Introduction to Market Structures
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Lecture No. 29
Bertrand Competition with Capacity Constraints

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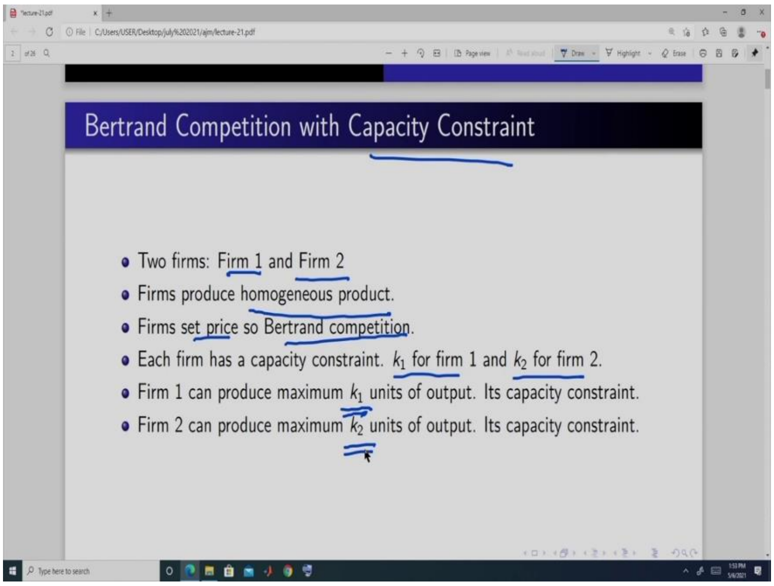

Hello everyone, welcome to my course introduction to market structures. So, today we are going to do Bertrand competition with capacity constraint. Now, we have already done Bertrand competition what is generally done in Bertrand competition. In Bertrand competition we have 2 firms and each firm chooses a price and the firm which sets the lowest price everyone or all the consumer buys from that firm.

So, there is a competition to set the price and we have seen that when there is no fixed cost and the marginal cost are same the both the firm sets the prices at price is equal to marginal cost and that is Bertrand paradox. Next when there are fixed cost we have seen that there is no pure strategy Nash equilibrium and when we have different marginal cost and 0 fixed cost at that in this situation also we see that there is no pure strategy Nash equilibrium.

Now, we introduce a new thing in this Bertrand competition and that is capacity constraint. What do we mean by capacity constraint? Capacity constraint means that the firms cannot produce whatever amount of output it wants to produce. It has some constraints on the output it can produce. So, to study this we have taken a duopoly market that is there are two firms firm 1 and firm 2. Both the firm produces homogeneous product that means the output whether

I buy from a consumer buys from a firm 1 or firm 2, it does not matter what the firm produces same type of good, okay.

And since each firm sets price so it is a Bertrand competition both the firms set a price. And now we specify the capacity. So, each firm has a capacity constraint that is k1 for firm 1 and k2 for firm 2. What do we mean by this capacity constraint? That means that firm 1 can produce maximum k1 units of output. So, it is given by its capacity and firm 2 can only produce maximum k2 units of output it cannot produce more than firm 1 cannot produce more than k1 units of output and firm 2 cannot produce more than k2 units of output. So, that is, this is given us capacity. Now, we specify the cost.

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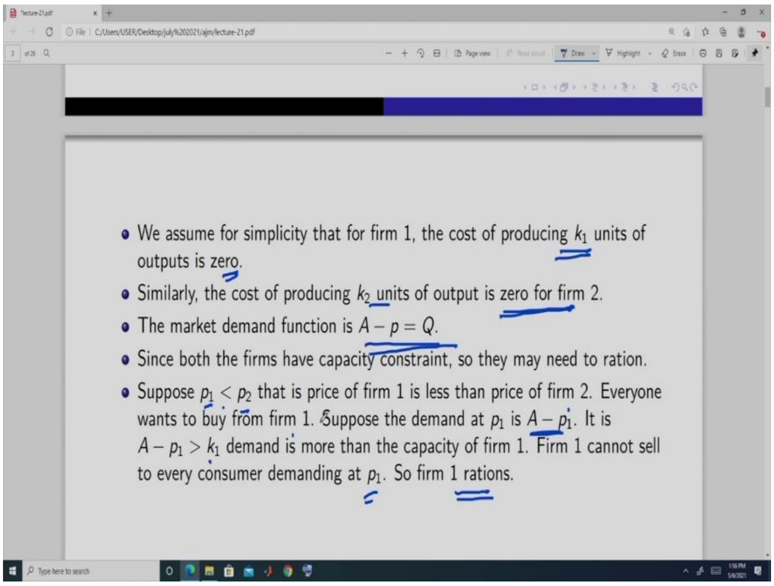

