Economics, Game Theory, and Sustainability

An Introduction to Strategic Thought

Kyle Woodward

Global Green Business Week
Center for International Business Education and Research
UCLA Anderson School of Management

July 18, 2011

What is economics?

- Is the stock market economics?
- Are interest rates economics?
- Is the trade deficit with China economics?

"Welfare:" economics' unifying concept

- Measures like GDP and the NASDAQ can tell us whether or not the economy is healthy
- Economists think people like money: more money means more choices
- The more choices are available, the better choices may be made
- Richer countries should have happier people; social welfare — the sum of everyone's happiness — is higher

Choices

- You have made a choice recently. What were your other options? What were the consequences?
- *Opportunity cost*, the value of the next-best thing you could have done
- Economists believe that people make decisions which bring them the most happiness
- Do we know what makes everyone happy?

Situation-based choice

- If economists care about how well-off people are, we need to know how people make choices
- Context matters; decisions are not made in a vacuum!
- We need a way to determine how people will act in a particular situation
- People respond to *incentives*, and the situation defines the incentives

Game theory

- *Game theory* studies how people act in strategic settings, called *games*
- Checkers is a game; so is whether you drive on the left- or right-hand side of the road
- A game gives us a set of rules and tells us what happens depending on how people act, according to these rules

Utility and payoffs

- To understand and predict behavior, we need to have some idea of what people are trying to achieve
- Economic agents — individuals, firms, governments, etc. — act to maximize *utility*, their own well-being
- What exactly *is* utility? It depends on the context. How would you measure utility? A capitalist firm?
- Can we compare utilities obtained by different people?
- In the context of games, we often refer to utilities as *payoffs*

The umbrella game

You wake up in the morning and it is raining. Should you bring an umbrella when you leave your house?

- Suppose you don't like getting wet
- Your payoff from staying dry is 0, but your payoff from getting wet is -10
- What might 0 and -10 represent here?
- What do you do?

Your decision to carry an umbrella (or not) is referred to as your *action*.

The umbrella game, redux

You are going to bed and need to give your robot butler instructions as to whether or not to pack your umbrella in the morning. You don't know yet what the weather will be tomorrow, but your robot butler will see whether or not it is raining before he packs (or doesn't pack) your umbrella.

- Your payoffs are the same as before if it is raining
- If it is not raining, your payoff from not having to carry an umbrella with you is 0, but your payoff from wastefully carrying an umbrella is -10
- What instructions do you give your robot butler?

The umbrella game, redux

You are going to bed and need to give your robot butler instructions as to whether or not to pack your umbrella in the morning. You don't know yet what the weather will be tomorrow, but your robot butler will see whether or not it is raining before he packs (or doesn't pack) your umbrella.

- Your payoffs are the same as before if it is raining
- If it is not raining, your payoff from not having to carry an umbrella with you is 0, but your payoff from wastefully carrying an umbrella is -10
- What instructions do you give your robot butler?

The contingent instructions — do X if Y, and do W otherwise — are referred to as a *strategy*. A strategy is a "plan of action."

Standard representation

- Consider the actions **U**mbrella or **N**o umbrella
- Payoffs when it is raining are

	U	N
1	0	-10

- Payoffs when it is not raining are

	U	N
1	-10	0

- Each of these figures is a *payoff matrix*

Limitations

- We now have the ability to describe when you will or won't carry an umbrella, buckle your seatbelt, or pay your taxes
- For a single person, these questions aren't very hard: take the action which yields the highest payoff
- What did you do the last time you hung out with your friends?

Adding other agents

- In reality, our payoffs are determined not only by what we do, but also what others are doing. Running a stop sign is not dangerous if there are no other cars on the road![1]
- Other people take actions and we act in response; but they are acting in response to what we are doing
- How can we find a clear method for describing and predicting behavior in groups of players?

[1] I do not advocate running stop signs.

The Battle of the Sexes

Economists love to give particular games a memorable name. This game is referred to as the *Battle of the Sexes* because it is meant to reflect the tension in a married couple deciding to go to a football game or to the ballet. Since this is passably sexist we change it a little bit.

