Petroleum Economics and Management
Prof. Anwesha Aditya
Department of Humanities and Social Sciences
Indian Institute of Technology, Kharagpur

Module - 08
Oligopoly and Game Theory
Lecture - 41
Competition versus collusion

Hi everyone. Welcome to the NPTEL course, Petroleum Economics and Management. I am Dr. Anwesha Aditya, your instructor for the course. So, here in module 8 of our course, where we are discussing Oligopoly and Game Theory. So, this is our lecture number 41 of the course, where we are discussing a very important part of our course, the Competition Versus Collusion using the very famous Prisoner's Dilemma Game.

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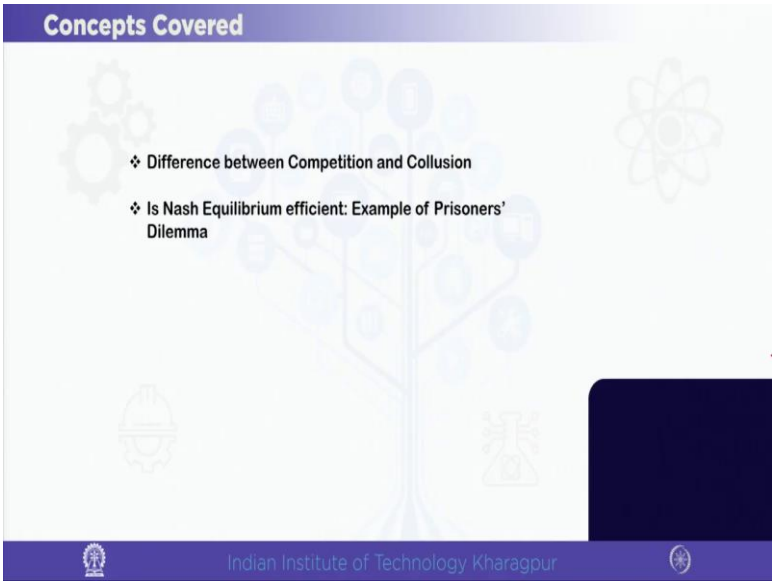

So, you see we have already discussed the concept of Nash equilibrium. We have already discussed many times why we need to study game theory to understand the oligopoly market, in particular the global or petroleum market. So, petroleum market, globally best resemble the cartel or the price leadership dominant firm model.

But as we have already seen in module 4, we have discussed why OPEC is Cartel, but it may not be very successful because OPEC could have exerted more market power, but

they have not done that. Many times we see that the individual member countries of OPEC, they supply more than what they agree to.

So, what is this cheating incentive? So, they are agreeing to a lower level of output. So, if a total output is less price will be higher, but ultimately they end up producing more. So, where from this cheating incentive come? So, here comes the very application of a very important game called a Prisoner's dilemma game.

So, in the last class, we have already discussed the very important concept of Nash equilibrium, which is path breaking in the area of game theory. And after the development of Nash equilibrium, we studied oligopoly models under the as an application of game theory or Nash equilibrium.

So, in today's class, we will be discussing on the second property of Nash equilibrium. If you remember in the first class, we have defined the Nash equilibrium, we have found out how to identify or how to solve the Nash equilibrium, but now we have to also see whether from Nash equilibrium, how to test for Nash equilibrium. So, that we will see by checking whether deviation from Nash equilibrium, it is profitable or not.

So, if it is a Nash equilibrium, then deviation is not profitable for the economic agents. So, we will do the Nash equilibrium test with the help of a very famous game and which is extremely relevant for our purpose of understanding the petroleum industry, is the Prisoner's dilemma game. And with reference to this game also, we will be studying the second property of Nash equilibrium.

So, Nash equilibrium has two important properties. One is that we can have multiple Nash equilibrium. So, this one we have already discussed with the help of the battle of the sexes game. Now, the second property is that the Nash equilibrium may not be efficient. So, that we are going to discuss with the Prisoner's dilemma game, ok.

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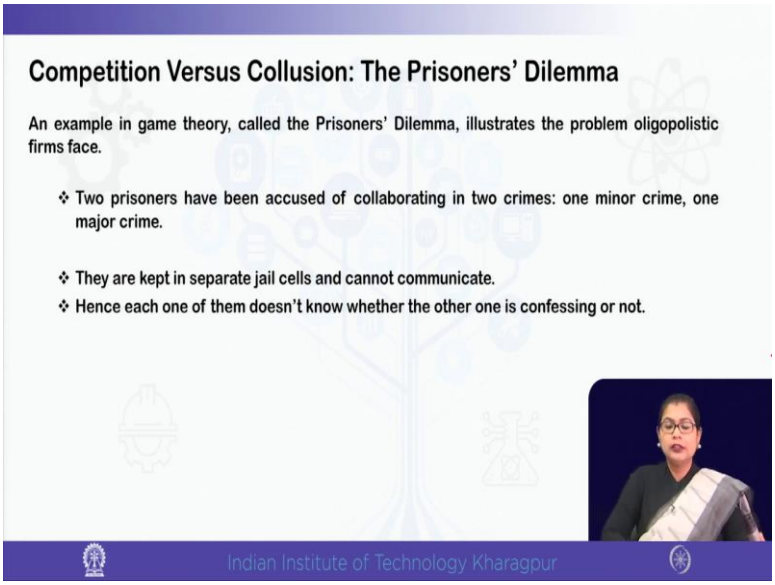

So, this is an example of game theory which actually best resembles the problem that the oligopolistic firms face, even the cartel firms also face, ok. So, first I will tell you the story and the background. See, the game of Prisoner's dilemma. It was developed, by two mathematicians of the Rand Corporation in 1950 - Flood and Dresher.

