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An Experiment to Summarize the Principles of Microeconomics

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AN EXPERIMENT TO SUMMARIZE THE PRINCIPLES OF MICROECONOMICS

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ABSTRACT

I present a classroom experiment designed to help students learn (1) decision-making using marginal analysis; (2) the prediction of the price; (3) the decentralized determination of a price by the market; (4) specialization; (5) the gains from trade; and (6) the ability of a competitive market to create a Pareto-efficient outcome. The innovation of the experiment is its comprehensiveness.

Keywords: Market, Experiment.

JEL Classification: A22, C92, D41.

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1. INTRODUCTION

Experiments are now recognized as being a useful tool to assist students learn the material presented in the classroom: the benefit is confirmed by Gremmen and Potters (1997). It is supposed that this learning advantage comes about because the experiments integrate class material with the student's own experience. I present below two linked experiments which I use in my classes to help students master six important ideas taught in an undergraduate class in microeconomic principles, viz. (1) decision-making using marginal analysis; (2) the prediction of the price; (3) the decentralized determination of a price by the market; (4) specialization; (5) the gains from trade; and (6) the ability of a competitive market to create a Pareto-efficient outcome.

There is an interesting history behind the use of market-based experiments in teaching.[1] Chamberlin’s (1948) market experiment is generally considered the first laboratory experiment in economics. In Chamberlin’s setting, students are divided between buyers and sellers; each buyer is dealt a card marked with a value and each seller is dealt a card marked with a cost. Students are encouraged to trade. Each buyer may buy one unit: if he buys, he earns the difference between the value he was dealt and the contract price he negotiates. Similarly, each seller may sell up to one unit: if she sells, she earns the difference between the contract price and the cost she was dealt. Because different buyers receive different values, a market demand curve may be constructed by ranking individual buyer values from highest to lowest; the market demand at a given price is the number of buyers with a value at or above the given price. Similarly, because sellers receive different costs, a market supply schedule may be constructed by ranking individual seller costs from lowest to highest, and the market supply at any given price is the number of sellers with a cost at or below the given price. The competitive price and quantity occurs at the intersection of the constructed market demand and supply curves. In Chamberlin's set-up, the market has little structure: students roam the classroom seeking a trading partner, form pairs and then bargain over a bilateral trade.[2] In Chamberlin's structure, each buyer knows only his own value and each seller knows only his own cost, so that it is not possible for either party to calculate "the equilibrium price". In addition, the experiment lasts only 10 minutes with each buyer or seller dropping out when he achieves a trade: buyers and sellers therefore have little opportunity to gain experience. Chamberlin noted that the quantity exchanged in the experiment tended to exceed the competitive quantity. He attributed this to the decentralized nature of trading. A buyer with a high value may meet a seller with a cost which is less than the buyer's value but which exceeds the "competitive price." They may negotiate a contract although this trade is not predicted at the competitive outcome. Overall, Chamberlin felt that his experiment failed to confirm the market outcome and he used the experiment to motivate his graduate course in monopolistic competition.

One of the graduate students participating in Chamberlin's experiment was Vernon Smith. Starting teaching in 1955, Smith

> "taught Principles of Economics, and found it a challenge to convey basic microeconomic theory to students. Why/how could any market approximate a competitive equilibrium? I resolved that on the first day of class the following semester, I would try running a market experiment that would give the students an opportunity to experience an actual market, and me the opportunity to observe one."[3]

Smith modified Chamberlin's structure, replacing the decentralized nature of trading with the centralized process of a "double auction."[4] In Smith's (1962, 1964) structure, buyers call out the highest price they are willing to pay ("bids") and sellers call out the lowest price they are willing to accept ("offers"). Bids and offers are centrally and publicly recorded - often on a blackboard. A buyer can accept an offer to earn the difference between his value and the accepted offer; a seller can accept a buyer's bid to earn the difference between the accepted bid and her cost. Smith also allowed the set-up to be repeated several times, thereby facilitating learning by the traders. Somewhat to his surprise, Smith found that his "experimental market converged "quickly" to near the equilibrium price and exchange volume."[5] This work on experimental markets was cited by the Nobel Committee in awarding him the 2002 Nobel Prize in Economic Sciences.

In both Chamberlin's and Smith's early experiments, payments were hypothetical.[6] However in a different experimental context Siegel and Goldstein (1959) found that subtle biases may be present when payments are hypothetical, but that these biases are removed by providing the subjects with financial incentives. In consequence it is now standard practice for subjects to earn a monetary pay-off in economics experiments run for research purposes. Since my experiment is proposed as a class tool, I replace the monetary pay-off with points earned towards the student's final grade.[7] Because students usually prefer their grade to be based on many different forms of evaluation (e.g. midterm and final exams, term papers, class participation), I find that most students welcome the use of their experimental score as an input to their grade.

The use of points towards a student's grade as the pay-off of the experiment requires that issues of fairness be addressed. First, all students must have similar opportunities. Chamberlin's or Smith's design in which students start with different values and costs is inappropriate, as the design favors a buyer being dealt a high value or a seller receiving a low cost. In my experiment there are three goods ("clothes", "food" and "housing") in addition to the numeraire, and each student is assigned one of three symmetrical technologies. A student with Technology A can manufacture "clothes" at a cost of 1 (unit of numeraire per unit of clothes), can manufacture "food" at a cost of 2 (units of numeraire per unit of food) and can manufacture "housing" at a cost of 3 (units of numeraire per unit of housing). Similarly, a student with Technology B can manufacture "food" at a cost of 1, "housing" at a cost of 2 and "clothes" at a cost of 3; and a student with Technology C can manufacture "housing" at a cost of 1, "clothes" at a cost of 2 and "food" at a cost of 3. Because of the symmetry, each student faces similar opportunities. Trade is induced because a student who can manufacture one good at low cost finds it advantageous to trade with a student who can manufacture another good at low cost. Second, it is important that the experiment is given *after* the relevant theory has been discussed in class, so that a student feels that his/her performance is related to his/her mastery of the material presented in the classroom. This aspect means that the experiment should be used to validate the theory and not to motivate the theory. For similar reasons, I use the de-brief following the completion of the experiment to discuss how the student could have used the theory presented in class to his/her advantage. In doing so, I stress the usefulness of theoretical models to make predictions.

The overall design has two experiments. In the First Experiment, each student chooses the quantities of "clothes", "food" and "housing" to produce with the chosen quantities affecting her pay-off from the experiment. This part is like autarky - students can produce but not trade. This experiment has two objectives - one objective is to introduce the students to the experimental design and the other objective is to provide an example of marginal analysis. In the Second Experiment, students can trade with each other in addition to producing goods: this part focuses on the competitive market. The innovation of the experiment as a teaching tool is its comprehensiveness: the students make consumption and production decisions.

The First Experiment is done by the students outside the classroom as assigned homework. The Second Experiment requires that students interact with each other, and this is facilitated by putting aside 90 minutes of classtime: at the end of this time, no student has indicated a wish to continue to seek trades. I have held the experiment in class sizes from 20 to 200 students. Although the experiment is designed for an introductory class in microeconomic principles, I also use the experiment in my intermediate microeconomic theory class and I have used it in my MA class: as I move to more advanced courses, there tends to be less variance in behavior and the outcomes more closely resemble the competitive outcome.[8]

This paper is organized as follows. Section 2 describes the First Experiment and Section 3 describes the Second Experiment. In each section I illustrate the experiment by showing the results from my Principles of Microeconomics class in Fall 2005 (180 students participating in the First Experiment and 184 students participating in the Second Experiment), and provide a discussion. Section 4 concludes.