So, here we assume for simplicity that the cost is 0 for firm 1 for producing k1 units of output, its cost is 0. So, it does not incur any cost to produce this output. This is actually a simplest to simplify the game a computation that we are going to do later on to find Nash equilibrium we make this assumption. Similarly firm 2 to produce k2 units of output it does not incur any cost, okay. And the market demand is a linear downward sloping demand curve and that is this- A-p=Q and more or less we have assumed this demand curve till now.

So, this is our demand curve. Now here since each firm has a capacity constraint. So, they may have to do something called rationing and what do we mean by that? So, it is suppose price of firm 1 is p1 and price of firm 2 is p2. And price of firm 1 is less than the price of firm 2, okay so this. So, what will happen everyone will want to buy from firm 1 because the price of firm 1 is less than the price of firm 2.

Suppose the aggregate demand a market demand at price p1 is this- $A - p_1^*$ and it is such that the demand is more then the capacity of firm 1. So, firm 1 cannot satisfy the demand that is generated in the market. So, firm 1 cannot sell to every consumer that is demanding at this price. So, it can only satisfy the demand of only a fraction of that or some portion of that some will be left untouched or we will not be served by firm 1. So, firm 1 has to do something called rationing. So, it is something like this suppose you have 4 chocolates and you have to distribute it among suppose 7 children.

Now, you cannot divide this chocolate. So, these 5 chocolates how you have to you have to choose 5 out of this 7 children how are you going to do it? You will use some rule. So, here also we will specify certain rules to ration how to select which consumers are going to get this product from firm 1, okay.

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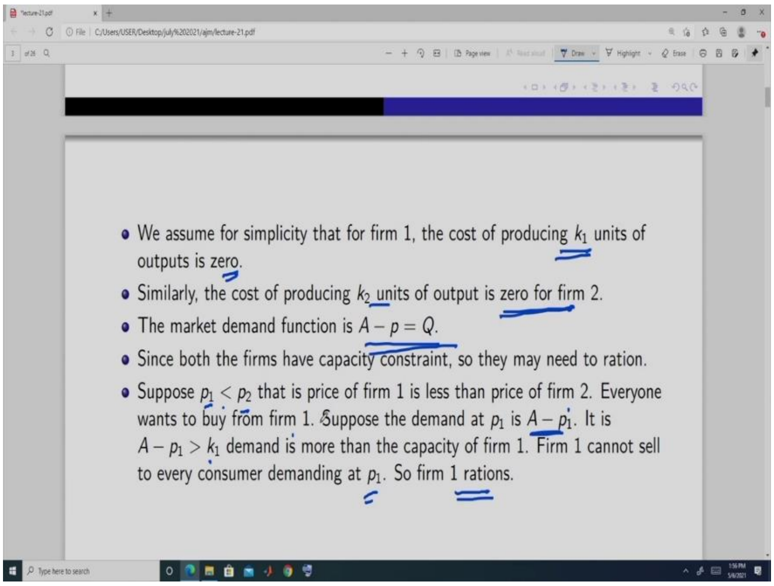

So, we have to specify a rule and one rule is this efficient rationing. So, efficient rationing says that those who value the good most they are going to get the that good from the low price firm. So, in this case firm 1 is going to serve or going to serve the demand of those consumers whose demand or whose valuation is highest or maximum and what do we mean by evaluation it means the willingness to pay. So, it means those whose willingness to pay is maximum or is highest they are going to be served first.