- My wife prefers **I**talian food to **M**exican food; I prefer **M**exican food to **I**talian food
- We'd rather go on a date together
- She gets utility of 2 from **I**talian food and utility of 1 from **M**exican food *if we go out together*; if we don't go out together she gets utility of 0
- My utility follows the same pattern, aside from my preferences

Normal form

	I	M
I	1, 2	0, 0
M	0, 0	2, 1

- This is the *normal form* of the game, or the *normal form payoff matrix*
- "Player 1" (me) chooses an action from the rows; "player 2" (my wife) chooses an action from the columns
- Payoffs are listed by choosing a row and a column matching the desired actions, and are listed as *player 1*,*player 2*
- **We assume that players take their actions at the same time**; I cannot see where my wife has gone to dinner before I make my choice of restaurant

Prediction

- What do **I** want to do if my wife goes out for **I**talian food? For **M**exican food?
- Does it matter that I like **M**exican food better than **I**talian food?
- What would you expect to happen if she and I played this game?

Nash equilibrium

- Let each player in the game pick a strategy
- If the actions taken in each player's strategy provide the maximum payoff given what the other player is doing, this pair of strategies is a *Nash equilibrium*
- How can we find such a pair of strategies?

The underline/overline trick

For each action that player 2 (the column player) can take, place an underline in the cell which matches the action which maximizes player 1's utility.

	I	M
I	$\underline{1, 2}$	$0, 0$
M	$0, 0$	$\underline{2, 1}$

For each action that player 1 (the row player) can take, place an overline in the cell which matches the action which maximizes player 2's utility.

	I	M
I	$\overline{1, 2}$	$0, 0$
M	$0, 0$	$\overline{2, 1}$

The underline/overline trick

Put the two payoff matrices together (or use a pencil on a single payoff matrix). Any cell which has both an overline and an underline is a Nash equilibrium.

	I	M
I	$\overline{\underline{1, 2}}$	$0, 0$
M	$0, 0$	$\overline{\underline{2, 1}}$

- Why does this work?
- What does this tell us about the meaning of “equilibrium”?

The Prisoner's Dilemma

One of the most famous games is *The Prisoner's Dilemma*. Two theives are caught robbing a donut store, and are suspected to be the Jelly Bandits responsible for a larger crime spree. They are brought down to the police station and are taken into separate rooms for questioning. Each is offered the following deal:

- If a thief rats out his partner while his partner remains silent, he will receive a small sentence of 1 year in jail; his partner will receive 10 years in jail.
- If both thieves rat on each other, each receives a 7-year sentence.
- If neither thief rats the other out, they are convicted only of the robbery for which they were caught and receive 3 years in jail apiece.

What are the actions in this story? What are the payoffs?

The Prisoner's Dilemma

	D	R
D	$-3, -3$	$-10, -1$
R	$-1, -10$	$-7, -7$

What is the prediction of equilibrium? Does this make sense? How would you play this game?

The Prisoner's Dilemma: equilibrium

	D	R
D	$-3, -3$	$-10, -1$
R	$\underline{-1, -10}$	$\underline{-7, -7}$

$+$

	D	R
D	$-3, -3$	$\overline{-10, -1}$
R	$-1, -10$	$\overline{-7, -7}$

$=$

	D	R
D	$-3, -3$	$\overline{-10, -1}$
R	$\underline{-1, -10}$	$\underline{\overline{-7, -7}}$

The Firm's Dilemma

There are two firms which produce paper towels. In their current production method, loggers clear-cut forests to provide lumber to turn into paper. However, each firm faces the choice of upgrading to a recycled-paper production method; producing paper towels from recycled paper is more expensive than from fresh lumber. A small group of citizens is refusing to use paper towels because they are not made in an environmentally-conscious way.

- If neither firm upgrades to the new production method, they each obtain \$5000 in profits
- If one firm upgrades to the new production method but the other does not, it will obtain \$4000 in profits while the other firm obtains \$10000
- If both firms upgrade to the new production method, each will obtain \$6000 in profits

Is there a story such that these payoffs make sense?

The Firm's Dilemma

The firms face a choice of **L**ogging or **R**ecycling.

	L	R
L	5, 5	10, 4
R	4, 10	6, 6

What is equilibrium?

The Firm's Dilemma

The firms face a choice of **L**ogging or **R**ecycling.

	L	R
L	5, 5	10, 4
R	4, 10	6, 6

What is equilibrium?

	L	R
L	5, 5	10, 4
R	4, 10	6, 6

How is this different from The Prisoner's Dilemma?