2. FIRST EXPERIMENT: MARGINAL ANALYSIS

2.1 Description of experiment

The formal instructions for the First Experiment are attached as Appendix A. Each student is given 100 units of "resources" which can be used to manufacture four goods, termed “clothes”, “food,” “housing” and “other things.”[9] In the Second Experiment, trade is induced by assigning different manufacturing technologies to different students. In order for the basic structure to be the same across experiments (enabling the gains from trade to be readily apparent) and for students to familiarize themselves with the technologies, the three technologies are introduced in the First Experiment. Table 1 describes the amount of "resources" which must be used to produce one unit of each type of good using each technology:

		Units of “resources” used to manufacture 1 unit of output using technology:		
		A	B	C
Output	clothes	1	3	2
	food	2	1	3
	housing	3	2	1
	“other things”	1	1	1

Table 1: the three technologies

Each student is assigned one technology, with one-third of the students being assigned Technology *A*, one-third of students being assigned Technology *B* and the remaining-third being assigned Technology *C*.

In the First Experiment, units cannot be traded so all output manufactured by a student is consumed by the student. Each student obtains "total benefit" *TB* from consuming *c* units of clothes, *f* units of food, *h* units of housing and *x* units of "other things" as[10]

$$TB \ = \ 10\sqrt{c} \ + \ 10\sqrt{f} \ + \ 10\sqrt{h} \ + \ x \, . \tag{1}$$

The experiment's instructions include a table giving values of $10\sqrt{i}$ for different values of *i*.[11] The maximum value of *TB* achievable in the first experiment is 145.8.

TB is converted into a score S_1 which goes towards the student's final grade. I set it so that the 100 possible points which a student can earn in the course are divided as: 90 points from the class exams and 10 points from the two experiments.[12] The student's score S_1 in the First Experiment is derived from *TB* as

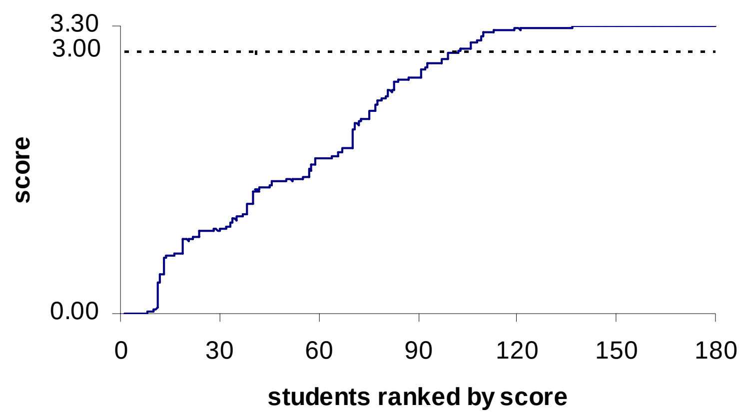
$$S_1 \ = \ \frac{1}{6} \max \, [\, 0 \, , TB \, - \, 126 \,] .$$

The floor of zero is imposed to ensure that a student who performs poorly in the experiment does not do worse than a student who does not participate.

Each student has to choose how to divide his/her "resources" between the manufacture of clothes, food, housing and "other things".

2.2 Results

The highest possible score is 3.3. The actual distribution of scores for the First Experiment is shown in Chart 1.



Mean score: 2.3; Median score: 2.8; Standard deviation: 1.0

Chart 1: First Experiment scores

45% of students achieved a score of 3.0 or above, and 17% achieved the maximum score.

2.3 Discussion

Chart 1 shows that most students make choices so that they score at or close to the maximum. However, on discussion, 80% of students spent more than two hours making the decision, and most students used trial and error or used a computer program. How can marginal analysis help?

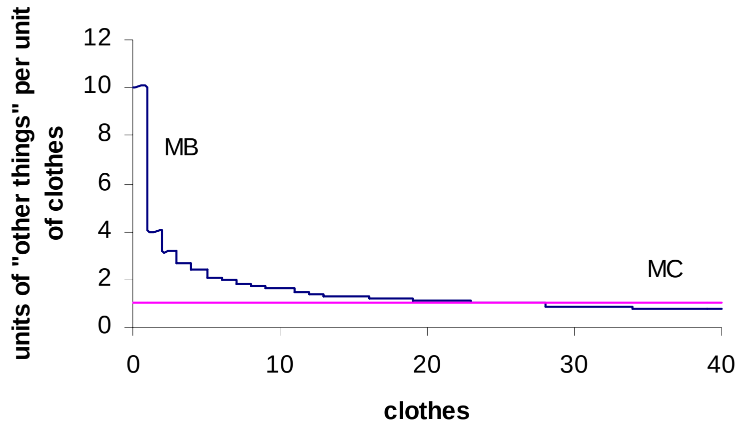


Figure 1: marginal benefit/marginal cost analysis

In the class de-brief, all students confirmed that they were choosing the quantities of clothes, food, housing and "other things" in order to maximize their total score, and that they realized that maximizing their total score is equivalent to maximizing their total benefit *TB* . For ease of presentation, I consider a student with Technology *A*. The student starts with 100 units of "resources" and 0 units of clothes, food, housing and "other things"; she must decide how many units of clothes to manufacture. Marginal analysis stresses that she does this by steadily increasing her production provided marginal benefit exceeds marginal cost. The marginal benefit of the *i*th unit is calculated as $10\sqrt{i} - 10\sqrt{i-1}$ using the values of $10\sqrt{i}$ shown in the appendix of the experiment's instructions; these values are shown as the curve *MB* in Figure 1. The marginal cost is the benefit foregone because one unit of resources is shifted from manufacturing a unit of "other things" into manufacturing a unit of clothes. For a student with Technology A, this cost is unity and it is shown as the curve *MC* in Figure 1.[13] [14] When the student has manufactured 23 units, an additional unit has a marginal benefit of 1 and a marginal cost of 1 - "total benefit" is unchanged if an additional clothes is manufactured (Law of Marginal Indifference). The analysis is then repeated for food (marginal cost of 2: optimal choice 6 or 7) and housing (marginal cost of 3: optimal choice 3). “Total benefit” is then 145.8 and the individual's highest achievable score is 3.3.