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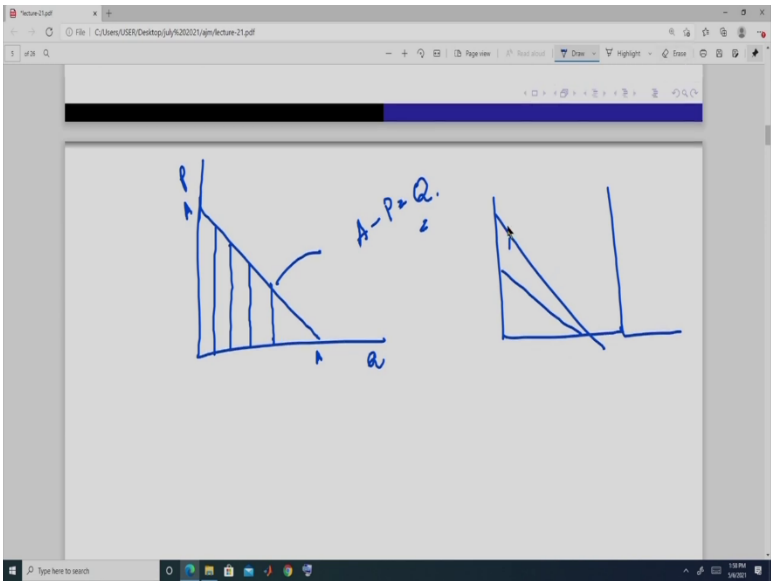

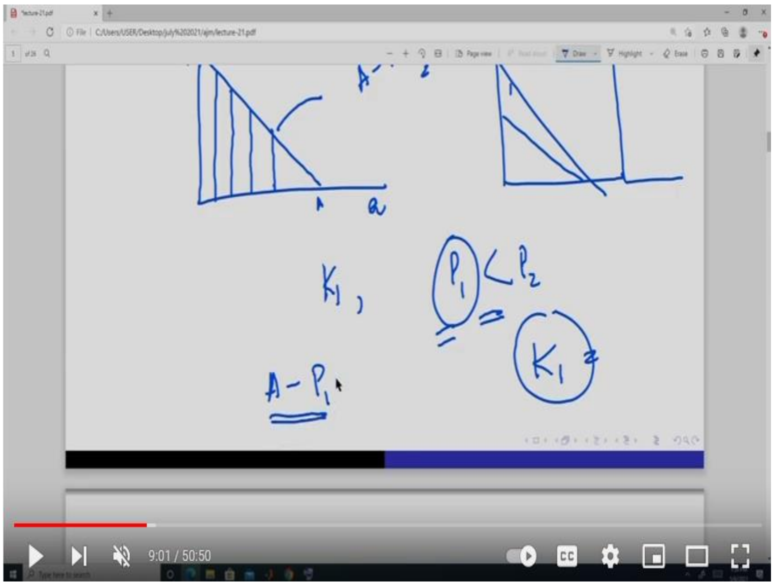

So, in terms of suppose in this case, our demand curve is this. Suppose this is q this is p, in this axis p this is A this is A. So, demand curve is this, right? This heights are giving the maximum willingness to pay by a consumer, okay. Now, this is a market demand curve. So, this demand curve we have got from horizon till summation of individual demand curves, okay. So, at so if you want this quantity what is the maximum it is willing to pay it is generally if we take individual demand curve of individual person then it is given by this height.

But here for simplicity we will assume that suppose this only gives you that willingness to pay. So, there may be some consumers who are willing to pay so, it may be something like this there is this one demand curve this is another demand curve and we have got the market demand curve firm horizontal summation of these two demand curves. So, that these demand curves everyone so, each individual whose demand curve is this their willingness to pay is higher than this something like this we will get, okay.

So, here so, capacity of firm one is this and we have assumed that this is the situation suppose- $P_1 < P_2$. So, everyone wants to buy from firm 1 since the price is less. But firm 1 can only sell this much amount only satisfy this much quantity demanded-K_1. And what is quantity demanded at this it is total demand is this-$A - P_1$.

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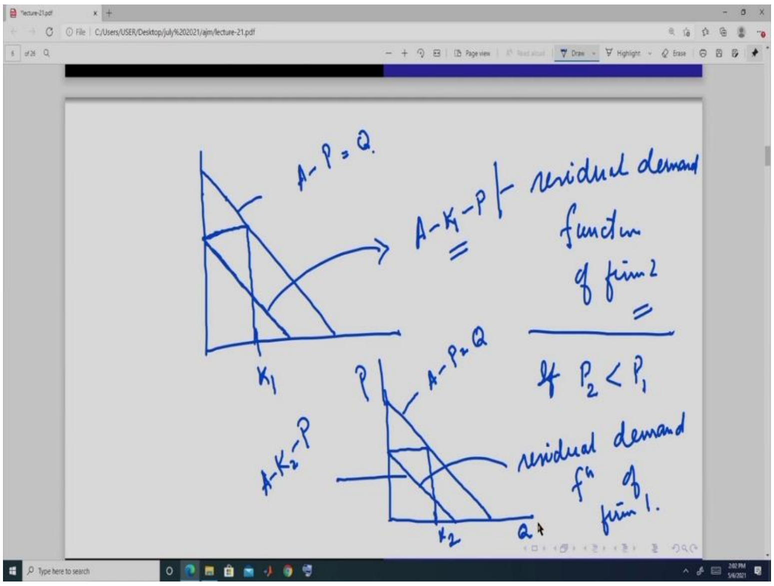

