

# Using STELLA Simulation Models to Teach Natural Resource Economics

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**Abstract:** Undergraduate students without a mathematical background struggle to develop an intuitive understanding of natural resource economics. I discuss how graphical simulation models created using STELLA software can be used present natural resource systems in an intuitive way in undergraduate natural resource economics classes. I provide a small introduction to STELLA and then explain two models I used in detail. I discuss informal feedback by students and end the paper by presenting how STELLA models can be incorporated in to the natural resource economics curriculum. The models allow students to develop an intuitive understanding of the economic aspects of natural resource systems.

**Keywords:** Simulation models, teaching economics, natural resource economics, STELLA, natural resource systems

**JEL Codes:** A20, Q20, Q30

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## **1 Introduction**

Undergraduate students without advanced calculus and optimization knowledge struggle to develop an intuitive understanding of natural resource economics. The difficulty partly stems from the mathematical framework used to model natural resource systems such as optimal harvesting models for forestry or population growth models in fisheries economics. I use graphical simulation models created using the STELLA (Structural Thinking Experimental Learning Laboratory with Animation) software in my undergraduate natural resource economics class at a leading research university to allow undergraduate students to develop an intuitive understanding of the economic aspects of natural resource systems. The class is typically taken by juniors and seniors and the models help the students develop an intuitive idea about complex natural resource systems. Since I create the models, the students are not required to learn STELLA and they can use the free trial version to experiment with the models to gain an understanding of the critical connections and parameters. The graphical nature of STELLA allows the students to change parameter values, draw graphs and measure and observe changes easily without any advanced programming knowledge.

In this paper I present my experiences with using STELLA models to enhance learning in a natural resource economics class. In section two of the paper, I present a basic introduction to STELLA. In section three, I describe two models I used in detail. In section four, I present student feedback and responses from students in class. The first model presents a basic fishery model based on a logistic growth function. The students are able to easily change the carrying capacity and growth rates to understand the impact of these parameters on the fishery. I then extend this model to a cohort fishery model and the students are able to test the impact of various fishery regulations on the sustainability of the fishery. The second model presents novel use of the STELLA to analyze the revenue maximizing entrance fee for a national park. I use the dynamic aspects of STELLA to generate a demand function and the students are able to use this to study how the shape of the demand function changes the revenue maximizing entrance fee. This paper highlights how simple simulation models can be easily integrated into a natural resource economics class to enhance learning without additional burden on the students and very little burden on the instructor.





## 2 Use of STELLA in Economics

STELLA software and similar dynamic simulation software such as SimApp, Simile, and VenSim allow complex systems to be modeled without requiring a high level of mathematical knowledge. Over the last decade STELLA has been used to conduct research in environmental and natural resource economics (Costanza et. al. 1998, Costanza and Gottlieb 1998, Costanza and Voinov 2001) and text *Modeling Dynamic Economic Systems* by Ruth and Hannon has been used at the graduate and advanced undergraduate level to teach modeling of economic systems. There is an untapped potential to use STELLA model as an interactive learning environment for undergraduate economics classes because of its ability to represent dynamic systems graphically and to allow the user to change parameters to perform sensitivity analysis. Therefore the use of STELLA complements the active learning paradigm, the belief that learning occurs when students engage with the material being taught by practicing and actually using the material.

I have not been able to find any previous instances where STELLA models have been used to teach natural resource economics and the only previous example of STELLA models being used in undergraduate in an undergraduate economics class are the macro models by Wheat (2004). Wheat (2004) conducts an experiment to test the effect of using the graphical features of STELLA on students by conducting a split sample study and the preliminary results indicate a significant improvement in scores for the split sample group of students.

## 3 Introduction to STELLA

STELLA models consist of four basic components. (ISEE, 2004)

Component	Icon	Meaning
Stock		Represents amount or populations
Flow		The in-flows and out-flows to and from a stock
Converter		Parameters, contains equations or constants
Connector		Connects stocks, flows and converters, passes information

**Table 1: Basic Components of STELLA**

Stocks within STELLA act as reservoirs and accumulate a population or an amount such as pollution, a population, etc. They can be initialized to any value and the value of a stock over time is determined by the flows coming in and the flows leaving the stock

Flows within STELLA act as conduits and effectively carry physical matter (fish, pollution etc) from one part of the models to another.