For courses which use indifference curves, indifference curves can be constructed. If an individual consumes *f* units of food and *h* units of housing and achieves “total benefit” *TB* :

$$TB \;=\; 10\sqrt{c} + 10\sqrt{f} + 10\sqrt{h} + x$$

or the “utility” achieved from clothes and “other things” is:

$$U \;\equiv\; TB - 10\sqrt{f} - 10\sqrt{h} \;=\; 10\sqrt{c} + x\,.$$

Hence, holding *f* and *h* constant, combinations of clothes *c* and “other things” *x* which gave the same utility *U* are:

$$x \;=\; U - 10\sqrt{c}\,.$$

Combinations of *c* and *x* which give utility levels *U = 100, U = 125* and *U = 150* are plotted as the three “indifference curves” in Figure 2:

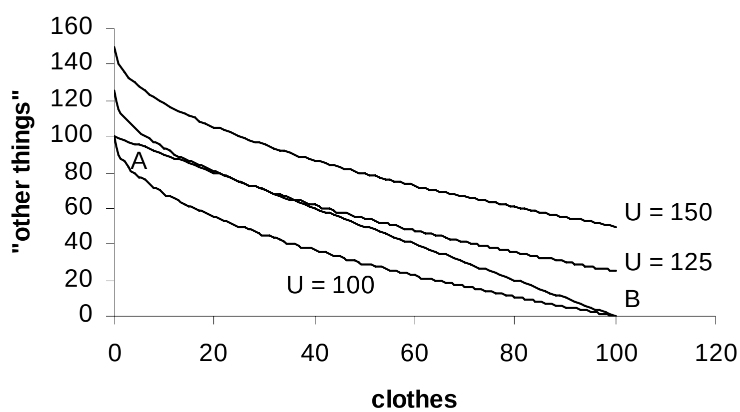


Figure 2: indifference curve analysis

Figure 2 represents the traditional optimization diagram. *AB* is the possibility frontier and the curved lines are lines of constant utility. Starting at *A*, moving down the budget line moves the student onto a higher indifference curve or increases the utility of the student until 23 units of clothes are manufactured. Because the score is rounded to one decimal place, the indifference curve is flat between 23 and 28 units, and lies on the possibility frontier: this illustrates the general idea that small movements along the possibility frontier, around the point of tangency of the budget line and the indifference curve, give no change in utility (Law of Marginal Indifference).

Repeating the analysis for food (opportunity cost is 2 units of "other things" per unit of food) and housing (opportunity cost is 3 units of "other things" per unit of housing) shows that the utility maximizing level of food is 6 or 7, and of housing is 3.

2.4 Desiderata

1. I run the First Experiment after consumer optimization has been covered in class.
2. I do not hold the experiment during class. Instead I assign it as homework.
3. In order to reduce the class time taken up, I do not read the instructions through with the students. Instead, I talk the students informally through the instructions - pointing out that their score depends on the quantities they choose - and direct the students to read the instructions carefully in their own time.
4. In the Second Experiment I assign a subject number to each student and each student is required to use her subject number. In order to get students familiar with their number, I

require that each student use her subject number in the First Experiment. I post a list with subject numbers and technologies on the course web-page as:

Student Name	Subject #	Technology
Adam Ainsel	1	A
Beatrice Bethoud	2	B
Charles Clarence	3	C
David Dolittle	4	A
Edward Englewert	5	B
Francine Frank	6	C
Georgina Grasington	7	A
...	...	...

5. For 20% of students, the score as calculated by the student in his Production Plan which he hands in differs from the score I calculate using his chosen quantities of clothes, food and housing. Therefore, because this is part the student's class grade, I calculate each student's score using his chosen quantities of clothes, food and housing using a spreadsheet program.

3. SECOND EXPERIMENT: TRADE

3.1 Description

The formal instructions for the Second Experiment are attached as Appendix B. As in the First Experiment, each student starts with 100 units of "resources" and each student has the same technology as she had in the First Experiment. The difference between the experiments is that in the Second Experiment students are allowed to trade. The incentive to trade arises because each student produces two goods at an opportunity cost exceeding unity (units of resources per unit of good). By trading with other students, a student can access technologies where these good are made at unit opportunity cost (units of resources per unit of good). Similar to Chamberlin’s experimental design, students roam the classroom seeking buyers and sellers, and prices are not centrally posted.

Each individual obtains total benefit *TB* from her consumption of clothes, food, housing and "other things" using the same formula as in the First Experiment (Equation (1)). In order to prevent the influence of the experiment on the student's grade becoming excessive, a ceiling as well as a floor is imposed on the score. The score S_2 in the Second Experiment is calculated from “total benefit” *TB* as

$$\text{if} \quad U < 138, \qquad S_2 = 0 \;;$$

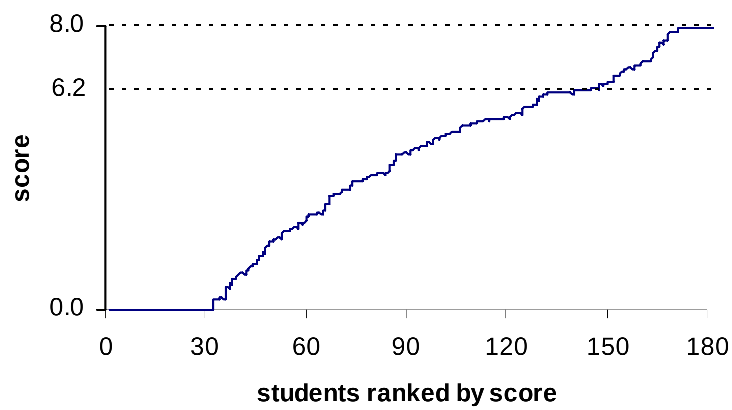
$$\text{if} \quad 138 \le U \le 186, \qquad S_2 = \frac{1}{6}(TB - 138) \;;$$

$$\text{if} \quad 186 < U, \qquad S_2 = 8 \;.$$

Note that, in the calculation of the student's score, in the Second Experiment 138 is subtracted from *TB* whereas in the First Experiment 126 is subtracted: this is done to better balance the influence of the two scores in the contribution to the student's grade.

3.2 Results

Under perfect competition, students with the least cost technology supply unlimited amounts at any price exceeding unity (units of resources per unit of good) , or the supply curve *S* for each good is perfectly elastic at a price of unity. The competitive equilibrium price is therefore unity. At the unit price, students consume between 23 and 28 units of clothes, food and housing. Students manufacturing goods make no profits and hence consume between 31 and 16 units of "other things". Hence, under perfect competition, each student would obtain a score of $S_2 = 6.2$. In fact, actual trades occur at various prices and students achieve lower or higher scores. The distribution of scores is shown in Chart 2.



Mean score: 4.1; Median score: 4.6; Standard deviation: 2.7

Chart 2: Second Experiment scores

The median score is 4.6 but that there is considerable variation around the median. 18% of students actually achieved a lower Total Benefit in the Second Experiment than in the First Experiment.

3.3 Discussion

3.3.1 The power of prediction

Students often ask: “How can I know whether to buy or sell at the start of the experiment?” In the de-brief a student is usually able to tell me that he would have known what to do if he had known what the price is likely to settle at - he would “sell high” or sell aggressively to any student willing to buy at a price exceeding his marginal cost and he would “buy low” or buy from any student willing to sell at a price equal or below the predicted future price. If the price initially exceeds the predicted future price, he would delay his purchases until the price fell to close to the predicted price. At this point I explain that he is able to predict the price using the framework of demand and supply![15]

The demand curve for each good is constructed using the method of marginal analysis discussed in Section 2.3: with 184 students taking part in the experiment, the demand curve for clothes is shown as curve *D* in Figure 3.