So, you see that is why I told many times that application of game theory is not limited to economics. So, it has application in mathematics, and field of social science, international relation. Many of the very famous games are developed by mathematicians or even other social scientist or people from other discipline apart from economics. It is wide application.

So, now this was developed in 1950. So, many specular that it was actually the time of the cold war. So, it was developed to emphasize on the strategic interaction or negotiation going on between US and the then Soviet Russia during the time of cold war. So, you see the importance of game theory in the context of international relation, international economics, international trade also. We will be discussing also the context of Prisoner's dilemma when it comes to trade policies.

So, for our purpose also for the oil market, it is extremely important. So, I request you that you pay attention and it will definitely you will be enjoying this Prisoner's dilemma story and how to find out the Nash equilibrium, and why the Nash equilibrium is may not be the best solution for all the players. So, that we are going to discuss with the game.

So, this in the original story there are two bank robbers, Elizabeth and Henry. So, here we are just saying prisoner 1 and prisoner 2. So, the story goes like this that there are two prisoners, prisoner 1 and prisoner 2. They have been accused of collaborating in two crimes, one minor crime and one major crime. And they are kept in two separate jail cells and they cannot communicate during the interrogation process. So, they cannot observe the action or the means the decision of the other prisoner.

So, when a particular prisoner, let say prisoner 1 is being interrogated, he or she does not know what prisoner 2 is, whether the prisoner 2 is revealing the crime or not. They cannot observe each other's interrogation process. So, each they do not know whether they are the other one is confessing or not.

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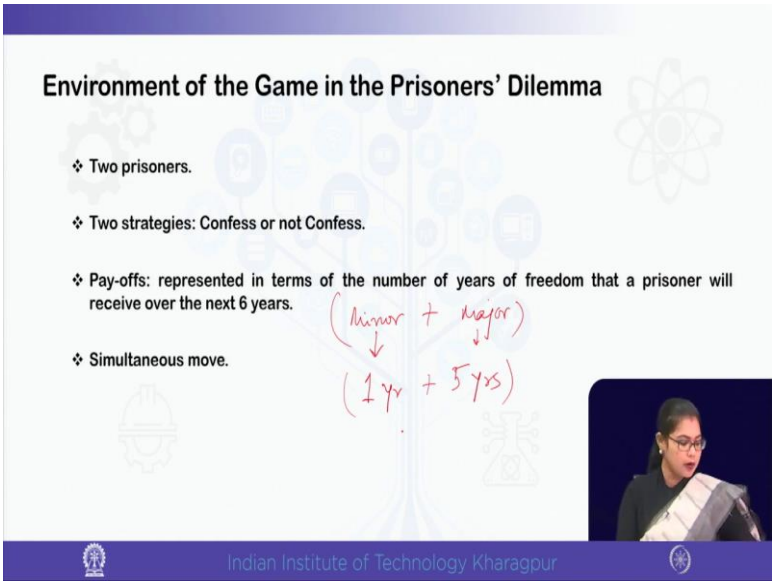

So, if I just specify the environment of the game, there are two prisoners. So, you remember in the environment of the game. What are the components? Number of players. So, here we have two prisoners. Second component in environment is the list of strategies. Now, you see here there are two strategies or two actions or decisions that can be taken by the two prisoners. So, that is either to confess the crimes or to not confess, ok.

And the third component in environment of the game is payoff. Payoff is the value associated with a particular action or strategy. So, here we represent; so, see the story

means there are different versions of the prisoner's dilemma game in many different books. It is written in many different ways.

Sometimes, the payoffs are written negatively in terms of the jail term. But I prefer I make it very simple ah. And we make the payoff, we are representing over here, the payoff written in terms of the number of years of freedom that a prisoner can get in the next 6 years. So, there are two crimes, you see minor crime and major crime.

So, suppose we are assuming that the jail term for minor crime is 1 year and the jail term for major crime is 6 years. Now, for minor crime, no needs to testify the crime. Means the prosecutor does not need anyone to confess for the minor crime. But for the major crime, sorry the jail term for the major crime should be 5 years. So, for jail term for the major crime is 5 years.

Now, but for to prove the major crime to convict one for the major crime, at least one of them should confess. So, that means, you see in total, what is the total number of jail terms, the maximum number of jail terms combining the minor and major crime can be 6 years.

So, what we are doing? Over here, we are writing the payoff just inversely. We are writing the payoff in terms of numbers of years of freedom that a prisoner will enjoy over the next 6 years because the maximum jail term can be of 6 years. So, that is the punishment. So, the freedom can be the next 6 years; how many years a prisoner can enjoy as free freely over the next 6 years period. Because 6 years is the maximum possible jail term.

So, minor crime plus major crime inclusive, the maximum possible jail term can be of 6 years. And of course, it is a simultaneous move because both of them are interrogated at the same time and they cannot observe each other's action. And we are sticking to one short. So, it is played only once. Because later I will tell you the implication what will happen if the game is repeatedly played. So, this is the story based on the story of the prisoner's dilemma. This is the environment of the game, ok.

