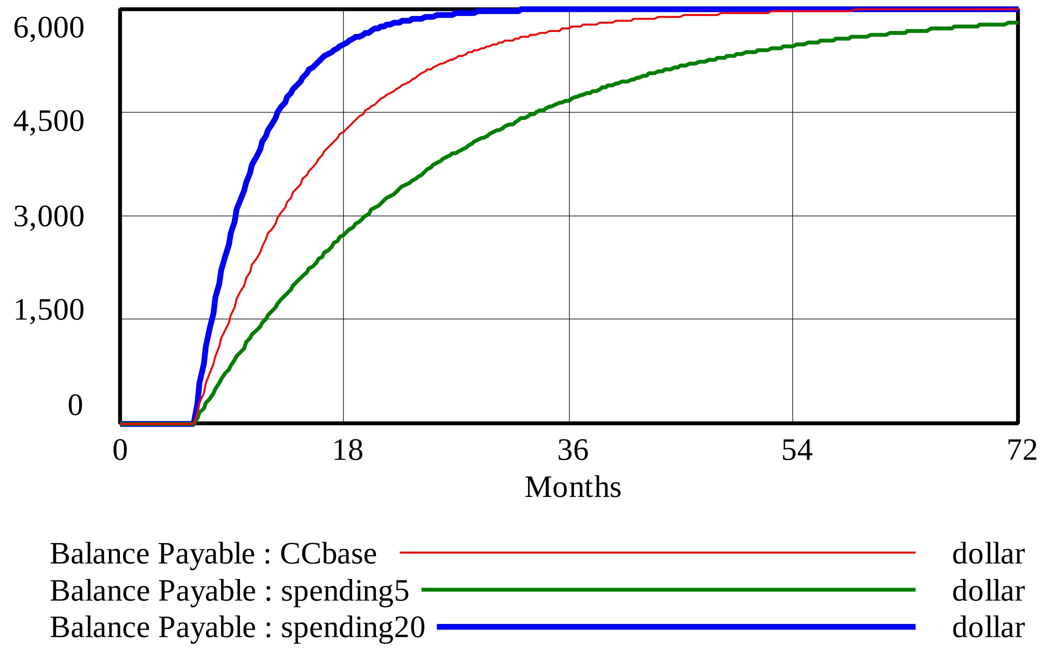


B. Perform sensitivity analysis on the model by altering the values of the constants. By varying the constants, can you change the type of behavior the model exhibits? How? In your assignment solutions document, include graphs of interesting model behavior, noting the parameter values used to produce that behavior.

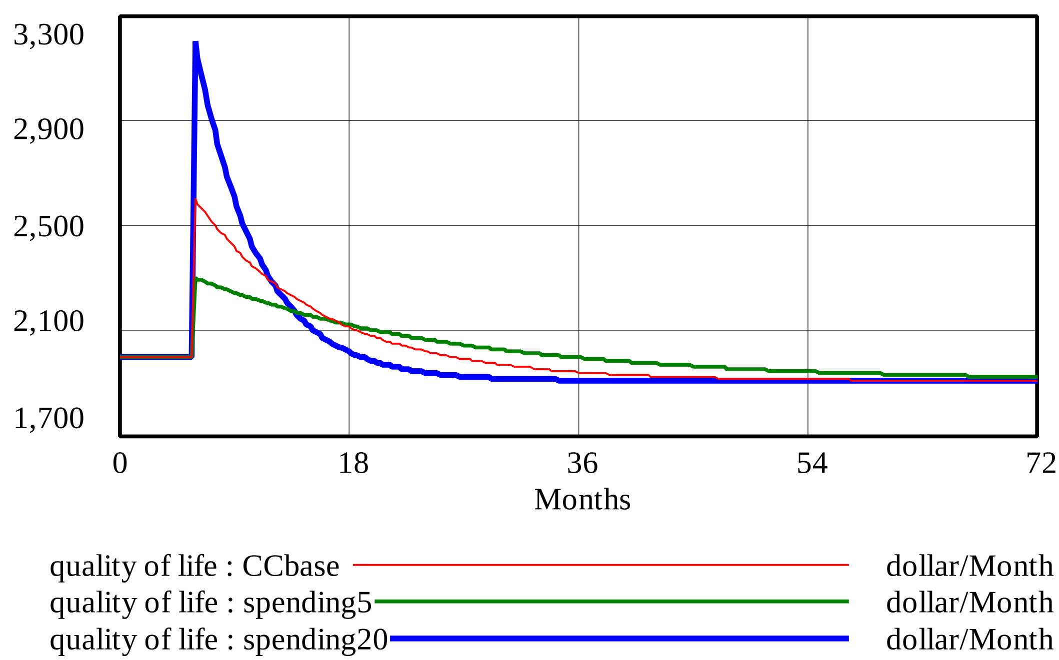
The model contains a first-order negative feedback loop connecting the stock "Balance Payable" to its inflow "credit card purchases" through the "available credit." The system, therefore, can only tend towards some type of equilibrium. In particular, "Balance Payable" only has an inflow that approximates the level to its goal, the "CREDIT LIMIT," at a rate that depends on the "SPENDING FRACTION." When "Balance Payable" equals "CREDIT LIMIT," the system reaches equilibrium. The model contains no other feedback loops, so changing parameter values alters only equilibrium values or the time needed to reach equilibrium. The basic behavior mode, the asymptotic growth of "Balance Payable" and the asymptotic decline of "quality of life," however, cannot be changed by altering parameter values.