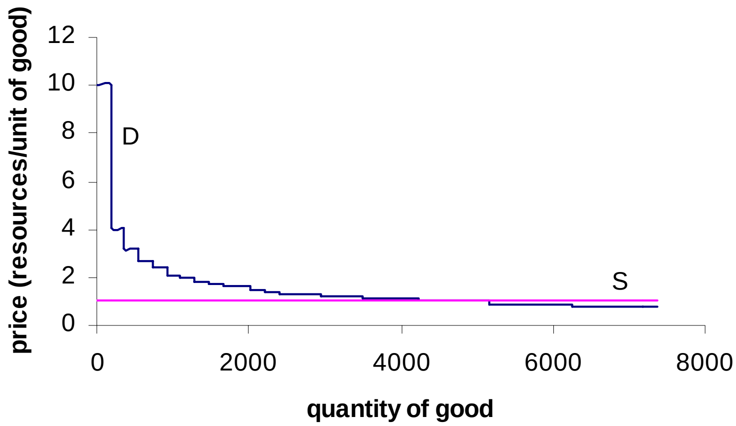
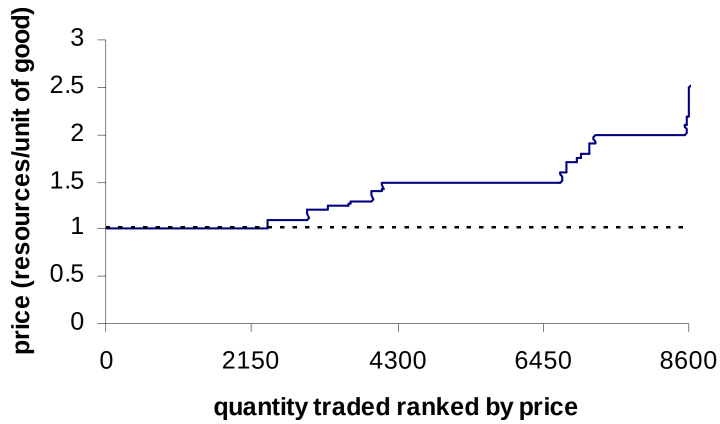


Figure 3: the competitive prediction

Under perfect competition, students with the least cost technology supply unlimited amounts at any price exceeding unity (units of resources per unit of good) , or the supply curve *S* for each good is perfectly elastic at a price of unity. The competitive equilibrium price is therefore unity. I believe that this ability of the economist to make predictions is an important but often overlooked component of the Principles of Microeconomics.

How well does our prediction match with what happened? The actual distribution of prices is shown in Chart 3.



Mean price: 1.4 ; Median Price: 1.5 ;   Standard Deviation: 0.37.

Chart 3: distribution of actual prices

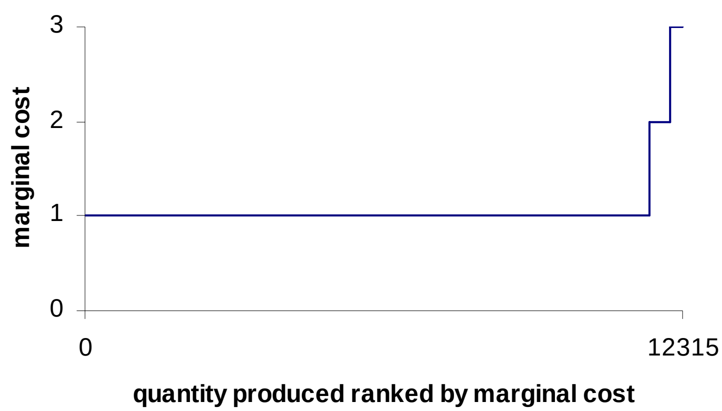
27% of the product traded is traded at the competitive price of unity. 75% of all trades are made at a price between 1 and 1.5. Casual observation suggests that most of the high-priced trades are made early on the first day and that the price "settles" at unity by the end of the experiment. I stress to students that most trades being made at a price exceeding the competitive price does not invalidate the prediction *per se*: the competitive model is an approximation. And it does predict what happens when the market "settles down" - approximately midway through the second class put aside for trading.

3.3.2 How price is determined in a market

At the end of the experiment, trades are being made at a price of unity. In the de-brief I ask students to reflect on how this price is not established by anybody but by everybody, or by the twin forces of demand and supply.

3.3.3 Specialization

Competitive theory predicts that specialization occurs with each good being made by the firms or individuals with the least cost technology. The least cost method of producing clothes, food or housing involves the use of 1 unit of resources per unit of output. This involves clothes being manufactured by students with Technology *A*, food being manufactured by students with Technology *B* and housing being manufactured by students with Technology *C*. Chart 4 shows that 95% of production is carried out at least cost.



Mean cost: 1.08; Median Cost: 1.00; Standard Deviation: 0.33

Chart 4: product specialization

3.3.4 The gains from trade:

Another important idea in the Principles of Microeconomics is the gains from trade: trade enables individuals to increase their well-being by being able to access product at a cost which is lower than that at which they could produce it.

Predicted Total Benefit - with trade allowed:	175
- with no trade allowed:	145.8
Predicted gain from trade:	29.2
Average of actual Total Benefits - with trade allowed:	158.9
- with no trade allowed:	138.6
Average actual gain from trade:	20.3
Standard deviation of actual gains:	28.4

Table 2: gains from trade.

Table 2 shows the gains from trade by comparing the Total Benefit obtained in the Second Experiment (trade allowed) with the Total Benefit obtained in the First Experiment (no trade allowed). There is a large increase in the students' predicted and actual Total Benefit as a consequence of trade.

3.3.5 The ability of the competitive market to create a Pareto-efficient outcome.

Probably the most important idea in a Principles of Microeconomics class is that of Adam Smith's Invisible Hand. At the Pareto-efficient outcome there is specialization in production with each good being manufactured by the individuals who have the technology with least cost. The output is distributed so that each individual consumes between 23 and 28 units of clothes, food and housing. Therefore, at the Pareto-efficient outcome between 69 and 84 units of clothes, food and housing are produced per subject. Units not consumed are exchanged, or between 46 and 56 units are traded per subject.[16] Table 3 shows that the actual quantities manufactured and the actual quantities traded are approximately the efficient quantities. In consequence, although the actual level of surplus gained is less than the efficient level, a large part of the potential surplus is gained.

Production: units of clothes, food and housing manufactured per subject:	
At the Pareto-efficient outcome	69-84
Actual average:	67
Exchange: units of clothes, food and housing exchanged per subject:	
At the Pareto-efficient outcome	46-56
Actual average:	47
Total Benefit::	
At the Pareto-efficient outcome	175
Actual average:	145.8

Table 3: the partial achievement of Pareto-efficiency.

3.4 Desiderata

1. I run the Second Experiment close to the end of term after all the topics - decision-making by the individual, decision-making by the competitive firm, competitive markets and the market attainment of Pareto-efficiency have been discussed in class.
2. As noted in the Introduction I put aside two fifty-minute class periods for trading. I have found that about half-way through the second period all students feel that they have made all the trades they want.
3. Because the instructions are so long, I do not read them through with the students. Instead, at the start of the class preceding the first class put aside for trading, I stress that each student's decisions in the experiment will affect their score. Then I show the

students how the slips and log are completed for a fictional sequence of transactions, using production slips, trade slips and the log which have been copied onto transparencies for overhead projection. E.g. “I have subject number 250 and Technology A. I manufacture 10 units of food. I meet subject number 420 and agree to buy 17 units of clothes at a price of 1.3 (units of resources per unit of clothes). I meet subject number 370 and agree to sell 5 units of food at a price of 2.1 (units of resources per unit of food). I manufacture 5 units of housing. I meet subject 372 and agree to buy 13 units of housing at a price of 1.6 (units of resources per unit of housing).” After reading each transaction I complete the entries on the overhead transparencies which show a production or trade slip and the log. Then I add: “If I stopped now, I would use the quantities in my log (clothes =17, food = 5, housing = 18 and “other things” = 32.6) to calculate my Total Benefit as 138.6 and my score as .1.” Finally I add: “Now that you have got an overview of the experiment, I strongly encourage you to read the instructions carefully and make a plan for the trading period in class.”