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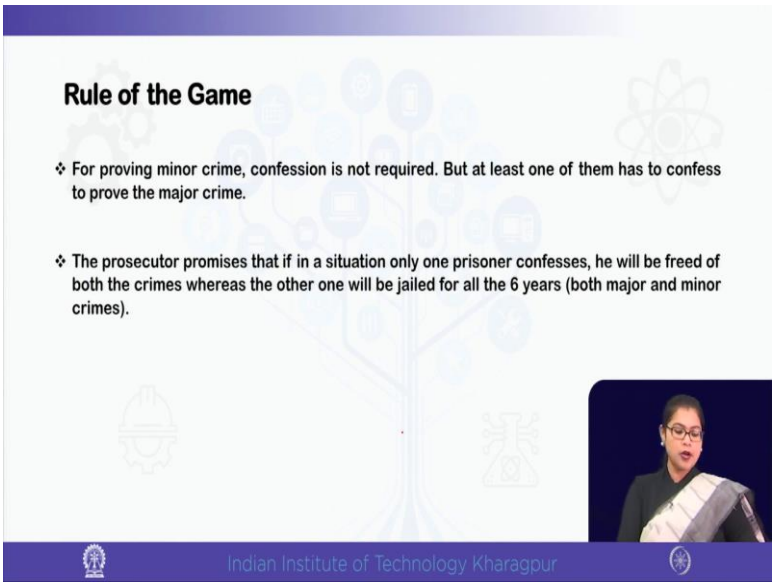

Now, just, so now, I mentioned that the rule of the game is that the prosecutor says that for proving minor crime, no confession is required. But for proving major crime at least one of them needs to confess. If both of them confess, then also the major crime is proved, but at least one should confess. So, that means, if none of them confess, major crime cannot be proved. So, they will be freed from the jail term of 5 years associated with the major crime. So, this thing we should keep in mind.

Now, the story goes like this, that the prosecutor promises that and this it is because of this rule we get the cheating incentive. So, listen to this very carefully. So, the prosecutor promises that if in a situation out of the two prisoners, only one confesses he or she will be freed from both the crimes, both major and minor crime, the one who is confessing.

So, that means, he or she will receive freedom of all the 6 years over the next 6 years period and that is our payoff. So, the maximum payoff can be 6 years, freedom over the next 6 years, right. So, in a situation if one is confessing, the other one is not confessing. So, the confessor will go free for all the 6 years. But the one who is not confessing will be jailed for both major and minor crime.

So, the one who is not confessing will be jailed for all the 6 years. So, that means, in terms of the payoff he or she, the not-confessor will be receiving 0, nothing.

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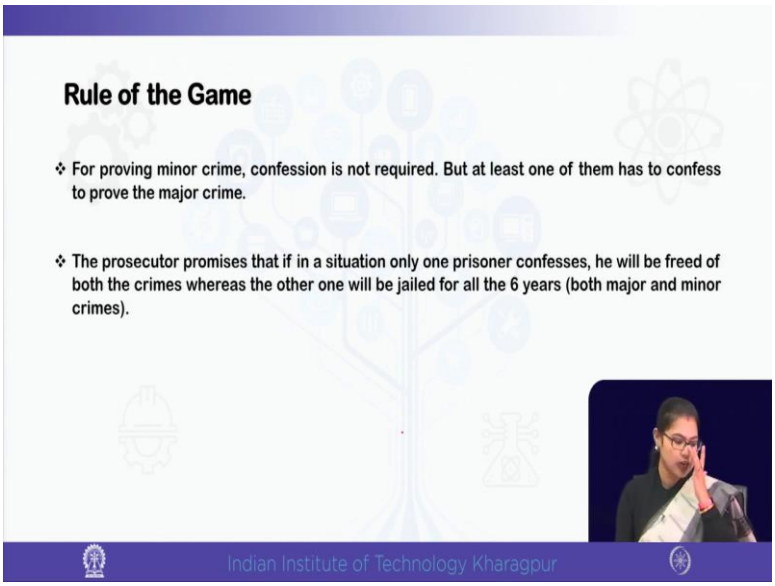

So, that means, he or she will be jailed for all the 6 years.

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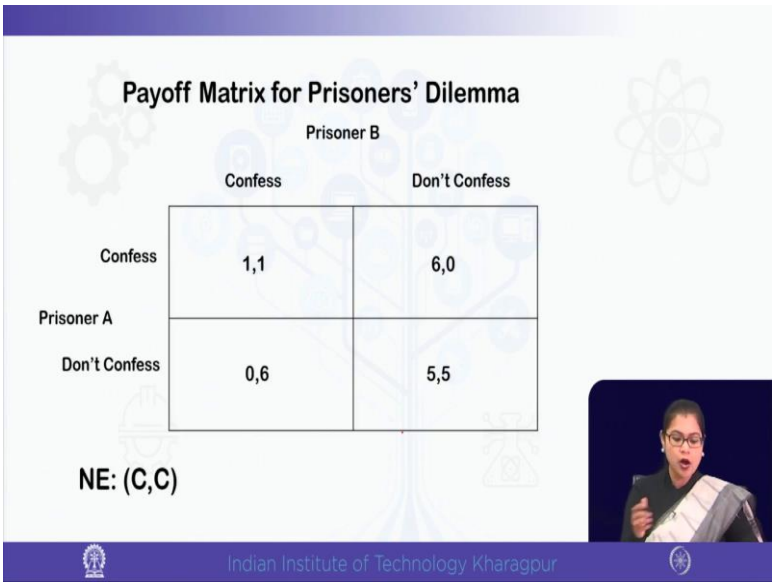

So, with this we are now representing the payoff matrix for the Prisoner's dilemma game in the a normal form a static strategic form game, it is a static game.