Sensitivity analysis of the model confirms these results. A greater "SPENDING FRACTION," for example, increases the initial rise in "credit card purchases," "Balance Payable," and "quality of life." The equilibrium values are not changed, but are reached sooner. The following figures show the behavior of "Balance Payable" and "quality of life" with "SPENDING FRACTION" equal to 0.05 (spending5) and 0.20 (spending20) per month, compared to the base run value of 0.10 (CCbase):

Balance Payable - changing spending fraction

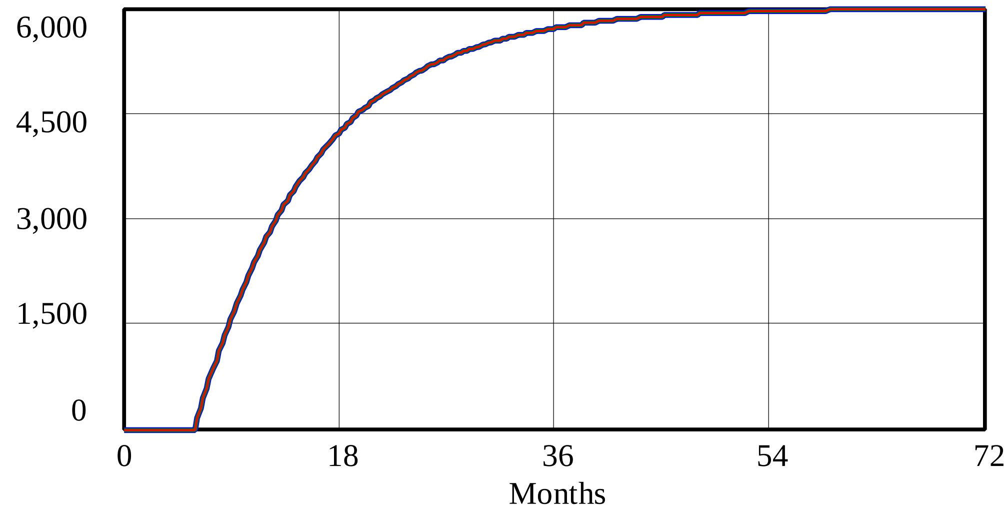


Quality of life - changing spending fraction



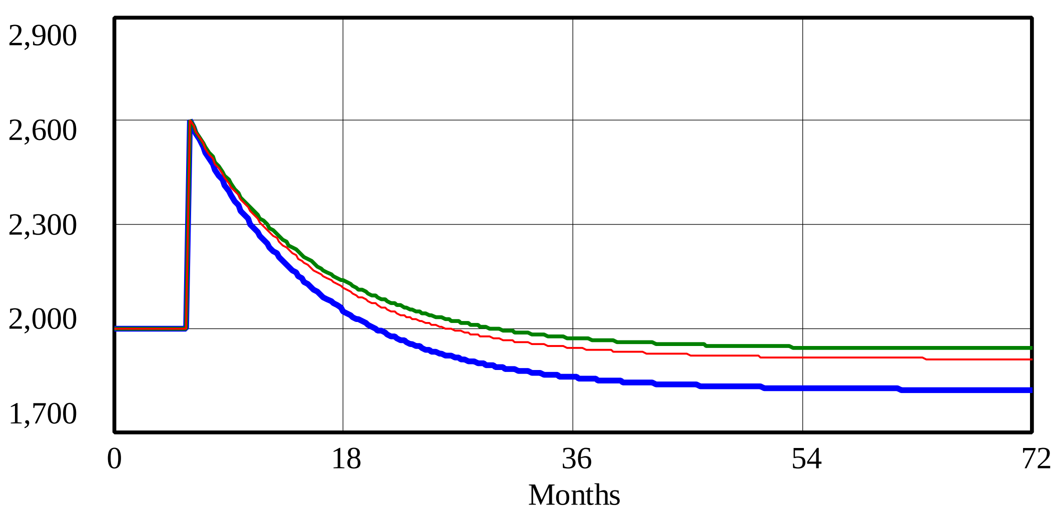
The "INTEREST RATE" does not affect the "Balance Payable," so changing the "INTEREST RATE" does not change the behavior of "Balance Payable." With a higher "INTEREST RATE," however, the equilibrium "quality of life" is lower. These results are shown in the following figures that show the behavior of “Balance Payable” and “quality of life” with “INTEREST RATE” equal to 0.01 (interest1) and 0.03 (interest3) per month, compared to the base run value of 0.015 (CCbase):