Converters within STELLA act as parameters and provide information for the stocks and the flows such as interest rates, harvest rates, etc. The converters can also be represented as graphical function, which allows is to simulate demand function as illustrated in the second STELLA model described below.

Connectors within STELLA link the information with the stocks and the flows.

STELLA models are created by clicking on icons and placing the icons on a blank canvass and then creating the links between the components. The user is then able to insert initial values and equations (for the flows) that describe the system. The most basic model, a dynamic population, can be represented by the following model.

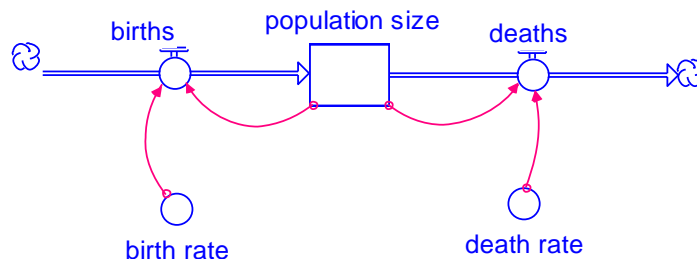


Figure 1: Basic Population Growth Model

The stock represents the population size and is affected by births and deaths which are flows. The value of the births and deaths is determined by the population size and the respective rates provided in the birth rate and death rate converters. The connectors ensure that the proper information is passed on to the relevant parts of the system.

When a model is running, the state of the system can be depicted both visually and numerically using tables and graphs. The system also allows the user to view different runs on the same graph and this assists students visually see the impact of changing parameters and policies.

With creative use of these four components it is possible to represent many natural resource systems used over time.

The students encountered seven STELLA models during the semester. I used four STELLA models for the class: Simple Difference Equation (with just the harvest and growth rates), Multiple Cohort Fisheries, Timber Harvest Model, Revenue Max Number of Visitors (A model about the number of visits to a park at different entrance fees) and two of the models are described below. In addition three guest lecturers presented STELLA models about managing Asian Carp, Deforestation in the Amazon, and Climate Change and the Polar Bear Population.

## **4 Two STELLA Models**

### **4.1 Model 1: Fishery Model**

The standard undergraduate natural resource economics class described the basic difference equation and expands on the equation by applying it to different natural systems such as fisheries and timber. I created the basic difference equation in STELLA and this allowed the students to understand the relationships between the death rates, growth rates and the increase and decrease in stock size. When teaching the section on fisheries I introduced the basic one-stock fishery model using the logistic growth equation and discussed it both mathematically and by using a STELLA simulation model. I then expanded the one-stock simulation model to a basic multiple cohort fishery model.

The basic logistic fishery model (without harvest) is represented as<sup>1</sup>

$$x(t+1) = x(t) + mx(t) - mx(t)^2/K \quad (1)$$

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<sup>1</sup> K - carrying capacity for stock, m - natural rate of increase - (with no crowding),  $mx(t)^2/K$  - crowding effect,  $x(t)$  - stock size at time t

where the last two terms represent the growth rate of the fish stock. The students are required understand how the parameters determine the optimal harvest rate (maximum sustainable yield) and corresponding stock size. This requires them to take the derivative of the growth term and conduct some algebraic steps and show how these change on a graph similar to the one below.

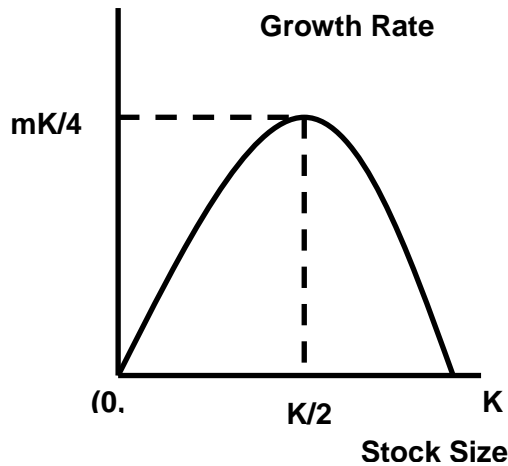


Figure 2: Graph of growth rate as a function of stock size

After going through the mathematical steps I introduced the following STELLA model.