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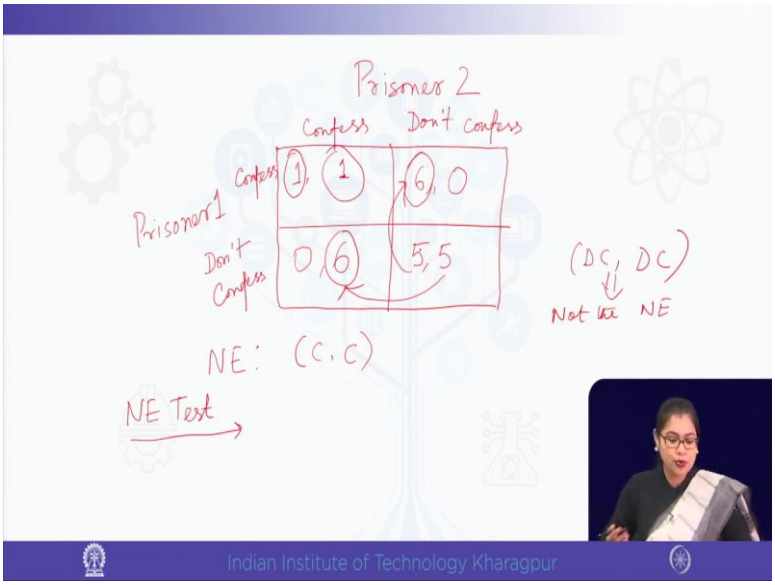

So, again, just like the battle of the sexes, let me draw the plot the game for your understanding. And let us find out the Nash equilibrium and then you do the Nash equilibrium test also. So, you see we are writing here prisoner 1 and prisoner 2. So, what are the strategies? Strategy is a to confess. For prisoner 1, there are two strategies either to confess or to not confess or do not-confess. Again for prisoner 2 also the strategy is a same either to confess or do not confess, ok.

Now, what are the payoffs? You see we have already told that the payoffs are represented in terms of the years of freedom. So, if both of them confess, so, what will happen? They will be; so, the major crime will be proved because by the rule of the game, if the one needs to confess to prove the major crime.

So, if both of them confess, of course, the major crime will be proved. So, they will be getting jailed for 5 years because both of them for both of them the major crime is proved. So, they get jail of 5 years and they receive freedom of 1 year each. So, 1, 1 because both of them are confessing, ok. So, we know already that the first one correspond to the payoff of player 1 or prisoner 1 and the second number correspond to the payoff of the prisoner 2.

Now, if both of them do not confess, so what will happen? If both of them do not confess, so; that means, then the you see what we have written over here as the rule of

the game. If both of them confess, so the major crime is proved. If none of them confess, so major crime cannot be proved.

So, that means, they will be jailed only for the minor crime and the jail term for the minor crime is 5 years. So, that means, they will be receiving freedom from the major crime, they cannot be penalized for the major crime. So, they will be receiving freedom of all the 5 years.

So, none of them confesses means the major crime cannot be proved and they receive freedom of 5 years. So, they are jailed only for the minor crime for which you do not need anyone to confess. So, this lower right cell correspond to the situation where none of them are confessing and they get payoff of 5, 5 years of freedom each. And upper left cell correspond to the situation both end up confessing and they get 1, where 1, 1 year of freedom each.

Now, what about the two other cells? So, if we now look at the lower left cell, what happens? Here you see this one correspond to the prisoner 1 not confessing where prisoner 2 is confessing. So, you see the rule of the game that the prosecutor promises that if only one confesses, confessor will go completely free and the one who is not confessing will be jailed for all the 6 years, for both major and minor crime. And one who is confessing will be freed for all the 6 years.

So, here what is happening? Prisoner 1 is not confessing, but prisoner 2 is confessing. So, prisoner 2 will be benefiting, but prisoner 1 gets all the punishment. So, that means, prisoner 1 is jailed for all the 6 years. So, in terms of freedom prisoner 1 is not receiving any freedom of in the next 6 years. So, prisoner 1 is receiving a payoff of 0, whereas, since prisoner 2 is confessing, so prisoner 2 is getting a payoff of 6, ok.

Similarly, you can now see the last cell that is the upper right cell where prisoner 2 is not confessing, but prisoner 1 confesses. So, it is just opposite to what we got in this lower left cell. So, here just the players, prisoners are just opposite. So, here prisoner 1 will get all the benefit because prisoner 2 is now jailed for both the crimes.

So, prisoner 1 will be freed for the next 6 years and will receive a payoff of 6 and prisoner 2 does not receive any payoff. That means, it is not receiving any freedom and its jail for all the 6 years. So, you can see, so we are writing this payoffs depending on

the rule of the game. So, we have described the prisoner's dilemma game in terms of the strategic form game.

Now, what is the next step? Next step is to find out the Nash equilibrium. How do we do that? We know that we find out the Nash equilibrium. We have to find out the best response. So, best response of each player given the strategy or action of the other player.

So, you see, we will be starting with prisoner 1, so we have to find out the best response of prisoner 1 given the strategies of prisoner 2. So, let us first concentrate on the left cells, ok left column. So, given that prisoner 2 is confessing, let us now concentrate on the prisoner 1's payoff. So, let us find out what is the optimal response of prisoner 1 given that prisoner 2 is confessing.

So, we can see that given that prisoner 2 is confessing, prisoner 1 is getting 1 year of freedom by confessing and prisoner 1 is getting no freedom by not confessing because prisoner 2 is confessing. So, we already know that 1 is of course, greater than 0. So, the best response of prisoner 1 is to confess, if prisoner 2 is also confessing.

Now, what is the best response of prisoner 1? If prisoner 2 does not confess. So, if prisoner 2 does not confess; that means, we now compare the values, the payoffs of prisoner 1 in the right cells. So, we compare the payoff of prisoner 1 from confessing and not confessing given that prisoner 2 does not confess. So, we see that prisoner 1 gets 6 years of freedom by confessing and 5 years of freedom by not confessing if prisoner 2 does not confess. So, of course, 6 is greater than 5, right.