Balance Payable - changing interest rate



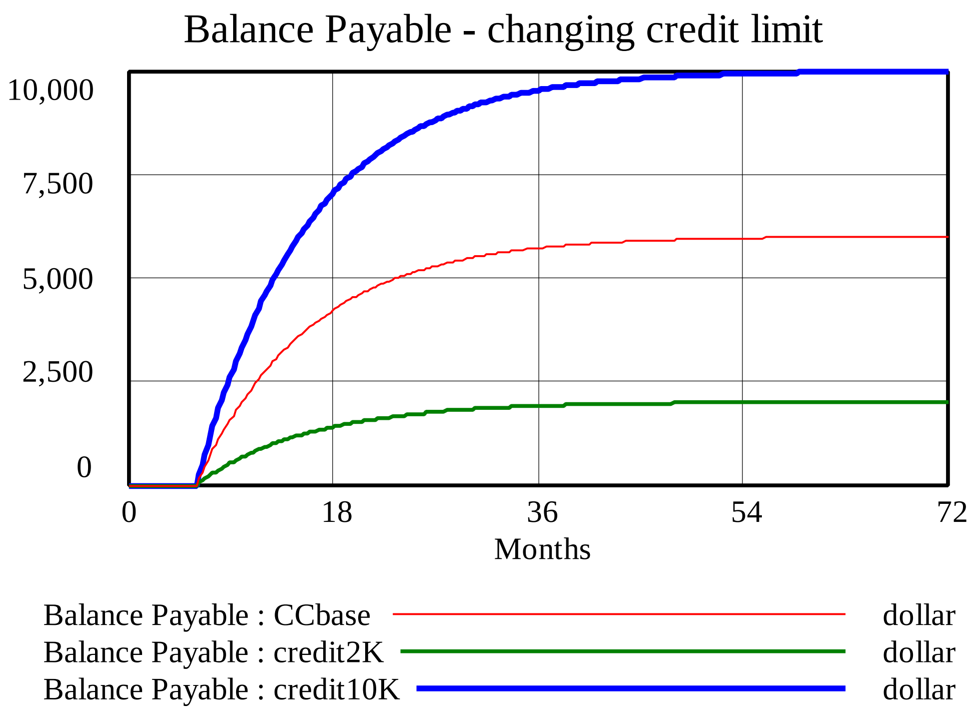
Balance Payable : CCbase dollar
Balance Payable : interest1 dollar
Balance Payable : interest3 dollar

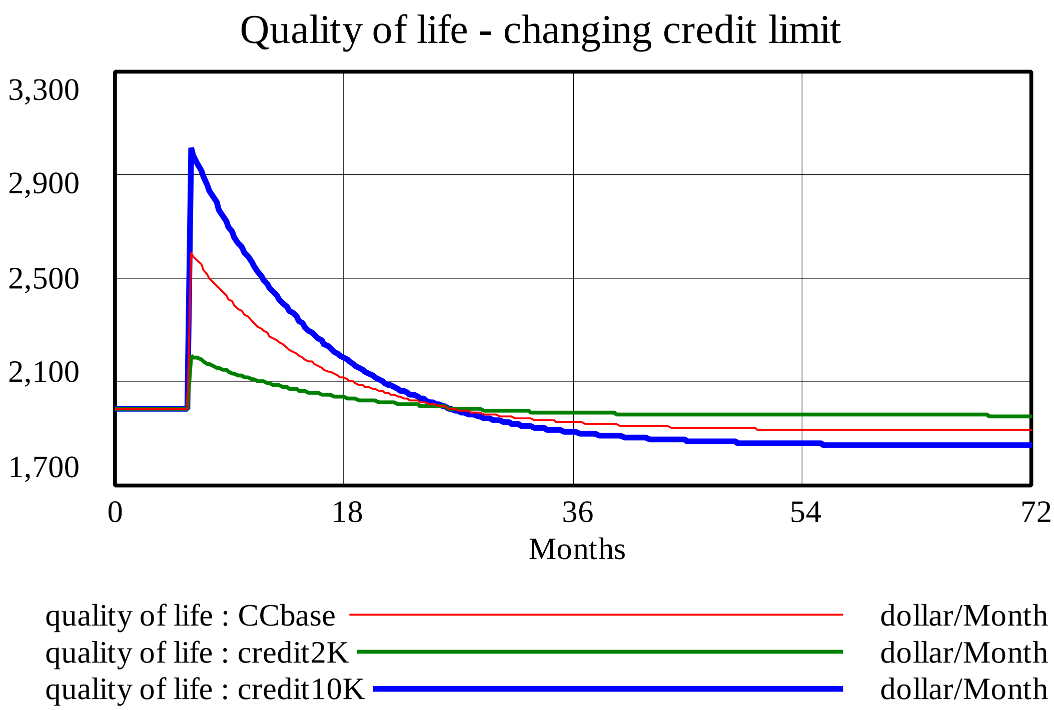
Quality of life - changing spending fraction



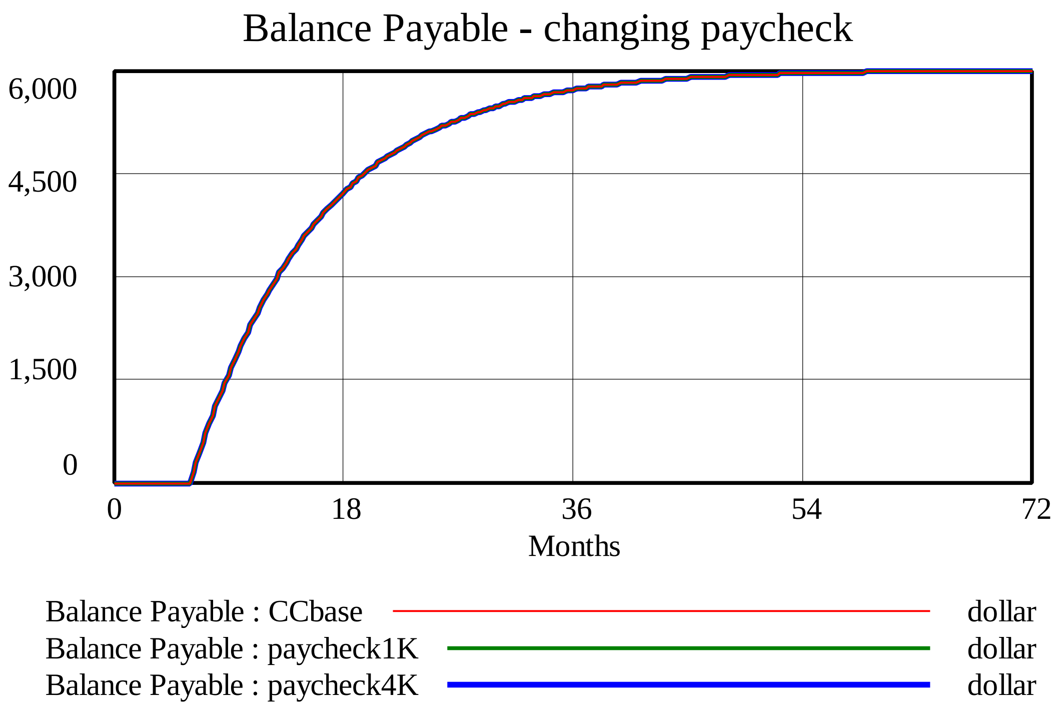
quality of life : CCbase dollar/Month
quality of life : interest1 dollar/Month
quality of life : interest3 dollar/Month