4. The two errors I have found students to make when recording a trade is (1) recording the total resources transferred in Part (5) of the trade slip instead of the price (units of resources per unit of commodity); and (2) the buyer and seller each completing a trade slip instead of only one trade slip being completed by them together. When showing how the trade slip is to be completed (see Point (3) above), I therefore stress that Part (5) of the trade slip records the price and that only one trade slip is to be completed

5. I bring a list of the student’s subject numbers and technologies to the class periods. At the start of each class period I stress that everybody must use their assigned subject numbers

and that any student who has mislaid his subject number must see me. I also bring in a large quantity of production slips, trade slips and extra logs.

6. Many students make mistakes in recording their logs. I therefore recreate the production and trade flows by entering the data from the production and trade slips into a spreadsheet. First I sort the production and trade slips into separate piles, and number them so that if a student queries a transaction I can readily find it. I then enter the data into a spreadsheet as:

PRODUCTION					
(1) Transaction #	(2) Subject #	(3) Technology	(4) Quantity Produced	(5) Product Type	
1	17	B	18	F	
2	4	A	9	C	
3	23	B	12	H	
...	...	...	...	...	
TRADE					
(1) Transaction #	(2) Seller #	(3) Buyer #	(4) Quantity Exchanged	(5) Product Type	(6) Price
1	17	4	8	F	1.6
2	23	17	4	H	1.7
3	4	17	4	C	1.3
...	..	...	...	...	...

I copy the trade date, interchanging Columns (2) and (3) so that Column (2) now lists the buyer and Column (3) now lists the seller, and paste below the original trade data as:

PRODUCTION					
(1) Transaction #	(2) Subject #	(3) Technology	(4) Quantity Produced	(5) Product Type	(6) Cost (per unit)
1	17	B	18	F	1
2	4	A	9	C	1
3	23	B	12	H	2
...	...	...	...	...	
TRADE					
(1) Transaction #	(2) Seller #	(3) Buyer #	(4) Quantity sold	(5) Product Type	(6) Price (per unit)
1	17	4	8	F	1.6
2	23	17	4	H	1.7
3	4	17	4	C	1.3
...	..	...	...	...	...
(1) Transaction #	(2) Buyer #	(3) Seller #	(4) Quantity bought	(5) Product Type	(6) Price (per unit)
1	4	17	8	F	1.6
2	17	23	4	H	1.7
3	17	4	4	C	1.3
...	...	...	...	...	...

Using the spreadsheet above, I create the spreadsheet below. In particular, quantity (Column (5)) is either quantity sold pre-multiplied by -1 (to reflect that a sale lowers the quantity owned of the good) or quantity produced or quantity bought. The resource change (Column (8)) is calculated as:

- quantity x price/cost

where the negative sign is introduced because a sale is associated with the gain of resources and production or a purchase is associated with the loss of resources.

(1) Transaction	(2) Subject #	(3) Transaction type	(4) Trading partner or technology	(5) Quantity	(6) Product	(7) Price/Cost (per unit)	(8) Resource Change
1	17	produce	B	+18	F	1	-18
2	4	produce	A	+9	C	1	- 9
3	23	produce	B	+12	H	2	- 24
...	...	...	...	...	...		...
1	17	sell	4	-8	F	1.6	+12.8
2	23	sell	17	-4	H	1.7	+6.8
3	4	sell	17	-4	C	1.3	+5.2
...	...	...	...	...	...	...	...
1	4	buy	17	+8	F	1.6	-12.8
2	17	buy	23	+4	H	1.7	-6.8
3	17	buy	4	+4	C	1.3	-5.2
...	...	...	...	...	...	...	...

Sorting by Column (2) and then Column (6) and then Column (5) gives the table:

(1) Transaction	(2) Subject #	(3) Transaction type	(4) Trading partner or technology	(5) Quantity	(6) Product	(7) Cost/Price (per unit)	(8) Resource Change
3	4	sell	17	-4	C	1.3	+5.2
2	4	produce	A	+9	C	1	-9
1	4	buy	17	+8	F	1.6	-12.8
...	...	...	...	...	...	...	...
3	17	buy	4	+4	C	1.3	-5.2
1	17	sell	4	-8	F	1.6	12.8
1	17	produce	B	+18	F	1	-18
2	17	buy	23	+4	H	1.7	-6.8
...	...	...	...	...	...	...	...
2	23	sell	17	-4	H	1.7	+6.8
3	23	produce	B	+12	H	2	-24
...	...	...	...	...	...	...	...

With the spreadsheet organized as above, the final quantities of clothes, food, housing and “other things” is readily calculated. E.g. Subject 4 has -4 + 9 = +5 units of clothes, +8 units of food, 0 units of housing and 100 + 5.2 - 9 -12.8 units of “other things”; these numbers are entered in a new spreadsheet to facilitate the calculation of the total benefit and the score for each subject.[17]

Subject #	clothes	food	housing	other	total	score
4	5	8	0	83.4	134.1	0
...	...	...	...	...	...	...
17	4	10	4	82.8	154.4	2.7
...	...	...	...	...	...	...
23	0	0	8	82.8	111.1	0
...	...	...	...	...	...	...

7. It typically takes me (or my Teaching Assistant) 15 hours to complete the spreadsheet for the Second Experiment with 200 students (it is much quicker for fewer students).

4. CONCLUSION

I use two linked experiments to illustrate six important principles of microeconomics. I find that students enjoy the experiments and the feedback I receive confirms that they are a useful learning experience. The experiments differ from other class experiments in their comprehensiveness.

APPENDIX A

FIRST EXPERIMENT: INSTRUCTIONS FOR STUDENTS WITH TECHNOLOGY A[18]

These instructions are for students with Technology A. If you have Technology B or C, please read the correct instructions.

This is an experiment in economic decision-making. The instructions are simple and, if you follow them carefully, you may earn points towards your grade.

Out of the 100 possible points used to calculate your final grade, 90 points come from your scores in the midterm and final exams, and 10 points come from your scores in this experiment and in the next experiment. You cannot earn a negative score in this experiment, and hence participating in the experiment cannot cause your score to be lower than if you do not participate.

Your "total benefit" *TB* depends on the goods you own as

$$TB = 10\sqrt{clothes} + 10\sqrt{food} + 10\sqrt{housing} + \text{"}other\ things\text{"} ,$$

where the labels "clothes", "food", "housing" and "other things" denote the units of these goods you own. Your score from this experiment depends on your "total benefit" as:

if $TB \leq 126$, your score is *0*.

if $126 \leq TB$, your score is $\frac{1}{6}(TB - 126)$.