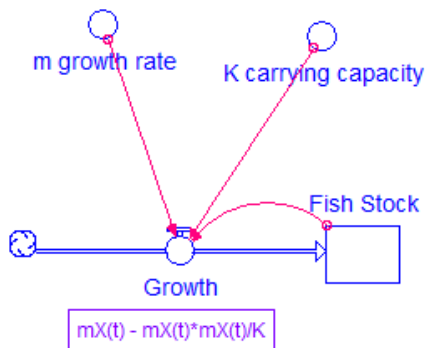


Figure 3: Basic logistic fishery model

The model has one stock variables that represents the fish stock, and one flow variable that represents the growth of the stock. Two converters for the growth rate and the carrying capacity allow the students to change the values of the growth rate and the carrying capacity.

I then created two graphs where the students are able to see the logistic growth function and the growth rate curve. As mentioned before STELLA

allows the user to change parameter values and observe how the output changes. Therefore students are able to change the growth rate and carrying capacity values and see the effect on the stock size and the growth rate as shown in the two figures below.

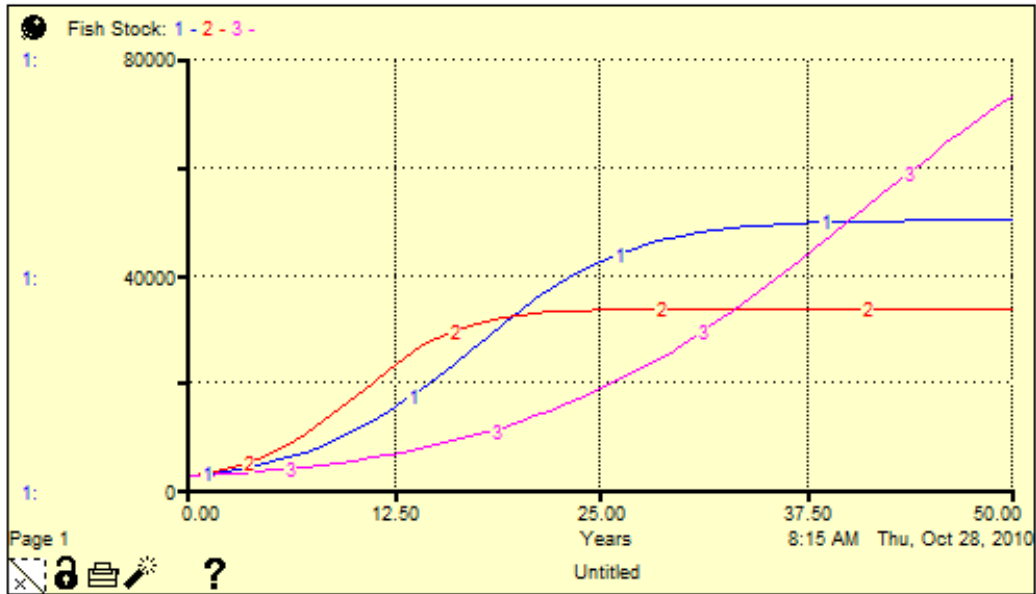


Figure 4: Logistic Growth Function

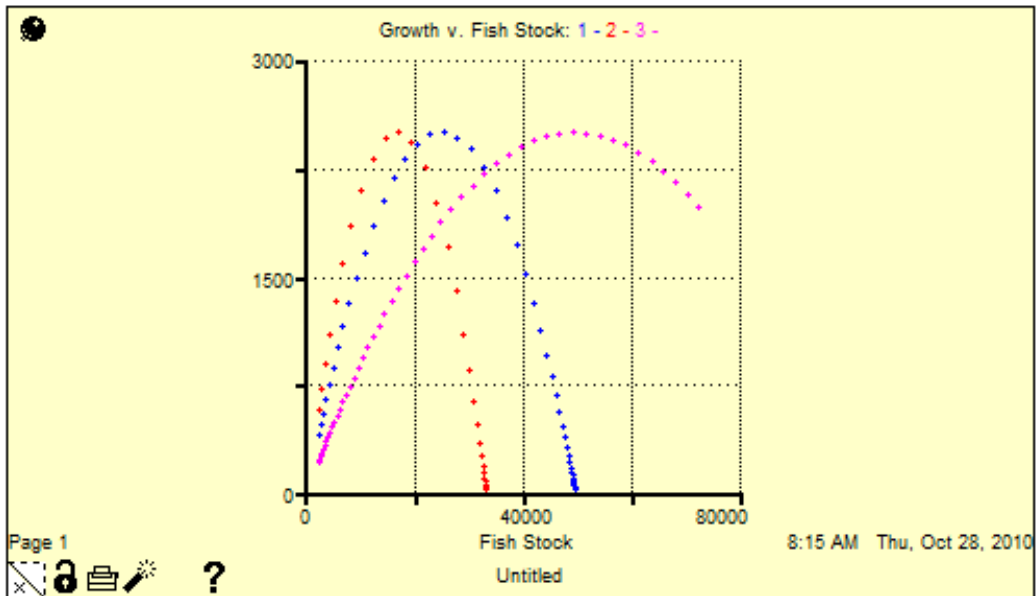


Figure 5: Graph of growth rate as a function of stock size

Next I introduce harvesting with corresponding prices and costs into the model and provide the students another version that they can experiment with. The students are able to learn the impact of different harvesting amounts on the stock and they can then identify the maximum sustainable yield and the impact of the growth rate and the carrying capacity.