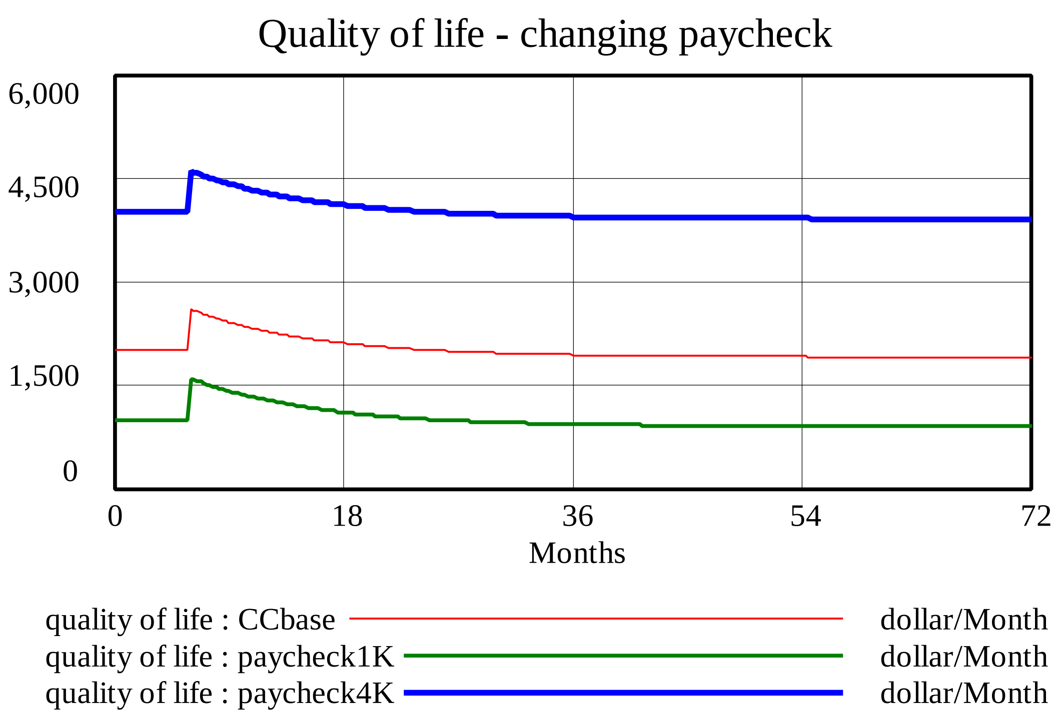
The "CREDIT LIMIT" determines the equilibrium values of several variables in the model. Increasing the value of "CREDIT LIMIT" increases the equilibrium value of "Balance Payable," which then increases the "interest on balance" and thus decreases the equilibrium value of "quality of life." The following figures confirm these results, showing the behavior of "Balance Payable" and "quality of life" with "CREDIT LIMIT" equal to 2,000 (credit2K) and 10,000 (credit10K) dollars starting in month 6, compared to the base run value of 6,000 (CCbase):





Changing Joe's "PAYCHECK" does not affect the behavior and equilibrium value of "Balance Payable," but changes the equilibrium value of "quality of life." A higher "PAYCHECK" results in a higher "quality of life," but "quality of life is still lower than it would have been without using the credit card. These results are confirmed in the following figures, showing the behavior of "Balance Payable" and "quality of life" with "PAYCHECK" equal to 1,000 (paycheck1K) and 4,000 (paycheck4K) dollars per month, compared to the base run value of 2,000 (CCbase):