You start with 100 units of "resources". You can acquire clothes, food, housing and "other things" by manufacture, but not by trade with somebody else. There are 3 technologies of manufacturing - technologies *A*, *B* and *C*. Each technology uses different quantities of "resources" as inputs to manufacture a unit of clothes, food and housing. In particular, the "resources" used up to produce a unit of clothes, food or housing using the different technologies are described as:

		Units of “resources” used to manufacture 1 unit of output using technology:		
		A	B	C
Output	clothes	1	3	2
	food	2	1	3
	housing	3	2	1
	“other things”	1	1	1

One third of students are using Technology *A*, one third of students are using Technology *B* and one third of students are using Technology *C*. *You can only use Technology A.*

You may only manufacture integer units of clothes, food, housing and "other things". Scores are rounded to 1 decimal point. For different values of *x*, the values of $10\sqrt{x}$ which you are to use to calculate your score are shown in the Appendix.

At the start of class on ____________________ or earlier, you must return your Production Plan of clothes, food and housing. “Resources” not used to produce clothes, food and housing are assumed to be used to produce "other things". The Production Plan form is shown at the end of these instructions. Production Plans handed in late will not be accepted.

EXAMPLES OF CALCULATING THE CONTRIBUTION TO YOUR GRADE

EXAMPLE 1: Your production is:

Clothes:	15 units
Food:	23 units
Housing:	9 units

To produce these outputs, you use up (15x1) + (23x2) + (9x3) = 88 "resources". Therefore, you have remaining 100-88 = 12 "resources" which you use to produce 12 “other things”.

TB is calculated as

$$TB = 10\sqrt{15} + 10\sqrt{23} + 10\sqrt{9} + 12 = 128.7 .$$

Your score is

$$\frac{1}{6}(128.7 - 126) = 0.45 .$$

EXAMPLE 2: Your production is:

Clothes:	3 units
Food:	21 units
Housing:	15 units

To produce these outputs, you use up (3x1) + (21x2) + (15x3) = 90 "resources". Therefore, you have remaining 100-90 = 10 "resources" which you use to produce 10 “other things”.

TB is calculated as

$$TB = 10\sqrt{3} + 10\sqrt{21} + 10\sqrt{15} + 10 = 111.8 .$$

Because $TB \leq 126$, your score is 0 .

APPENDIX: VALUES OF x AND $10\sqrt{x}$[19]

x:	$10\sqrt{x}$
1	10.0
2	14.1
3	17.3
4	20.0
5	22.4
6	24.5
7	26.5
8	28.3
9	30.0
10	31.6
11	33.2
12	34.7
13	36.1
14	37.4
15	38.7
16	40.0
17	41.2
18	42.4
19	43.6
20	44.7
21	45.8
22	46.9
23	48.0
24	49.0
25	50.0
26	51.0
27	52.0
28	53.0
29	53.9
30	54.8
31	55.7
32	56.6
33	57.5
34	58.4
35	59.2
36	60.0
37	60.8
38	61.6
39	62.4
40	63.2

PRODUCTION PLAN: TO BE HANDED IN

SUBJECT #: ________________

TECHNOLOGY: ________________

Name: ________________

My production plan is:

Clothes : ____ units.

Food : ____ units.

Housing : ____ units.

I am using the "resources" left over after the manufacture of the above quantities of clothes, food and housing to manufacture "other things".

I calculate my "total benefit" as: _____ .

I calculate my score in this experiment as: _____ .

APPENDIX B

SECOND EXPERIMENT: INSTRUCTIONS FOR STUDENTS WITH TECHNOLOGY A[20]

Your subject number and technology for this experiment are the same as the ones assigned to you for the First Experiment. They are shown on the course web-page, or you can get them by asking the instructor.

The instructions shown below are for students with Technology A. If you have Technology B or C, please read the correct instructions.

When recording production or trades, you must use your subject number which has been assigned to you: using a number which has not been assigned to you could affect the score of another student.

This is an experiment in economic decision-making. The instructions are simple and, if you follow them carefully, you can earn points towards your grade.

Out of the 100 possible points used to calculate your final grade, 90 points come from your scores in the midterm and final exams, and 10 points come from your scores in the last experiment and from this experiment. Note that it is possible for your total score from the two experiments to exceed 10, e.g., you could score 3.3 in the first experiment and 8 in the second experiment making your total score from both experiment as 11.3 out of 10. You cannot earn a negative score in this experiment, and hence participating in the experiment cannot cause your score to be lower than if you do not participate.

Your "total benefit" *TB* depends on the goods you own as

$$TB \;=\; 10\sqrt{clothes} \;+\; 10\sqrt{food} \;+\; 10\sqrt{housing} \;+\; \text{"}other\ \ things\text{"}\ ,$$

where the labels "clothes", "food", "housing" and "other things" denote the units of these goods owned. Your score from this experiment depends on your "total benefit" as:

if $TB \le 138$, your score from this experiment is *0* .

if $138 \le TB \le 186$, your score from this experiment is $\frac{1}{6}(TB - 138)$.

if $186 \le TB$, your score from this experiment is *8* .

Scores are rounded to 1 decimal point. For different values of *x*, the values of $10\sqrt{x}$ which you are to use to calculate your score are shown in the Appendix.

You start with 100 units of "resources". You can acquire clothes, food, housing and "other things" by manufacture, or by trade with somebody else.

Manufacture:

Clothes, food, housing and "other things" may be manufactured. There are three technologies - technologies *A*, *B* and *C* . Each technology uses different quantities of "resources" as inputs to manufacture a unit of clothes, food and housing. In particular, the "resources" used up to produce a unit of clothes, food or housing using the different technologies are described as:

		Units of "resources" used to manufacture 1 unit of output using technology:		
		A	B	C
Output	clothes	1	3	2
	food	2	1	3
	housing	3	2	1
	"other things"	1	1	1

One third of students can use Technology *A*, one third of students can use Technology *B* and one third of students can use Technology *C*. *You can use only Technology A.*

You manufacture clothes, food and housing for your own use or to trade with other students. "Resources" left over at the end of the experiment are assumed to be used to manufacture "other things" .

Trade:

Clothes, food and housing can be traded only for "resources". The buyer of the goods must own the "resources" he/she gives in exchange for the good, and the seller of the goods must own the goods he/she sells. E.g., if you agree to buy 6 food from Subject 125 at a price of 1.4 (units of "resources" per unit of food), you must have at least 6x1.4=8.4 "resources" on hand and Subject 125 must have at least 6 food - acquired either by production or by trade.

Only integer units of clothes, food and housing can be manufactured, sold or bought, but prices need not be integers. Trades which have been effected cannot be altered.

The next section describes how to record production, how to record a trade and how to calculate the final contribution towards your grade. The official record of a production decision is a signed production slip. The official record of a trade is a trade slip signed by both you and the student with whom you trade. I will calculate your score using only official records.

A log is provided at the end of these instructions to help you keep track of your decisions. Some production and trade slips are attached: please see the instructor if you need more

Class-time on ____________________ and ____________________ is put aside for you to trade. Production and trade slips completed during these sessions should be handed in during these sessions. At the start of class on ____________________ you must return your Final Outcome sheet giving your final ownership of clothes, food, housing, and "resources". At the same time all outstanding production and trade slips must be handed in.