So, from this demand curve, what do we get is? So, first K units are going to be sold to those who value the goods maximum. So, this demand curve is something like this- $A - K_1 - P_1$.. This is the residual demand curve of which is faced by firm 2. So, firm 1 is always going to sell this much at each prices. So, if the price is below this price then only it can sell its full capacity that is k1 otherwise if the price is here then it will be able to sell only this much amount of quantity if here it is only this much.

So, for prices less than this it is going to first sell this much so, firm 2 whose price is higher than the price of firm 1 is going to get this demand curve. So, from this demand curve we remove this much quantity and what is left is this that is being served by firm 2, okay. So, this is how the effect of rationing. So, what we do that when price of suppose price of firm 2 is less than the price of firm 1. So, in that case here it will be something like this. So, if price of firm 2 is less than price of firm 1, so in that case so firm 2 is going to sell the first k2 units to those who value it maximum.

This is the residual demand function of firm 1 in this situation this. So, this is A minus k2 minus p- $A - K_2 - P_1$, okay. So, P is here Q is here, okay. So, now I hope you have understood what do we mean by the rationing So, rationing here when the moment a firm rations it means it will only serve those consumers whose valuation is high. Now how they are going to identify that we are not bothered about it. So, we are not modeling.

So, that is a very valid question and it is a very difficult question also to set to address. But we are not addressing it here we have address such kind of thing when we were doing price discrimination in the case of Monopoly market. But here we are assuming that suppose firm 1, if it sets a price lower than the price of firm 2, it can identify the buyers who is valuing more and who is valuing it less, okay.

And if firm 2 sets a price lower than the price of firm 1, then it can identify the buyers in terms of their valuations, okay. We assumed that. So, now we come to the demand function of each firm.

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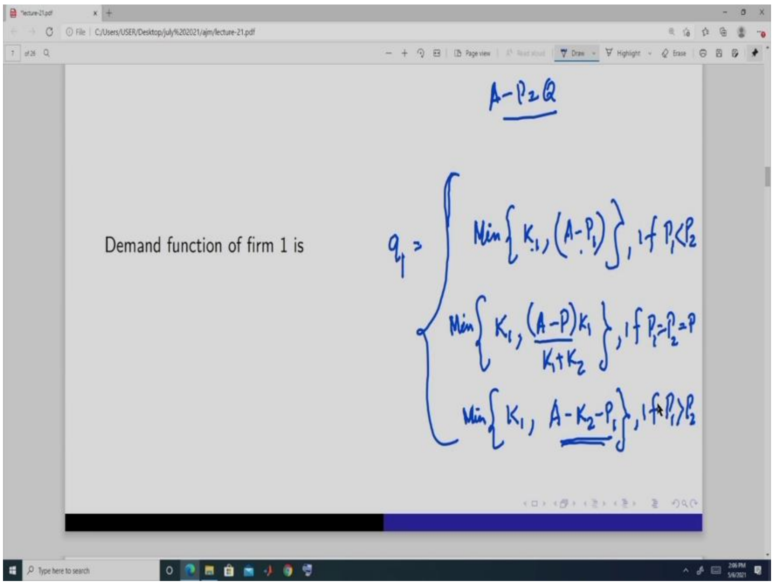

So, demand function of firm 1 that it faces is so its quantity demanded is q1 it is equal to minimum of k1 if p1 is less than p2- $q_1 = \text{Min}\,\{K_1, (A - P_1)\}, \text{if } P_1 < P_2$. If firm 1 sets a price less than the price of firm 2 can either. So, total demand is A minus p1 since the demand curve is A minus is this, right? now its capacity is k1 so it is can satisfy the demand of k1 or whichever is less than this, okay. And it is mean k1 A minus P k1 K1 plus k2 if p1 is equal to p2 is equal to p- $q_1 = \text{Min}\,\left\{K_1, \frac{(A-P_1)K_1}{K_1+K_2}\right\}, \text{if } P_1 = P_2 = P$.