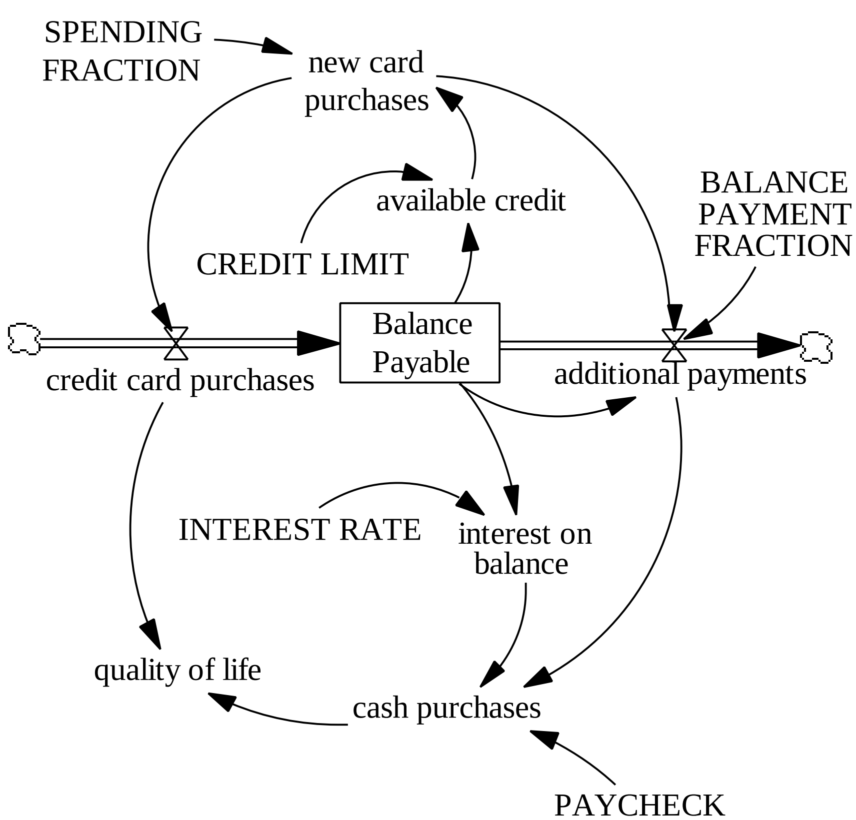




C. The way the model appears in the paper, Joe's balance keeps rising until it reaches the limit, at which point Joe continuously pays off only the interest charges on the "Balance Payable," and the "Balance Payable" itself stays constant. Suppose Joe *realizes that by not reducing the balance, he will be paying interest indefinitely. Joe decides that he wants to gradually eliminate his account balance. Think of a reasonable and realistic payment policy to achieve Joe's goal. Model the new policy, simulate the new model, and see if the policy is indeed an effective one at eliminating Joe's account balance. In your assignment solutions document, please include the modified model diagram, documented equations, and graphs of model behavior. Discuss the short- and long-term effects of the policy change on the "quality of life."*

Suppose that Joe decides to eliminate his credit card balance only after the quality of his life falls below its initial value, which occurs around month 26. Let us therefore implement his new payment policy starting in month 30. If Joe wants to eliminate his "Balance Payable," he should pay not only the monthly interest charges, but also his monthly "credit card purchases." In addition, he may want to pay a constant fraction of his "Balance Payable" every month. Joe's new policy is represented by the following model:

<u>Model diagram with Joe's new payment policy:</u>



<u>Modified model equations:</u>

additional payments = STEP(new card purchases + (Balance Payable * BALANCE PAYMENT FRACTION), 30)
Units: dollar/Month

The "additional payments" are the amount of money that Joe pays to International Express in addition to the interest payments. Starting in month 30, Joe repays his "new card purchases" as well as a constant "BALANCE PAYMENT FRACTION" of his "Balance Payable."

Balance Payable = INTEG (credit card purchases + additional payments, 0)

Units: dollar

The "Balance Payable" is the amount of money Joe owes to International Express.

BALANCE PAYMENT FRACTION = 0.1

Units: 1/Month

The fraction of "Balance Payable" that Joe pays each month in order to eliminate his balance.

cash purchases = PAYCHECK - interest on balance - additional payments

Units: dollar/Month

The purchases made each month with the money left from the "PAYCHECK" after paying the "interest on balance" and the "additional payments."

credit card purchases = new card purchases

Units: dollar/Month

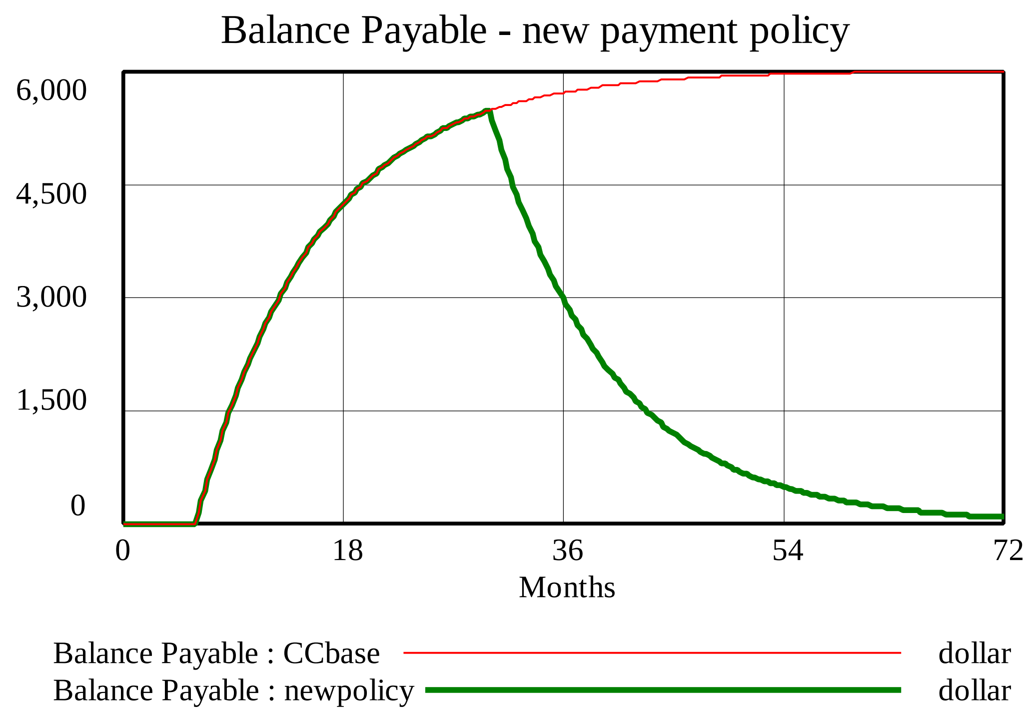
Joe's new credit card purchases every month.