HOW TO RECORD A PRODUCTION DECISION

A sample production slip looks like:

PRODUCTION SLIP: SUBJECT USING TECHNOLOGY A
Subject # (1)________ manufactures (2)_____ units of (3)__________.
Signature: (4)_________________.

You record the manufacture of clothes, food or housing by completing the spaces on the production slip as:

(1) write your subject number.
(2) write the number of units manufactured.
(3) write the product (i.e., clothes, food or housing) manufactured.
(4) write your signature.

If a production slip is completed in a class trading session, it is to be handed to the instructor at the end of the session. Otherwise it is to be handed in when the Final Outcome sheet is handed in.

To keep track of your decisions, you should update your log.

EXAMPLE OF PRODUCTION:

Your subject number is 450 and the last entry in your log looks like:

	Holding after action			
	Clothes	*Food*	*Housing*	*"Resources"*
....				
11. *Bought* *10* *food* for *15* "resources "	*10*	*10*	*14*	*74*

You decide to manufacture 5 units of food. You complete the production slip as:

PRODUCTION SLIP: SUBJECT USING TECHNOLOGY A

Subject # (1) *450* manufactures (2) *5* units of (3) *food* .

Signature: (4) *xxxxxxxxxxx*

To update your log: write your action in the left part of the log, add 5 units to your holding of food and subtract the inputs used, 10 units, from your holding of "resources". You carry forward your holdings of clothes and housing. Your log now appears as:

	Holding after action			
Action	*Clothes*	*Food*	*Housing*	*"Resources"*
....				
11. *Bought* *10* *food* for *15* "resources "	*10*	*10*	*14*	*74*
12. *Manufacture* *5* *food* for *10* "resources "	*10*	*15*	*14*	*64*

HOW TO RECORD A TRADE

A sample trade slip appears as:

TRADE SLIP

Subject # (1)________ sells to Subject (2)________

(3)_____ units of (4)__________

at a price of (5)_____ (units of "resources" per unit of good sold)

Signature of seller: (6)_______________ Signature of buyer: (7)_______________

A trade is recorded when both buyer and seller complete the spaces on the same trade slip as:

(1) write the subject number of the seller of the clothes, food or housing.
(2) write the subject number of the buyer of the clothes, food or housing.
(3) write the number of units of clothes, food or housing sold.
(4) write the goods (i.e., clothes, food or housing) sold.
(5) write the agreed price (units of "resources" per unit of good sold).
(6) write the seller's signature.
(7) write the buyer's signature.

If a trade slip is completed in a class trading session, it should be handed to the instructor at the end of the session. Otherwise it is to be handed in when the Final Outcome sheet is handed in.

Note: only one trade slip is handed-in for each transaction. The seller and the buyer do NOT each complete a separate trade slip.

Note: the price recorded in (5) is the price *per unit* sold and NOT the total resources transferred.

To keep track of your decisions, you should update your log.

EXAMPLE OF SELLING:

Your subject number is 450 and the last entry of your log looks like:

Action	*Holding after action* Clothes	Food	Housing	"Resources"
.....				
12. *Manufacture* _5_ *food* for _10_ "resources "	*10*	*15*	*14*	*64*

You agree to sell 4 units of housing to Subject 135 at a price of 1.75 (units of "resources" per unit of housing). You and the buyer together complete a trade slip as:

TRADE SLIP

Subject # (1) *450* sells to Subject (2) *135*

(3) *4* units of (4) *housing*

at a price of (5) *1.75* (units of "resources" per unit of good sold)

Signature of seller: (6) *xxxxxxxxxx* Signature of buyer: (7) *yyyyyyyyyy*

To update your log: write your action in the left part of the log, subtract 4 units from your holdings of housing and add the "resources" gained, 4x1.75=7 units, to your holdings of "resources". You carry forward your holdings of clothes and food. Your log now appears as:

Action	*Holding after action* Clothes	Food	Housing	"Resources"
......				
12. *Manufacture* _5_ *food* for _10_ "resources "	*10*	*15*	*14*	*64*
13. *Sell* _4_ *housing* for _7_ "resources"	*10*	*15*	*10*	*71*

EXAMPLE OF BUYING:

Your subject number is 450 and the last entry in your log looks like:

	Holding after action			
	Clothes	*Food*	*Housing*	*"Resources*
.....				
13. *Sell* 4 *housing* for 7 "resources"	*10*	*15*	*10*	*71*

You agree to buy 6 units of clothes from Subject 125 at a price of 1.4 (units of "resources" per unit of clothes). You and the seller together complete a trade slip as:

TRADE SLIP

Subject # (1) *125* sells to Subject (2) *450*

(3) *6* units of (4) *clothes*

at a price of (5) *1.4* (units of "resources" per unit of good sold)

Signature of seller: (6) *zzzzzzzzzz* Signature of buyer: (7) *xxxxxxxxxxx*

To update your log: write your action in the left part of the log, add 6 units to your holdings of clothes and subtract the "resources" given up, 6x1.4=8.4 units, from your holdings of "resources". You carry forward your holdings of food and housing. Your log now appears as:

	Holding after action			
Action	*Clothes*	*Food*	*Housing"*	*Resources"*
....				
13. *Sell* 4 *housing* for 7 "resources"	*10*	*15*	*10*	*71*
14. *Buy* 6 *clothes* for 8.4 "resources"	*16*	*15*	*10*	*62.6*

EXAMPLES OF CALCULATING YOUR SCORE

EXAMPLE 1:The last entry in your log looks like:

Action		Holding after action			
		Clothes	*Food*	*Housing*	*"Resources"*
....					
14.	*Buy* *6* *clothes* for *8.4* "resources"	*16*	*15*	*10*	*62.6*

You use the remaining 62.6 resources to manufacture 62.6 "other things." Your “total benefit” *TB* is calculated as

$$TB \ = \ 10\sqrt{16} \ + \ 10\sqrt{15} \ + \ 10\sqrt{10} \ + \ 62.6 \ = \ 172.9$$

Your score is

$$\frac{1}{6}(172.9 - 138) \ = \ 5.8$$

EXAMPLE 2: The last entry in your log looks like:

Action		Holding after action			
		Clothes	*Food*	*Housing*	*"Resources"*
......					
16.	*Sell* *8* *housing* for *13* "resources"	*3*	*21*	*20*	*21.6*

You use the remaining 21.6 resources to manufacture 21.6 "other things." Your “total benefit” *TB* is calculated as

$$TB \ = \ 10\sqrt{3} \ + \ 10\sqrt{21} \ + \ 10\sqrt{20} \ + \ 21.6 \ = \ 129.4 .$$

Because *TB* < *138*, your score is 0.

EXAMPLE 3: The last entry in your log looks like:

	Holding after action			
Action	*Clothes*	*Food*	*Housing*	*"Resources"*
....				
18. *Buy* *4* *clothes* for *13* "resources"	*28*	*30*	*16*	*75*

You use the remaining 75 resources to manufacture 75 "other things." Your “total benefit” *TB* is calculated as

$$TB = 10\sqrt{28} + 10\sqrt{30} + 10\sqrt{16} + 75 = 222.8.$$

Because *186 <TB*, your score is 8.