So, if both the firms set a same price that is p then either its firm sell its capacity given if the total demand is less than its capacity, then it is shared proportionally based on their capacity it is this. So, this is the demand at price this and if so, this-$\frac{(A-P_1)K_1}{K_1+K_2}$ is proportionally shared. So, out of these k1 fraction of this whole capacity is going to be served by firm 1. And the next is k1 if firm sets a price which is greater than the price of firm 2, then either its sales is full capacity that is k1 or it serves only the residual whichever is less- $\text{Min}\,\{K_1,\ A - K_2 - P_1\}, \text{if } P_1 > P_2$.

If the residual demand is less than its capacity it is only sells is residual. So, this is the quantity demand that the firm faces in this kind of Bertrand competition with capacity constraint, okay. So, we have consider all the possible cases here.

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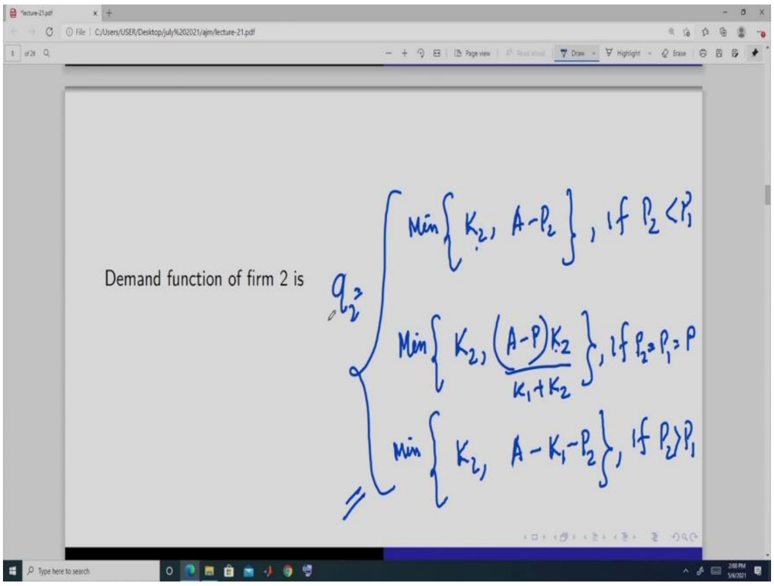

Next, similarly, for firm 2, we get q2 is equal to min k2 or A minus p2 if p2 is less than p1- $\text{Min}\,\{K_2,\ A - P_2\}, \text{if } P_1 > P_2$. So, if p2 is less than p1 then it serves if the whole demand at p2 is this, so, either it can sell this much amount or its capacity that is k2. Or it sells k2 if price of firm 1 and firm 2 are same and that is suppose p then either firm 2 sales up to its capacity or if the aggregate demand at that price is less than the aggregate capacity then its capacity then it sells this fraction- $\text{Min}\,\left\{K_2, \frac{(A-P)K_2}{K_1+K_2}\right\}, \text{if } P_1 = P_2 = P$, okay. And when it sets the higher price either it sells its capacity or it sells up to sells its residual demand if p2 is greater than p1, okay. So, this is the demand curve faced by firm 2- $\text{Min}\,\{K_2,\ A - K_1 - P_2\}, \text{if } P_1 < P_2$.

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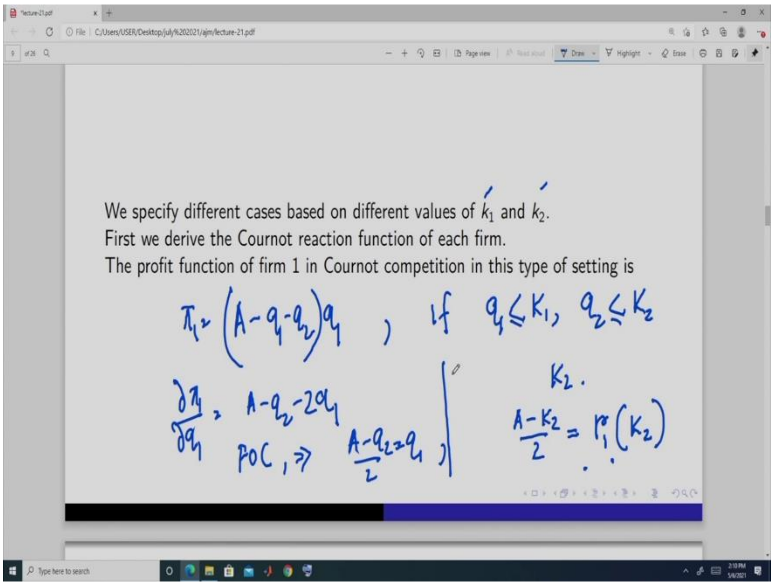