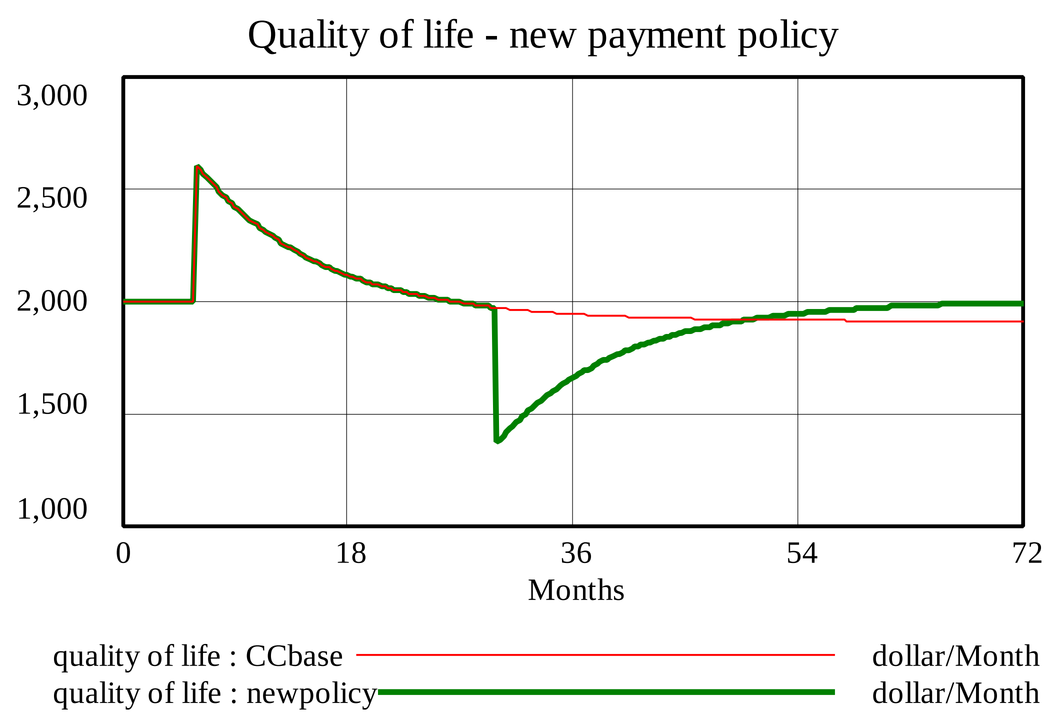
new card purchases = available credit * SPENDING FRACTION

Units: dollar/Month

The credit card purchases that Joe makes every month are a constant "SPENDING FRACTION" of his "available credit."

<u>Model behavior:</u>





As one can see from the above figures, Joe succeeds at eliminating his "Balance Payable" with this new payment policy. Immediately after month 30, Joe's "additional payments" start to reduce his "Balance Payable," and by the end of the simulation, "Balance

Payable" is almost eliminated. Joe is still using his credit card to make "credit card purchases." In order to repay his "credit card purchases," however, he has to reduce his "cash purchases" by the same amount. Notice also that immediately after Joe begins his new payment policy, his "quality of life" is reduced drastically because he is spending most of his "PAYCHECK" to repay the accumulated "Balance Payable." Eventually, however, as his "Balance Payable" is reduced to 0, Joe no longer has to pay any interest, so "quality of life" stabilizes at 2,000 dollars/month, the same value as without the credit card.

Again, the credit card model demonstrates an interesting characteristic of complex systems: the conflict in short-term and long-term results, or "worse before better." In other words, to eliminate the "Balance Payable," Joe has to go through a short-term drop in his "quality of life." In the long-term, however, the new payment policy is beneficial because Joe's "quality of life" climbs back to the value of his "PAYCHECK." Notice that the base run of the credit card model illustrated the reverse behavior: "better before worse." In the base run, Joe's "quality of life" initially increased because of borrowing, but then was reduced to a value lower than the "PAYCHECK" because he had to pay interest on "Balance Payable."

3. Systems thinking: critical thinking skills for the 1990s and beyond

In the top paragraph on page 114 of this paper, the author poses the following question to his readers: "How can the framework, the process, and the technologies of systems thinking be transferred to the rest of the world in an amount of time that is considerably less than what it currently takes to get a master's or Ph.D. degree in our field?" What is your opinion on this question? In formulating your answer, you should consider not only the speed and the quantity of the transfer, but also the quality of the material being taught.

My experience in this field, the last 3 years, show me that there are a lot of people interested in 'System Thinking' but few are practicing it and when push comes to shove they resort back to traditional ways of thinking and dealing with problems. In my opinion, the only true successful way of transferring system thinking methodology is to begin with the youth. It's hard to train an old dog, but young ones are much more amenable to new training. This belief is also backed by Dr. Forrester's lead in getting system dynamics taught in grade schools and high schools. This may not seem like a quick avenue to take, but in the end, it will be the most effective.