Finally I introduce a multiple cohort-fishery model, I create three different age cohorts based on the above simple model and include death rates and growth rates and birth rates for each cohort. I introduce a policy component to the model where a social planner decides on the harvest rate for each cohort. To make the model realistic while keeping it simple I introduce a human population that solely depends on the fishery for survival. I then let the students study the impact of having different fishing quotas based on multiple-cohort fisheries. This model is too complicated to illustrate mathematically for an undergraduate class of students, many of whom have not taken calculus. Therefore the STELLA model allows the students to gain an intuitive understanding of the value of both accounting for disaggregated cohort based fisheries and also of various policy alternatives.

#### 4.2 Model 2: Revenue Maximizing Entrance Fee

As part of the natural resource economics class I used an in-class exercise where the students had use a travel cost method to generate a demand curve for visiting a park. As the next step we discuss what the revenue maximizing entrance fee should be and how changes in the demand for recreation affect the revenue maximizing price.

The standard graphs used to represent demand curve and the revenue maximizing entrance fee are shown in Figure 6 below.

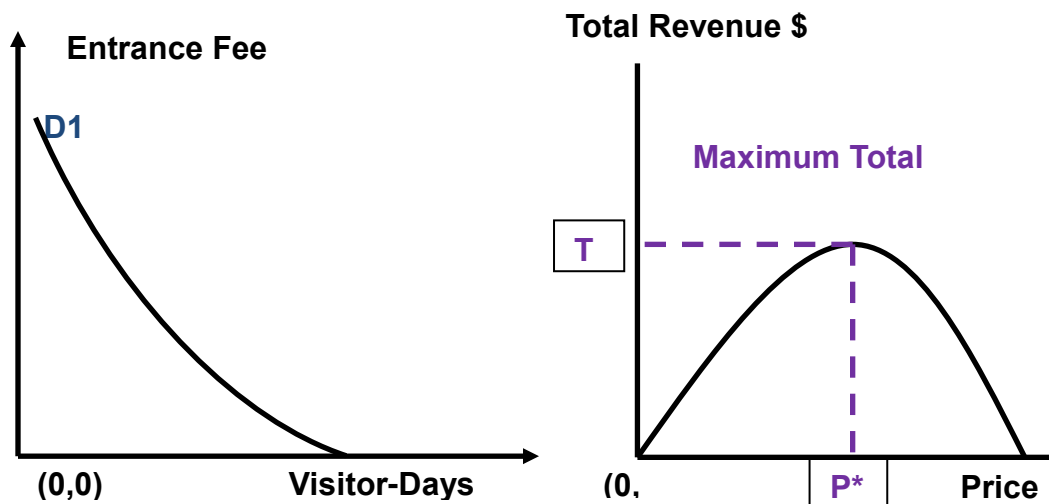


Figure 6



I use a the simple STELLA model below to allow students to gain an understating of how the demand curve for recreation and the revenue maximizing entrance fee and the socially optimal number of visits are related.