FINAL OUTCOME: TO BE HANDED IN

SUBJECT #: ________________

Name: ________________

Student I.D. #: ________________

I calculate my final outcome as:

Clothes : ____ units.

Food : ____ units.

Housing : ____ units.

I am using any “resources” left over after my manufacturing and trading decisions to manufacture “other things”. I calculate my final amount of “other things” as:

“Other things” : ____ units.

I calculate my "total benefit" as: _____ .

I calculate my score in this experiment as: ____ .

APPENDIX: VALUES OF x AND $10\sqrt{x}$[21]

x:	$10\sqrt{x}$
1	10.0
2	14.1
3	17.3
4	20.0
5	22.4
6	24.5
7	26.5
8	28.3
9	30.0
10	31.6
11	33.2
12	34.7
13	36.1
14	37.4
15	38.7
16	40.0
17	41.2
18	42.4
19	43.6
20	44.7
21	45.8
22	46.9
23	48.0
24	49.0
25	50.0
26	51.0
27	52.0
28	53.0
29	53.9
30	54.8
31	55.7
32	56.6
33	57.5
34	58.4
35	59.2
36	60.0
37	60.8
38	61.6
39	62.4

LOG

		Holding after action			
	Action	*Clothes*	*Food*	*Housing*	*"Resources"*
START		0	0	0	100
1.	________ ____ ____ for ____ "resources"	____	____	____	_____
2.	________ ____ ____ for ____ "resources"	____	____	____	_____
3.	________ ____ ____ for ____ "resources"	____	____	____	_____
4.	________ ____ ____ for ____ "resources"	____	____	____	_____
5.	________ ____ ____ for ____ "resources"	____	____	____	_____
6.	________ ____ ____ for ____ "resources"	____	____	____	_____
7.	________ ____ ____ for ____ "resources"	____	____	____	_____
8.	________ ____ ____ for ____ "resources"	____	____	____	_____
9.	________ ____ ____ for ____ "resources"	____	____	____	_____
10.	________ ____ ____ for ____ "resources"	____	____	____	_____
11.	________ ____ ____ for ____ "resources"	____	____	____	_____
12.	________ ____ ____ for ____ "resources"	____	____	____	_____
13.	________ ____ ____ for ____ "resources"	____	____	____	_____
14.	________ ____ ____ for ____ "resources"	____	____	____	_____
15.	________ ____ ____ for ____ "resources"	____	____	____	_____
16.	________ ____ ____ for ____ "resources"	____	____	____	_____
17.	________ ____ ____ for ____ "resources"	____	____	____	_____
18.	________ ____ ____ for ____ "resources"	____	____	____	_____

EXAMPLE OF PRODUCTION SLIP

PRODUCTION SLIP: SUBJECT USING TECHNOLOGY A

Subject # (1)________ manufactures (2)_____ units of (3)__________.

Signature: (4)_________________.

EXAMPLE OF TRADE SLIP

TRADE SLIP

Subject # (1)________ sells to Subject (2)________

(3)_____ units of (4)__________

at a price of (5)_____ (units of "resources" per unit of good sold)

Signature of seller: (6)_______________ Signature of buyer: (7)_______________

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ENDNOTES

1. In addition to Chamberlin (1948) and Smith (1962, 1964), Joseph (1965) and Joseph and Saunders (1970) report a class experiment which is similar to Chamberlin's design.
2. In most experiments, when a trade was completed its price was posted on the blackboard.
3. From autobiography of Vernon Smith, published in *Les Prix Nobel, the Nobel Prizes*, edited by T. Frangsmyr. Nobel Foundation, Stockholm, 2003.
4. DeYoung (1993) provides a summary of the use of the Double Auction as a teaching tool.
5. From autobiography of Vernon Smith, published in *Les Prix Nobel, the Nobel Prizes*, edited by T. Frangsmyr. Nobel Foundation, Stockholm, 2003.
6. Hong and Plott (1982) report an experiment which is similar to Chamberlin's design but in which subjects receive monetary pay-offs.
7. The pay-off could be made as points which form extra credit.
8. For example, in the Second Experiment the competitive prediction is a score of 6.2. In Principles of Microeconomics Fall 2005, the mean score was 4.1 and the standard deviation was 2.7; in Intermediate Microeconomics Spring 2007, the mean score was 4.5 and the standard deviation was 2.9. For Microeconomics for MA students in Fall 1996, the mean score was 6.1 and the standard deviation was 0.9.
9. Davis and Holt (1993) suggest that it is good practice to avoid reference to any particular good to avoid unobserved connotations from biasing the results. I believe that the typical Principle of Microeconomics student prefers labeling goods as "food", "clothing", "housing" and "other things" to more abstract labeling "*w*", "*x*", "*y*" and "*z*". However, abstract labeling may be used if desired.

10. Note that the objective is linear and separable in x (the numeraire) and so an analysis based on consumer and producer surplus is appropriate.

11. The values of $10\sqrt{i}$ are rounded to one decimal and, in order to be consistent with the Law Of Diminishing Marginal Benefit, slightly adjusted so that $10\sqrt{i} - 10\sqrt{i-1}$ decreases steadily as i increases.

12. It is possible for a student to earn 3.3 points in the first experiment and 8 points in the second experiment, or for a student's score from the two experiments to be 11.3 out of 10. At the competitive outcomes, the student scores 9.5 out of 10.

13. The units on the vertical axis in Figure 1 are "Units of "other things" per unit of clothes" because the marginal benefit is technically measured as the units of numeraire ("other things") which gives the same increase in benefit as the unit of clothes, and the marginal cost is measured as the units of numeraire ("other things") foregone when a unit of clothes is manufactured.

14. It is easy to rephrase the analysis using the comparison of the marginal rate of substitution and the opportunity cost.

15. This is why, unlike in the experiments of Chamberlin (1948), Smith (1962) and others, my instructions inform each student of all the existing technologies.

16. At the Pareto-efficient outcome, individuals with the least cost method of manufacturing a good may either manufacture units for own use or acquire units from others with the same technology. In practice, very few units are bought by individuals having the least cost method of manufacturing that good (in the experiment described, 320 units of good were bought by individuals who had the least cost method of manufacturing that good), and I ignore this potential trade in my discussions.

17. If a student's final quantity of clothes, food or housing is negative (i.e. the student's sales exceeds his production plus purchases), I "correct" the entry by forcing the student to manufacture the shortage. E.g. a student has Technology B and his entry for clothes is -6. I force the student to manufacture 6 additional units of clothes and reduce his "other things" by 18.

18. The instructions for students with Technology B (C) are identical except that "food" ("housing") replaces "clothes"; "housing" ("clothes") replaces "food"; "clothes" ("food") replaces "housing" .

19. As noted in Section 2, the values of $10\sqrt{x}$, rounded to one decimal, have been adjusted so that $10\sqrt{x} - 10\sqrt{x-1}$ decreases as *x* increases.

20. The instructions for students with Technology B (C) are identical except that "food" ("housing") replaces "clothes"; "housing" ("clothes") replaces "food"; "clothes" ("food") replaces "housing" .

21. As in the First Experiment, the values of $10\sqrt{x}$, rounded to one decimal, have been adjusted so that $10\sqrt{x} - 10\sqrt{x-1}$ decreases as *x* increases.