When I started thinking of this question, I thought of H. Ross Perot for some reason. I could just see him sitting there with behavior over time graphs and Stella models all made up and ready to go on national television. Mass media is going to be the only way to get this information out in a rapid way. If you think about it, Ninja Turtles introduced kids to the names of some very famous painters. Captain Planet, another comic super hero, introduced environmental concerns to the youth of America. There needs to be something like that for this field. I watch my 5 year old watch The Magic Schoolbus on PBS and think that there lies our answer. Turn the information into a PBS show with characters that children can relate to. The children will be exposed to these ideas at a very young age, and the parents who watch TV with their kids might accidentally absorb some of the information as well.

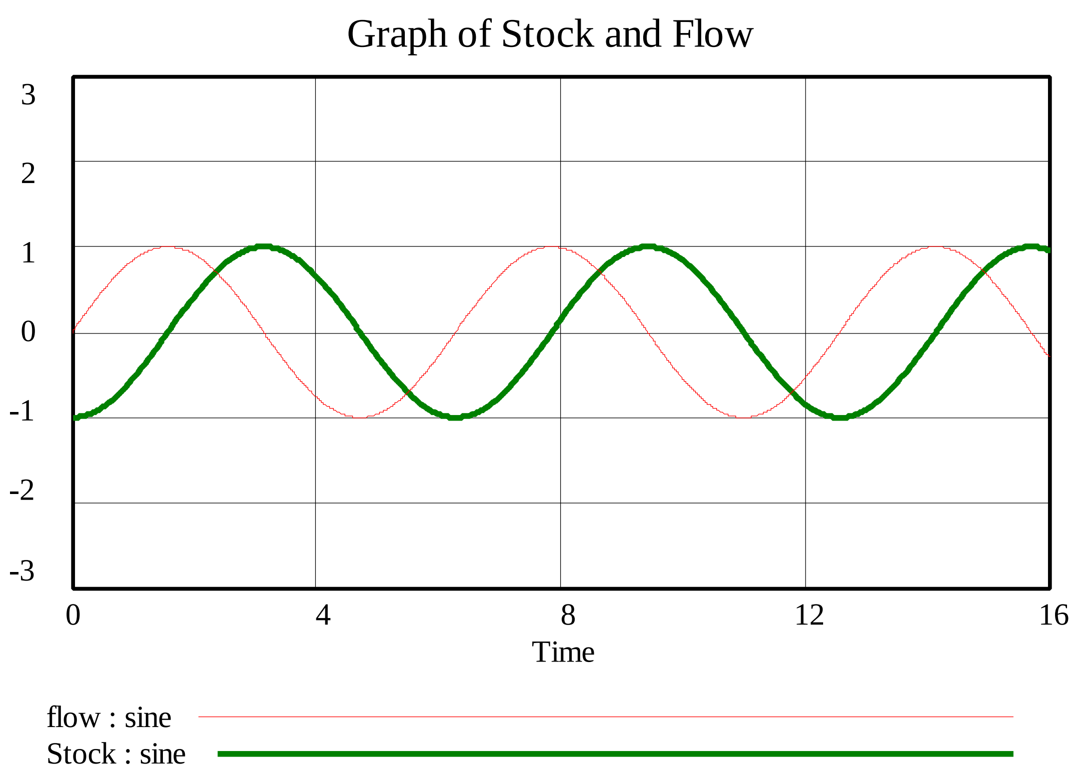
4. Mistakes and Misunderstanding: Use of Generic Structures and Reality of Stocks and Flows

Read this paper carefully. You do not have to answer any questions for this paper but if you can think of an instance when you made the same mistake, feel free to share the lesson gained with us.