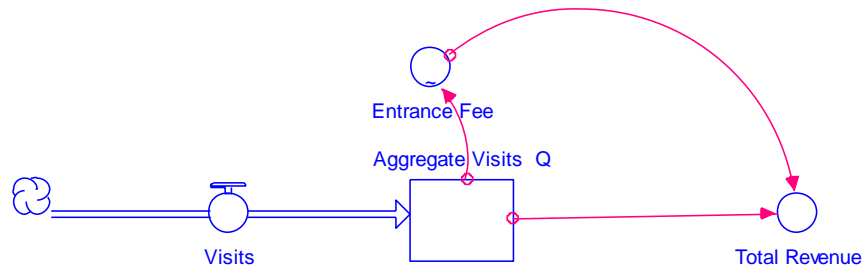


Figure 7

The above model is designed to generate the total revenue graph and display the entrance fee as a function of the total number of visitors. I present the model here because it is not as intuitive from the sense of modeling a system, but it highlights how STELLA models can be tweaked to generate different outputs.<sup>2</sup> The model has one stock, the total number of visitors, and one in-flow to the stock, the number of individual visitors.

The number of visitors increases by one over time (the value of the *Visits* flow equals one) and allows us to generate the total quantities for drawing the demand and total revenue graphs. The *Entrance Fee* converter represents the demand function for recreation and is used to identify the entrance fee as a function of the number of total visitors. Clicking on the *Entrance Fee* converter opens up the graphs as shown in Figure 8 and the students are able to manipulate this demand function by dragging and the mouse to change the shape of the demand function.<sup>3</sup>

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<sup>2</sup> I am referring to the fact that the stocks and the flows don't necessarily represent a real world system, but rather in some sense a "trick" to generate the real world graphs.

<sup>3</sup> The values for the demand function can also be entered as an equation or as a table, but I believe the graphical demand function makes it easier for the students to visually see how the demand function changes.

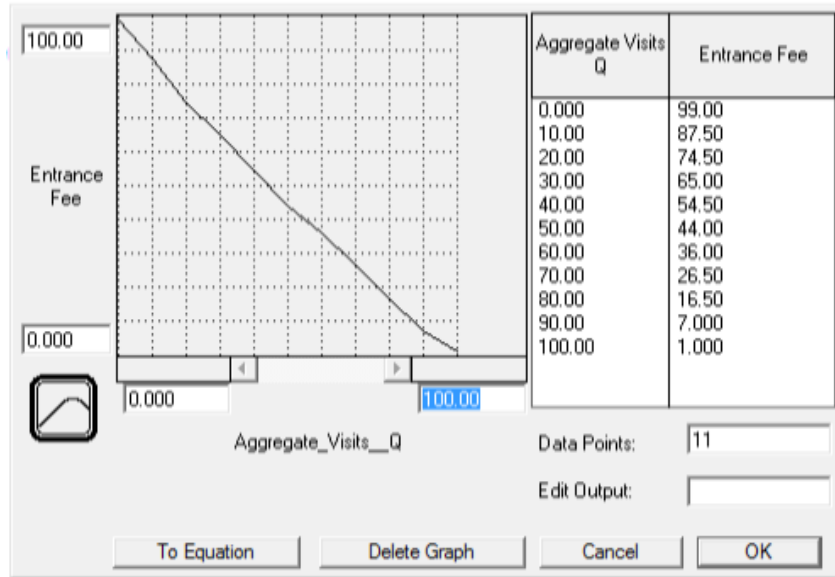


Figure 8

I then generate two graphs of the Total Revenue and the Entrance Fee (the entrance fee graph is the demand function represented in the *Entrance Fee* flow). An example of the graph space is shown in Figure 9.