Now, we will specify different values of k1 and k2 different way and based on that we will specify different combinations of k1 and k2 to solve the, or to find the pure strategy Nash equilibrium. So, before doing that let us first look at the Cournot reaction function of this in this case. So, profit of firm 1 can be written in this way if k1 is like this- $\pi_1 = (A - q_1 - q_2)q_1, \text{if } q_1 \leq K_1, q_2 \leq K_2$. Now, so, this is the Cournot profit function and provided this are satisfied then optimizing with respect to q1 we get.

So, first order condition gives us. So, this is the Cournot reaction function- $\frac{A-q_2}{2} = q_1$. From this reaction function we can derive another reaction function and it is of this nature. Suppose capacity of firm 2 is k2, okay. Then what is the best response suppose firm 2 is producing at its capacity k2, what is the best response of firm 1? Best response of firm 1 based on this is this- $\frac{A-K_2}{2}$. So, this we can write in this way as the reaction function of firm 1 when firm 2 is producing at its capacity.

So, now plug in different values of k2 different capacity of firm 2 and you will get the best response of firm 1 what is the best capacity it wants this or it wants to produce it is this from the Cournot thing, right? So, we will require this remember.

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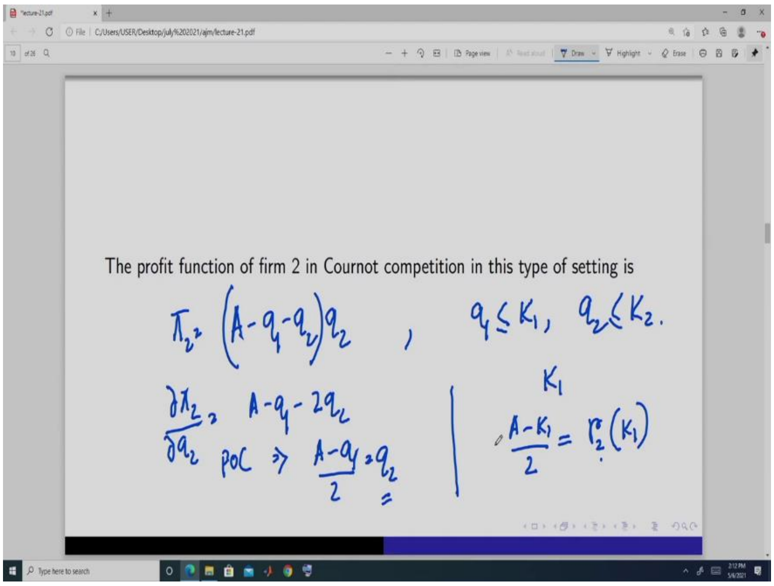

Next profit of function of firm 2 in this Cournot if we take this is the aggregate price this is the market price and this is the output given this since 0 cost so, cost portion is not there, i.e. $\pi_2 = (A - q_1 - q_2)q_2$. So, first order condition gives us this- $\frac{A-q_1}{2} = q_2$. So, this is the reaction function of firm 2 given output of firm 1. So, now suppose the capacity of firm 1 is k1 you plug in the capacity here of firm 1 suppose it is producing at its capacity then the firm 2 the best output a base response of firm 2 is given by this function.

And this is so, plug in values of capacity of firm 1 and you will get the best response of firm 2 this- $\frac{A-K_1}{2} = P_2(K_1)$, right? So, these are the so, now we will define the capacities based on these two reaction functions, okay.