Strategic thinking

This game is called the *p-beauty contest*.

- Everyone chooses a whole number between 1 and 100
- The person who guesses closest to $\frac{2}{3}$ of the average guess wins!

Group thinking

This game is called *The Stag Hunt*. We'll need some volunteers.

Group thinking

This game is called *The Stag Hunt*. We'll need some volunteers.

- All players must go hunt for dinner
- In version A, if *everyone* agrees to hunt for stag, the stag will be caught and everyone has a bountiful meal
- In version B, if *at least half* of everyone agrees to hunt for stag, the stag will be caught and everyone has a bountiful meal
- Players may also choose to hunt rabbit; it only takes one player to catch a rabbit, but the meal is much more meager

Resources

- A common issue with regards to sustainability is the use of resources
- Roads are a resource
- If one person drives on a street, there is no traffic; if many people drive on the street, there is a traffic jam
- Does equilibrium tell us that we should see traffic jams in real life?

Externalities

- When one agent's actions affect the payoffs of others, they are imposing an *externality* on the other agents
- The Prisoner's Dilemma has a clear externality
- Traffic jams are the result of externalities
- Do people think about the externalities they generate when they make their decisions?

Gone grazing

There are two shepherds raising sheep. Each shepherd puts his flock out to graze in the public commons in the middle of town, and when the flock returns he shears it to sell wool. The amount of wool grown by each sheep depends on the amount of grass they can eat, but the amount of grass they can find depends on the number of other sheep in the commons. Suppose that the amount of wool grown by the sheep belonging to shepherd i when he puts s sheep to pasture is

$$w_i(s, S) = s^2 + s(100 - 2S)$$

Here, S is the total number of sheep put to pasture *by both shepherds*.

Equilibrium

- Even though we no longer have a normal form payoff matrix, we still can compute Nash equilibrium
- How?
- Suppose that s is the number of sheep put to pasture by shepherd i, and z is the number of sheep put out by the other shepherd
- Rewrite the "wool sheared" equation as

$$w_i(s,z) = s^2 + s(100 - 2(s+z)) = 100s - 2sz - s^2$$

Finding the optimum

- To find the optimum, we figure out the best that shepherd i can do *taking the decision z by the other shepherd as given*
- This is a quadratic equation in s,

$$w_i(s, z) = -s^2 + (100 - 2z)s$$

- We can use calculus or knowledge of quadratic equations

Finding the optimum

- To find the optimum, we figure out the best that shepherd i can do *taking the decision* z *by the other shepherd as given*
- This is a quadratic equation in s,

$$w_i(s, z) = -s^2 + (100 - 2z)s$$

- We can use calculus or knowledge of quadratic equations
- The optimum is $s = 50 - z$

Equilibrium assumptions

- We could have used the same logic for the other player!
- Then we should also have $z = 50 - s$
- To keep things "fair," we assume that both shepherds make the same decision; that is, $z = s$

Equilibrium outcome

- When all of this is put together, $s = 25$ is the optimum number of sheep
- Then $S = s + z = 50$
- Hence each shepherd obtains a quantity of wool of

$$w(25, 25) = 25^2 + 25(100 - 2(25 + 25)) = 625$$

Equilibrium outcome

- When all of this is put together, $s = 25$ is the optimum number of sheep
- Then $S = s + z = 50$
- Hence each shepherd obtains a quantity of wool of

$$w(25, 25) = 25^2 + 25(100 - 2(25 + 25)) = 625$$

- ...but could they have done better?

Collusion

Suppose now that the shepherds can come to a gentleman's agreement prior to leaving the putting their flocks out that day. They agree that they will each put out the same number of sheep. How many sheep should each put out for grazing?

- Shepherd i now knows that $s = z$
- When he decides how much to suggest grazing, this means he knows $S = 2s$
- His problem has become

$$w_i(s) = s^2 + s(100 - 4s) = -3s^2 + 100s$$

The social optimum

- To find the maximum amount of wool he can shear, we again use calculus or properties of quadratic functions

[2] For now, assume that baby sheep are "fractional sheep." That is, $\frac{50}{3}$ represents 16 adult sheep and two baby sheep.