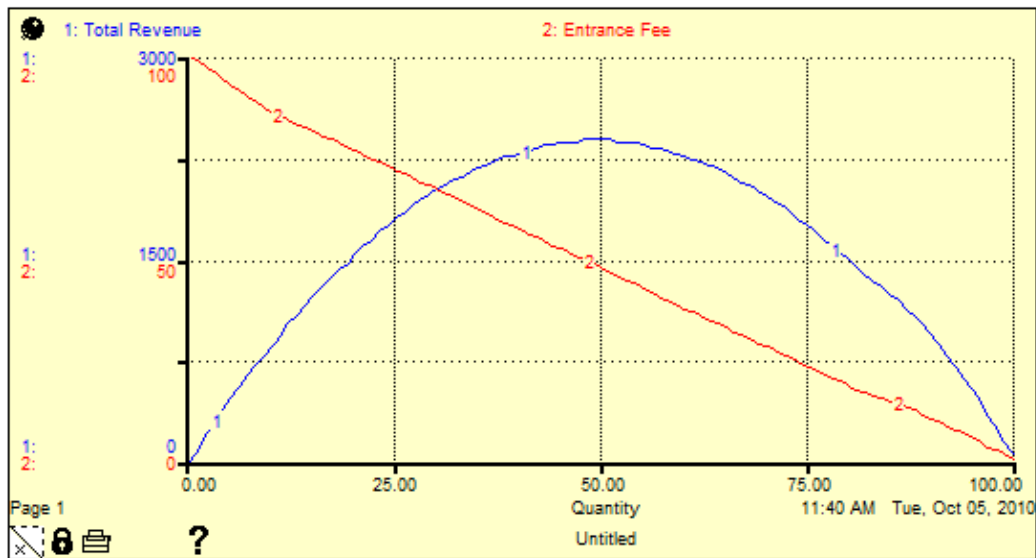


Figure 9

The students can identify the revenue maximizing price by identifying the highest point in the Total Revenue curve (identified by "1") and the relevant quantity, and then looking up the price in the Entrance Fee curve (identified by 2), which in the above graph is approximately \$50.00.

The students are then able to change the demand curve and see the impact on the Revenue Maximizing Price as shown in the two graphs below.