That means, what? So, we see that again if prisoner 2 does not confess, the best response of prisoner 1 is to confess. So, you see what we conclude from this. Does not matter what the other one is doing. It is always the best response of prisoner 1 is to confess. So, always prisoners 1, prisoner 1's best response is to confess irrespective of what prisoner 2 is doing confessing or not confessing.

Now, we will be finding out the best response of prisoner 2. So, now we compare the values of the second value which correspond to prisoner 2. So, given that prisoner 1 is confessing, so if we now look at the first row, so we compare the payoff of prisoner 2

from confessing or not confessing. So, we see that prisoner 2 gets 1 by confessing and 0 by not confessing.

So, of course, 1 is greater than 0, so given that prisoner 1 is confessing the best response of prisoner 2 is to confess. So, if we now look at the row below, so there we see that if prisoner 1 does not confess, the best response of prisoner 2 is to confess, because by confessing prisoner 2 is getting 6 years of freedom and by not confessing prisoner 2 is receiving 5 years of freedom, and 6 is greater than 5.

So, you see, we again we see that does not matter what prisoner 1 is doing the best response of prisoner 2 is to always confess. So, what do you find from this? That best response of both the players is to always confess does not matter what the other one is doing. Now, you can easily find out the Nash equilibrium. So, Nash equilibrium is the strategy profile where the best responses match.

So, what is that here? C, C, confess, confess. So, both of them end up confessing. So, again let me point out that, we do not write the Nash equilibrium in terms of the payoff, but we write it in terms of the strategy profile. So, confess, confess is the unique Nash equilibrium in the prisoner's dilemma game. So, no longer we have multiple Nash equilibrium. We have an unique Nash equilibrium.

Now, what do you think? Are the players doing the best? Are the players doing the best given the situation, given the circumstances? Is there any possibility that they could have gained a higher payoff? So, you can see that they are getting much lower payoff by confessing, right? They are getting only 1 year of freedom whereas, you can now compare this with the do not confess, do not confess strategy profile, ok. You see if both of them do not confess, they receive a freedom of 5 years each.

So, which one is greater 1 or 5? Of course, 5 is greater. So, that means, they could have done better by not confessing, but you see this do not confess, do not confess is actually not the Nash equilibrium. It may be a better outcome for both of them and that is why we say that and that is the second property of Nash equilibrium that it may not be always the optimal solution, ok. The players could have done better, but they are not doing that.

So, we will discuss that, but before that let us do the Nash equilibrium test that was remaining in our battle of the sexes game because this Nash equilibrium test will be very

relevant in this case. So, what are the steps in involved in finding out the Nash equilibrium? So, we first find out the best responses of each of the player, given the strategy of the other player and then Nash equilibrium is the strategy profile where the best responses match.

In the second step, we do we carry out the Nash equilibrium test. What is the Nash equilibrium test? We test whether deviation is profitable or not. So, you see how we define the Nash equilibrium? So, only Nash equilibrium has this very important property that if it is a Nash equilibrium, then no one will have an incentive to deviate.

So, what let us see, with the example of prisoner's dilemma if they have an incentive to deviate from this confess, confess strategy. So, this is, what we are doing? We are starting with the strategy profile, ok. So, let us look at the payoffs over here. So, you see given that prisoner 2 is confessing, prisoner 1, does he or she have any incentive to deviate from confess?

No, because you see by if prisoner 2 is confessing, prisoner 1 gets payoff of 1 by confessing and gets nothing by not confessing and 1 is of course, greater than 0. So, prisoner 1 being rational will she or he be interested to deviate from confession? No. So, prisoner 1 does not have any incentive to deviate from confess. If prisoner 2 is confessing, so there is no incentive of deviation.

Let us check what happens for prisoner 2. Given that prisoner 1 is confessing, is there any incentive for prisoner 2 to deviate from confess? If prisoner 1, prisoner 2 deviates from confess, given that prisoner 1 is confessing, then prisoner 2 is worse off. So, there is no incentive of deviation, right. So, you see that here the Nash equilibrium, the unique Nash equilibrium satisfies the Nash equilibrium test that no player has incentive to deviate.

But now, you can check the with the other strategy profile which is the you can say this is the Pareto optimal solution, this do not confess, do not confess. So, if we now look at this strategy profile do not confess, do not confess DC, DC. So, we can see, it can be efficient, it can be giving both of them higher payoff, but this is not the Nash equilibrium.

Why? Because first of all you see the best responses do not match there and also we can see that there will be incentive of deviation. How? I am just removing this one. So, and see how there can be an incentive of deviation from DC, DC, ok. Now, if we stick to this DC, DC cell, so what we see now? Given that prisoner 2 is not confessing, now you compare whether prisoner 1 has any incentive to deviate.

And what you see? Yes, prisoner 1 has an incentive to deviate, right. Because if prisoner 2 is not confessing, so you see if prisoner 1 confesses, so he or she gets 6 because that is by the rule of the game. If the other one is not confessing and you are confessing, you are freed from both the crimes.

So, you see given the prisoner 2 is not confessing, prisoner 1 is better off by confessing. So, will prisoner 1 stick to this do not confess strategy? No. So, prisoner 1 we can see has incentive to deviate. Earlier we saw that C, C and Nash equilibrium C, C, no one has an incentive to deviate, but with this we can now check for prisoner 2 also.

So, given that prisoner 1 is not confessing, now you check for prisoner 2. Again, you see prisoner 2 will be better off by confessing because by confessing prisoner 2 gets a higher payoff of 6. And by not confessing he or she was getting a lower payoff of 5. So, that means, what? That means, DC, DC cannot be is not the Nash equilibrium. Because both of them have incentive. They have incentive to deviate from DC, DC strategy profile. So, it cannot be sustained as the Nash equilibrium.