The social optimum

- To find the maximum amount of wool he can shear, we again use calculus or properties of quadratic functions
- At the optimum[2], $s = \frac{50}{3} < 25$
- Hence each shepherd obtains

$$\begin{aligned} w\left(\frac{50}{3}, \frac{50}{3}\right) &= \left(\frac{50}{3}\right)^2 + \frac{50}{3}\left(100 - 2\left(\frac{50}{3} + \frac{50}{3}\right)\right) \\ &= \frac{2500}{9} + \frac{50(100)}{9} \\ &= \frac{2500}{3} \\ &> 625 \end{aligned}$$

[2] For now, assume that baby sheep are "fractional sheep." That is, $\frac{50}{3}$ represents 16 adult sheep and two baby sheep.

Why don't economists expect this?

- So by cooperating with each other, *both* shepherds are better off than in the Nash equilibrium
- Do the individual shepherds have a reason to cheat?
- If you were putting out your flock and knew that the other shepherd was grazing a flock of $\frac{50}{3}$, how many sheep would you put out?

The tragedy of the commons

- This problem is referred to as *the tragedy of the commons*, due to the nature of the grazing occurring on the public commons
- Are the shepherds in our story being malicious, or are they just being selfish?
- Self-interested people and profit-seeking firms will act in their own interest, even if cooperating is advantageous for everyone
- Aside: could we improve traffic in the city if every day was "Carmageddon"?

Long-term effects

- The grazing example gives us some insight to the challenge of sustainability
- Some resources are of finite, fixed quantity; others are renewable but may only regenerate at a particular rate
- A single firm using resources will take this into account
- Many firms using the same resource may not fully-economize, since any sacrifice they make will mean an advantage for their competitor

Choice over time

- Unfortunately, modeling sustainable production over time is more difficult than our time allows
- Production decisions today affect possible production decisions tomorrow
- When you put money into a savings account, you are delaying consumption; when you remove the money from the savings account to purchase something, you are losing the ability to purchase something else later

A tree farm

You have a small stand of 10 trees on a plot of land. To make money, you chop trees and sell lumber to a local paper towel factory. Each tree you don't chop not only lives to see another year, but has a sapling which itself becomes a new tree on your plot. Since your plot is small, it can sustain at most 10 trees; there is not adequate space for any more.

- Resource extraction is *sustainable* if it may continue into perpetuity
- The *maximum sustainable yield* is the greatest level of resource extraction which is sustainable
- What is the maximum sustainable yield of your tree farm?
- Are there other sustainable levels of resource extraction?

A forest

Now suppose that instead of the small plot being your private property, it is a public forest. There are 10 lumberjacks in town, each of whom wants to sell lumber to the town's paper towel factory.

- If the lumberjacks can work together, how many trees might they cut down each year?
- If the lumberjacks cannot work together, how many trees might they cut down each year?
- Do we expect the lumberjacks to work together?
- Is there a role for government in this situation?

Present discounted value

We should be careful, though: private ownership will not necessarily solve the problem of sustainability.

- A dollar today is not the same as a dollar tomorrow
- Your savings account earns some interest (or it did before 2008)
- A private owner will balance the upside from future extraction against the downside of compounded interest

Present discounted value, formally

- Suppose the interest rate is r
- \$100 this year is worth $\$100(1 + r)$ next year
- What is \$100 next year worth today?

Present discounted value, formally

- Suppose the interest rate is r
- \$100 this year is worth $\$100(1+r)$ next year
- What is \$100 next year worth today? $\frac{\$100}{1+r}$
- Given an income stream over time, $I = \langle I_1, I_2, \ldots \rangle$, the *present discounted value* is the sum of each period's worth today
- If the interest rate is 25%, which is better: \$50 this year or \$65 next year?

The private owner's problem

- The owner of the plot of land wants only to maximize his own profits; this is how economists view firms
- When will the owner sustainably harvest the forest?
- What happens when the interest rate is extremely high?
- What if the owner thinks that he will die next year?

Market forces

Some resource extraction and production technologies are necessarily unsustainable. What is the maximum sustainable yield of the world's oil wells[3]? Can Apple continue building iPads until the next Ice Age?

- Is it true that our consumption of gasoline is unsustainable?
- When there are gas shortages (as in the 1970s), what should happen to gas prices? What will happen to demand?
- How is gasoline different from the Dodo, hunted to extinction?

[3] Short of more dinosaurs dying and becoming buried.