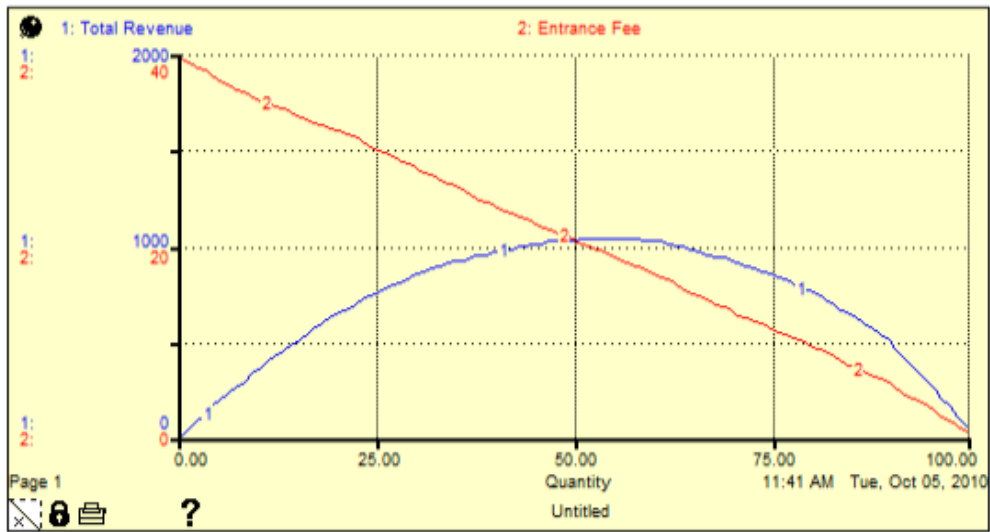


Figure 10

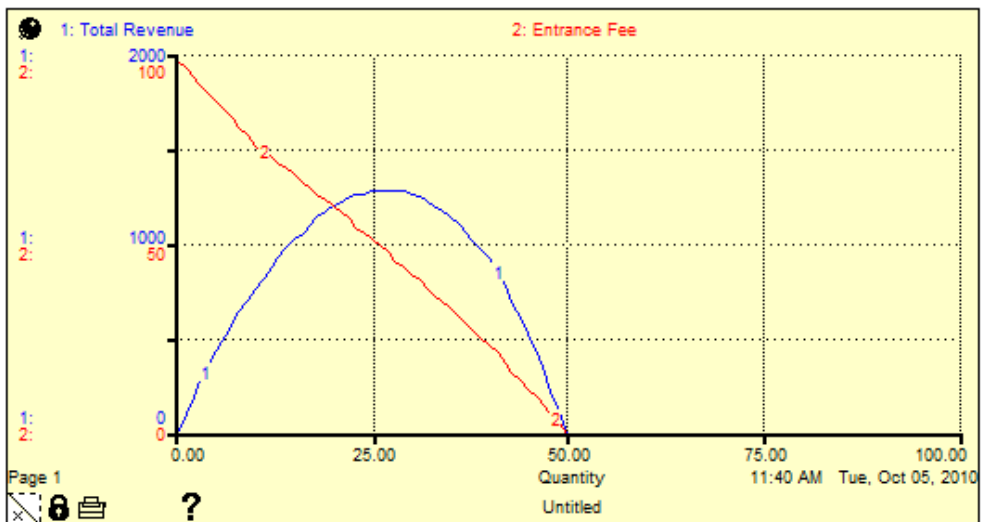


Figure 11

This model allows students to understand the relationship between demand and total revenue. This model also allows the students to understand the implication of various price policies on the revenue for outdoor recreation activities. The two models described above highlight how STELLA models can be used to represent economic concepts and natural resource systems in a graphical and intuitive manner.

## 5 Student Feedback

The students in my class provided informal feedback about the use of STELLA in the classroom a natural resource economics class. It needs to be emphasized that the feedback is not from a formal survey but was collected using an anonymous online feedback form. Out of a class of 120 students 22 student's respondent to the survey.<sup>4</sup> A summary of the quantitative and qualitative survey results are provided below.

Question	Measure	Mean	STD
Did the STELLA models help you understand a difficult economic/natural system concept in ACE310.	Yes = 1 No = 0	0.71	0.46
Do you think STELLA models can be a good method to explain natural/economic systems in a natural resource economics class.	Yes = 1 No = 0	0.86	0.36
How useful were the STELLA models in helping you understand the economic/natural systems we learned about?	Rate 1 – 5 5 being most useful	3.55	0.99
Based on 22 responses			

**Table 2: Summary of Quantitative Feedback**

The biggest strength of using STELLA according to the students was to quote one students response “They were an excellent method to visualize the economic concepts discussed in

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<sup>4</sup> The survey was sent 4 months after the end of the class. I feel that this would have decreased the response rate and biased the responses more towards students who remembered (and therefore liked) the STELLA modeling experience provided in the class room.

class”, a viewpoint echoed by other students. The students also stressed that the ability to change parameters and visually see the effect helped them understand the system and the impact of policies.

The two biggest criticisms that the students had was that they were not able to download a free version and save changes (University of Illinois does have STELLA installed on some public access computer labs), and since the models did not appear on exams there was no incentive to spend time to learn and understand the model, specially the more complex models.<sup>5</sup> The students also stressed that they felt that there wasn’t enough time spent on teaching STELLA and if more time had been spent teaching STELLA they would use the model more. This is something of a concern since my desire to use STELLA is partly driven by its user friendliness and ease of use that would imply students can use and play with it without having to spend much class time to teach STELLA.

## **6 Conclusion**

This paper presents my experiences in using STELLA models to complement the material taught in an undergraduate natural economics course. I have provided a brief introduction to STELLA, discussed two models that I used and summarized informal student feedback. I believe that STELLA models can play a large role in making the presentation of complex and mathematical natural resource systems intuitive and easy to understand for students in undergraduate natural resource economics classes.

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<sup>5</sup> Given that this was a new addition to the class and since the class was a class on Natural Resource Economics I did not test the students on anything directly related to STELLA models. I believe this should be the case whenever a simulation model such as STELLA gets used in a natural resource (or any other) class. The purpose is to assist student understand the systems used in the class and not become proficient in modeling or using the simulation software.

## 7 References

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