So, you see how individual interest, so self-interested individuals they are driven by their own interest and that can yield a suboptimal outcome. They could have done better, but they cannot do so, why? It is because of the rule of the game you see there is a cheating incentive.

So, this cheating incentive comes from here that if I do not confess and the other one is confessing, the other one will give the higher payoff and I will be penalized. So, they cannot trust each other right and this is happening because they cannot communicate during the time of interrogation.

So, if they could have communicated then they could have cooperated also. But since they cannot communicate during the time of the interrogation, so they cannot observe each other's choice and you see the prosecutor is giving the incentive of confession. So,

if you confess and the other one is not confessing, so you go free and the other one will be punished.

So, you always think that your the other one will confess; and if you are not confessing, so you are jailed for all the 6 years. So, you will be punished. So, you have an incentive to deviate you see.

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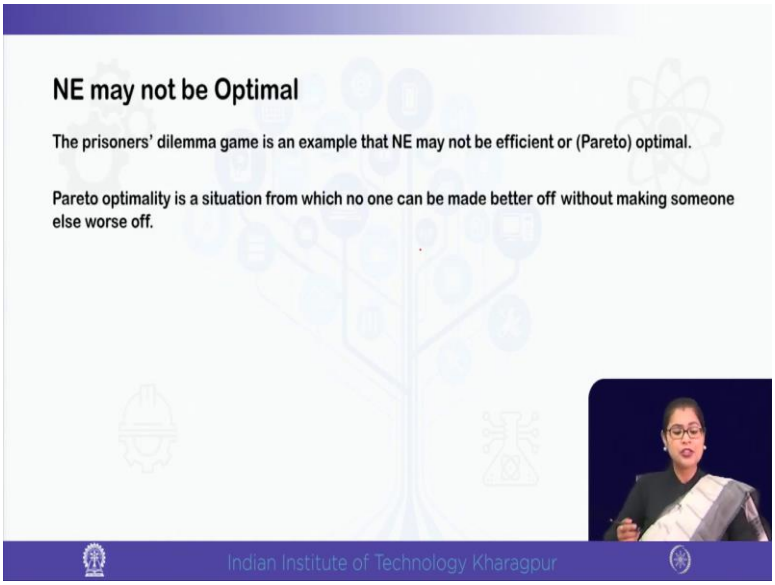

So, it is a prime example that the Nash equilibrium may not be efficient or Pareto optimal. So, Pareto optimal it is a situation where no one can be made better off without making someone else worse off. So, you see you can say that this do not confess, do not confess strategy profile that may be a Pareto optimal because this is the best solution here means in terms of the payoff, both of them are getting 5, 5, so if you add.

So what will be the total number of years of freedom in do not confess, do not confess? That is 10 years. And what is the total number of years of freedom in confess, confess? That is 2 years. But you see this Pareto optimal may not be the Nash equilibrium and the Nash equilibrium is not the Pareto optimal.

So, that is why we can say that the Nash equilibrium cannot be the, may not be always the Pareto optimal that is the property second property that Nash equilibrium may not always be the most efficient outcome. But this is the Nash equilibrium, so it will be the realistic one, not the efficient outcome, ok.

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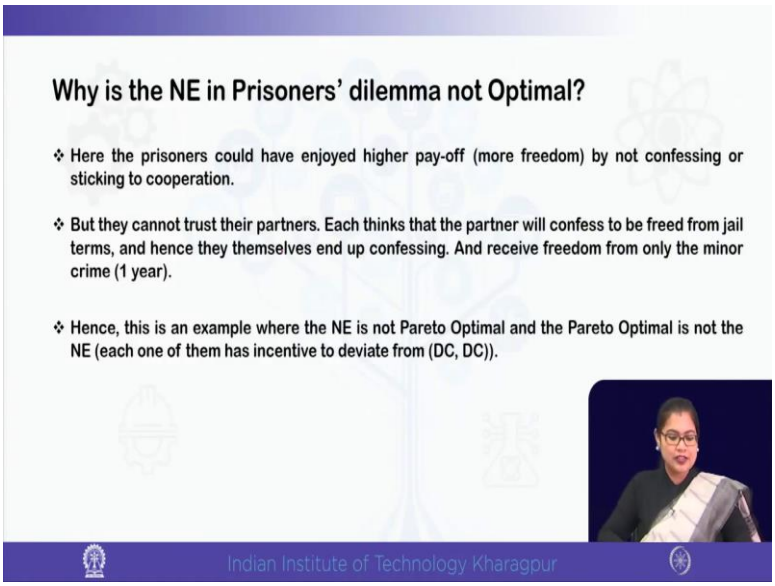

So, you can understand the cheating incentive. So, the prisoners could have enjoyed a higher payoff of more freedom by not confessing or sticking to cooperation. Confessing means, not confessing means cooperating, but they cannot trust their partner. So, each of them think that I will not confess, so I will be jailed for all the 6 years jail term. But the other one will just go free. So, it is because of lack of trust. So, we are getting that non-cooperation is the outcome, ok.

So, here we see that it is not a Pareto optimal one and the Pareto optimal one is not the Nash equilibrium, because from the Pareto optimal solution of DC, DC both have incentive to deviate.