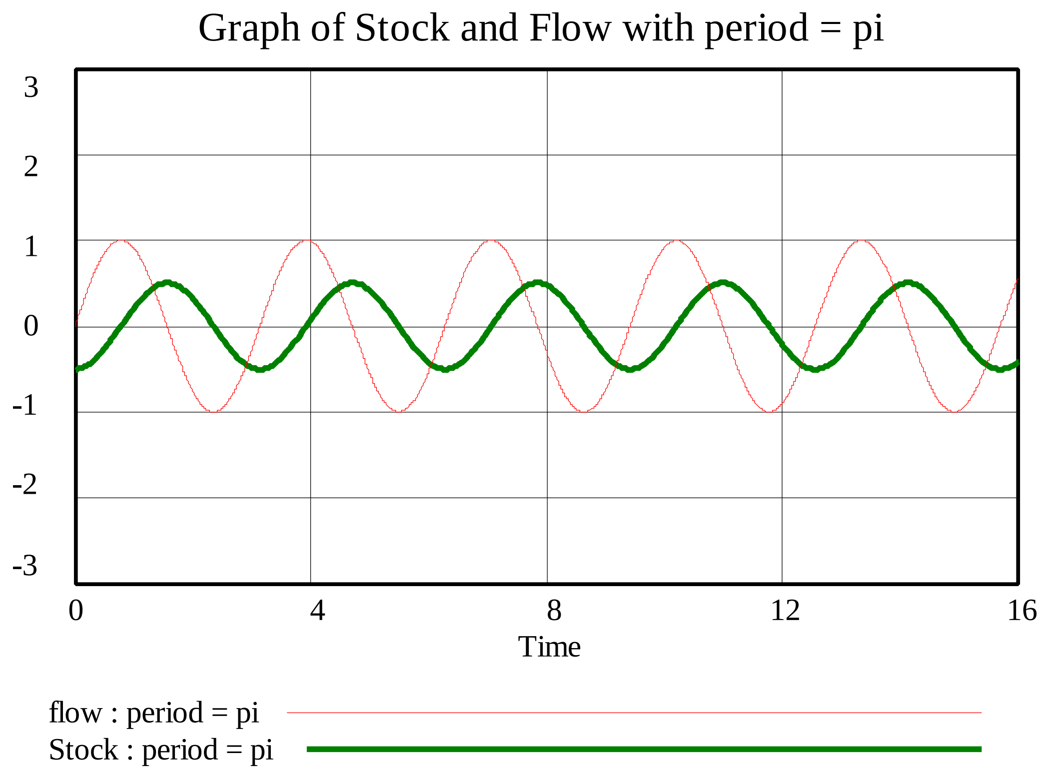
5. Understanding Oscillatory Systems

This is the second in a series of exercises designed to help your understanding of oscillatory systems. Use the model from Exercise 2 in Assignment 17 to complete the following exercises.

A. Simulate the model again. In your assignment solutions document, include the graphs of the behavior of the "flow" and of the "stock" in the base run.

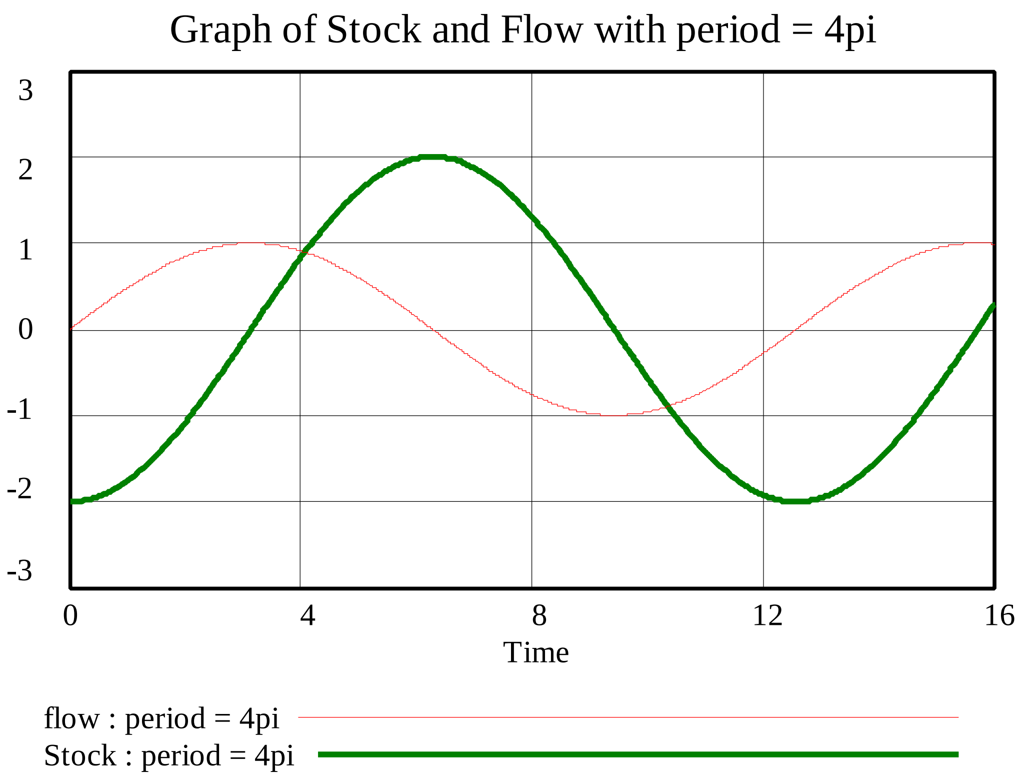


B. Create a new dataset and simulate the model with "period" equal to Pi. In your assignment solutions document, include graphs of the behavior of the "flow" and of the "Stock" in this simulation. You may wish to change the initial value of the "Stock." Describe the relationship between the two graphs and compare the simulation to that from part A.



The two graphs show oscillating behavior with the same period equal to Pi. The amplitude of the "flow" is still equal to 1 but the amplitude of the "Stock" is reduced to 0.5. Because the period of the "flow" has been shortened, the "flow" is positive for a shorter amount of time and hence adds less to the value of the "Stock." Therefore, the "Stock" does not rise as high as it did in the base run. Compared to part A, the period of both "flow" and "Stock" has halved, and the amplitude of the "Stock" has halved. The "Stock" still lags one quarter of a period behind the flow. Notice that we changed the initial value of the "Stock" to –0.5 to make the "Stock" oscillate around 0.

*C. Repeat part B with "period" equal to 4*Pi.*



The two graphs show oscillating behavior with the same period equal to 4*Pi. The amplitude of the "flow" is still equal to 1 but the amplitude of the "Stock" is increased to 2. Because the period of the "flow" has become longer, the "flow" is positive for a longer amount of time and hence adds more to the value of the "Stock." Therefore, the "Stock" rises higher than it did in the base run. Compared to part A, the period of both "flow" and "Stock" has doubled, and the amplitude of the "Stock" has doubled. The "Stock" still lags one quarter of a period behind the flow. Notice that we changed the initial value of the "Stock" to –2 to make the "Stock" oscillate around 0.

D. What conclusions can you make about the relationship between an oscillating flow and its stock as the period of the flow changes?

As the period of the "flow" changes, the period of the "Stock" changes to the same value. A change in the period of the flow has the additional effect of changing the amplitude of the "Stock" by the same factor, but it does not affect the amplitude of the "flow." Also, no matter what the period is, the "Stock" always lags one quarter of the period behind the "flow."