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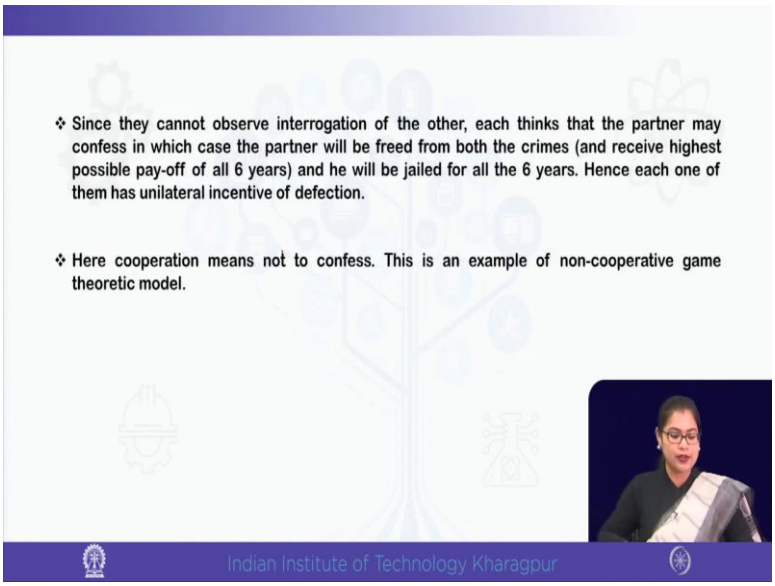

So, and that is happening as I mentioned that they cannot observe each other during the interrogation process. So, each things that the partner may confess and in which case the partner will be freed and he or she will be jailed for all the 6 years. And so, each of them have unilateral incentive to deviation. So, the cooperation means not to confess. So, you can easily see that this is an example of non-cooperative game theory or non-collusive model.

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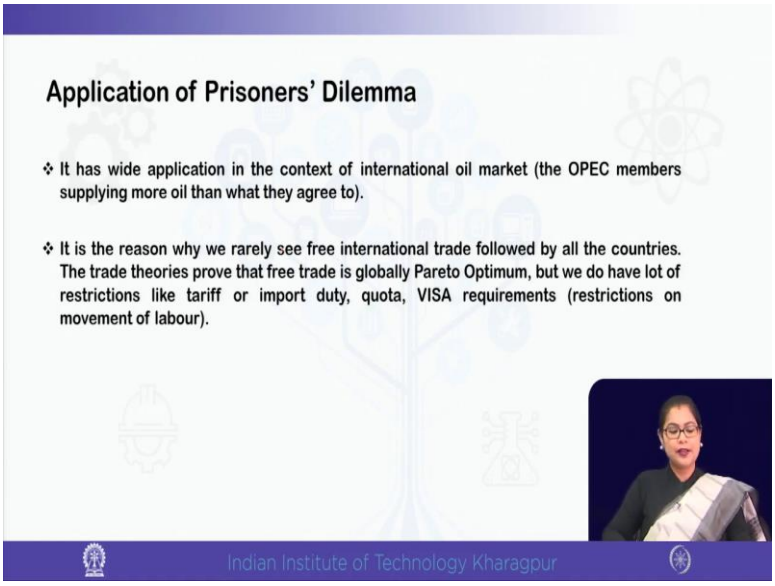

And it was wide application in the context of the global petroleum industry. As we have already seen that the OPEC members, they actually they agree to supply a particular output level, but they end up supplying more because they also have this cheating incentive. The thing that if I increase the output slightly so, I will be able to sell more I will be earning more revenue.

And we have already seen with empirical data that how the OPEC countries they are reliant on oil rents, they are reliant on export earning from exporting oil. So, that is why the thing that if I slightly increase the output so, I can earn more. So, you see there is there is incentive of deviation, ok.

So, it is very important, the Prisoner's dilemma game is very important to understand the complexities of the global petroleum industry. And that is why we see that OPEC could have exerted more price power given its market share. But it has not done so, because they end up supplying more. And we know by the basic understanding of demand and supply, if every one of them are supplying more total output will be high price will be low.

And that is precisely the reason why OPEC has not increased the price so much. Otherwise price of oil could have increased even further. We have already seen the price movement of oil and role of OPEC. So, you can now understand the cheating incentive of the OPEC member countries with the application of Prisoner's dilemma. Prisoner's dilemma is also applicable in the context of international trade also.

If you remember, when we classified game in terms of value of the game, I mentioned that there are situations where we can have a positive sum game. So, total value of the game can be positive; that means, there are scopes in reality where all the economic agents can gain at the same time. So, gain may not be coming at the cost of the other, but so, so one prime example of a positive sum game is multilateral free trade.

So, there are trade theories which tell that if all the countries follow free trade so, that will be globally optimum, that will be welfare maximizing for the entire world economy. But you see we do have lot of trade restrictions. We hardly have free trade. So, we have lot of tariff, quota, movement on labor and capital.

So, these trade then if we theoretically say that multilateral free trade or global free trade is Pareto optimal. So, why do we have trade policies? So, again it is the incentive the Prisoner's dilemma motive. So, global free trade is Pareto optimal, the welfare of the global economies highest possible.

But as I mentioned in the previous lectures also individual countries can gain further by imposing trade policy. Can their welfare individual countries welfare can increase above the free trade level if they impose trade restrictions, trade barriers or trade policies. But now what will happen?

This additional gain over free trade, this extra gain will come from the partners. So, your gain will be at the cost of your trade partner. So, it is not globally Pareto optimal you see. So, your gain is coming from other's loss, your gain is actually other's loss. So, but you see the individual countries are maximizing their own welfare and that is why they have unilateral incentive to deviate.

So, now you can also then ask that how do we then sustain cooperation? We also have a lot of trade free trade going on; means trade agreements, and that then you see the importance of institutions like World Trade Organization who want to promote free trade or even you might have heard about the trade agreements, Free Trade Area or FTA or regional trade agreement.

So, the countries can enter into negotiations or agreements where they mutually follow free trade or they decide or agree upon to eliminate or reduce the trade barriers or remove the trade restrictions. So, unless there is some punishment mechanism or some regulatory authority, it is difficult to follow free trade. But even then even after having WTO or trade agreements, we have lot of trade policies in place.

And the countries also come up with new type of trade policies because WTO has already put restrictions on imposing taxes like tariff or imposing quantity restriction like quota policies. So, countries come up with various ways of regulating trade like a quality regulation, rules and regulations regarding to environmental standards, use of child labor. And the developing countries say that these are basically ways of protects protection is in protecting the domestic economies.

So, it is basically the incentive of going for means trade policies nothing but the Prisoner's dilemma incentive, so cheating incentive. Because of this unilateral incentive of achieving a higher level of welfare than following a free trade policy gives the countries the incentive to impose trade barriers. So, you see.

Another point is that you may then ask that we do see cooperation also in reality that is also possible because one limitation in this model was that we are considering the game to be just one shot. It is just one shot. So, in one shot game you do not think about the future. You are not interested about the future. So, you just think about the present. So, you cannot trust your partner.

But we do see cooperation in real life also and that is how business also goes on. I think in one of the classes I was taking example where the many firms firm in the manufacturing unit can take raw materials from agriculture units and we have this kind of business relation going on over generations.

So, many times we see that we can sustain cooperation in when the game is played many times in dynamic games. So, if the same prisoner dilemma game is played many times. So, the players the prisoners will know that again in next period they will be cooperating, they will be collaborating in committing the two crimes. So, they may not be cheating, they can cooperate with each other.

So, there are theorems, called the folk theorem which tells that it depends on how you value future. So, you can calculate the discount rate and you can see if they value the, players value future. So, we can find out that cooperation can be sustained. So, this DC, DC which is the Pareto optimal solution can be sustained in a dynamic framework, right.

You can think of the famous movie Sholay, where Jay and Veeru they committed many crime, right. So, and they trusted each other because they know that even after coming out from the jail, they will again collaborate to for the next crime. So, that is why you see you we do find cooperation in reality, so if the game is played many times.

And in reality as I mentioned earlier also see we may not know, this see we are not immortal, but we cannot we do not know the last stage when a game is played, right So, this class, this course let say it is a finite game because we know that we have a fixed number of classes, 60 classes. So, it is a finite game.

But in otherwise you see the games in reality are infinite games because they may not be played infinite times, there may be a last stage, but the last stage is uncertain. Like the example I was giving, this business relation over generations. So, there may be a last stage, but you do not know the last stage. When you know the last stage, it will be difficult to sustain cooperation because you know that you will be cheated in the last stage.

So, if you fold back, so you will be starting to cheat from the very first stage. So, we may be able to sustain cooperation if the games are played infinitely. So, in finite game even it is dynamic or repeatedly played, it is difficult to sustain cooperation. But in infinite game you do not know the last stage, so there we find out the possibility of cooperation like Jay and Veeru did in the movie Sholay, ok.

So, there are these theorems, folk theorems those who are interested you can definitely study those. But for our purpose we are just sticking to the one-shot Prisoner's dilemma game. And the application of Prisoner's dilemma is so relevant for our purpose to understand the global petroleum industry.

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So, with this, I end today's lecture. So, we compared between collusion and competition in a game theoretic framework using the very famous Prisoner's dilemma game. So, we depicted the game, we found out the unique Nash equilibrium which is not the Pareto efficient one in the Prisoner's dilemma game. And we saw the application of Prisoner's

dilemma, in the context of global petroleum industry, in the context of international trade.

And we also briefly discussed that cooperation might be sustained when the game is repeatedly played, ok.

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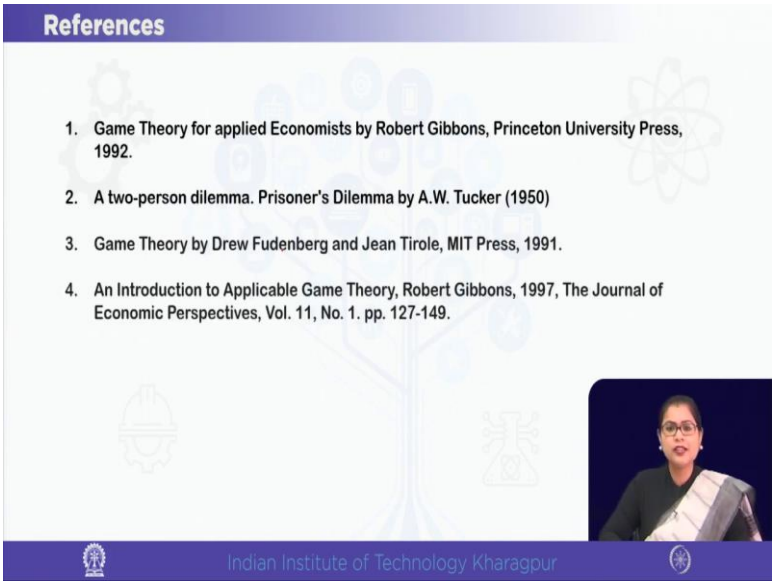

So, these are the main references Gibbons, Fudenberg and Tirole, and the other you can also see the paper of Tucker. Actually, as I mentioned that originally the game was developed by mathematician, but they did not give the name of Prisoner's dilemma. That name was given by Tucker. So, we have also referred to the original papers. So, I request those who are interested, go through the original papers.

So, I actually be hope that this course, enables you, means this course helps you to get interest in this area, so you also explore these things yourself. Because it is not possible to cover all the aspect because it is so complex, the global petroleum industry is so complex. So, you can also explore on your own. But the course is should be the triggering point of generating your interest for further studying or exploring the global oil market.

So, thank you very much. Look forward to see you in the upcoming lectures.