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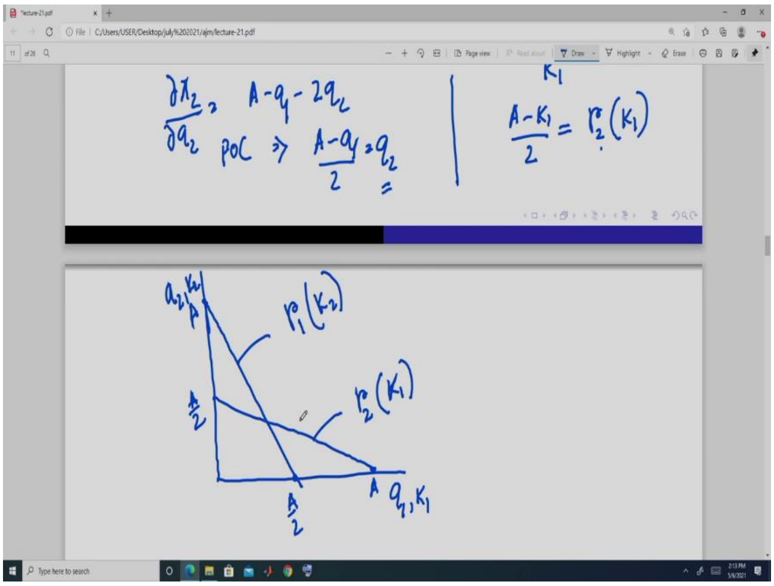

So, if we simply plot these reaction functions this. So q1, q1 comma k1, q2 comma k2 this is A and this point is A by 2 and this you can say this from this here when this- $P_2(K_1)$, is equal to 0 that means k2 is A k2 is here for each k2 we get and when k2 is 0 this is A by 2. So, we get this; similarly, the reaction function of this is A and this is A by 2 and this is react, plug in the value of k1 we get the best response of firm 2 when k1 is 0 this k1 is 0 this is equal to A by 2 this is this and when this is equal to 0, so, it is A, right?

So, when k1 is A this is equal to 0 you can say. Now, we so, this hope you are following what I have done. Now, we specify the case.

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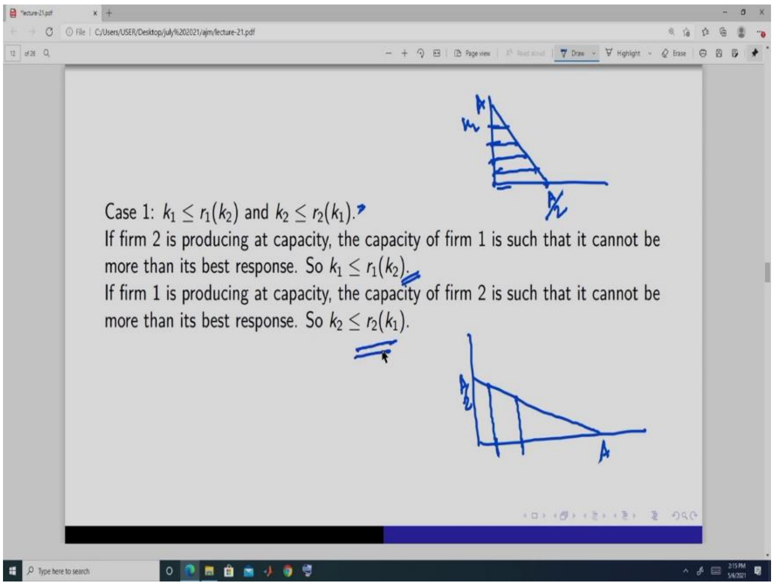

So, first case is this that capacity of firm 1 is always less than equal to this function this reaction function of firm 1. And capacity of firm 2 is always less than equal to this reaction function. That means, here if firm 2 is producing at its capacity that is k2 the capacity of firm 1 is such that it cannot be more than its best response. So, that is why it is this. So, in this situation if this is A and this is A by 2 you plug in any value here k2 you will the k1 is here if it is k2 is this k1 is this if k2 is this k1 is this k2 is this k1 is this if k2 is 0 k1 is this A by 2, okay.

Similarly this if firm 1 is producing at capacity, then capacity of firm 2 is such that it cannot be more than its best response. So, k2 is less than k1, i.e $k_2 \leq r_2(k_1)$ so, it is something like this. So, plug in here suppose this is the capacity of firm 1 if it is producing here firm 2 is capacity is should not be greater than this, if capacity of firm 1 is this capacity of firm 2 should not be greater than this. So, it is from here, okay.

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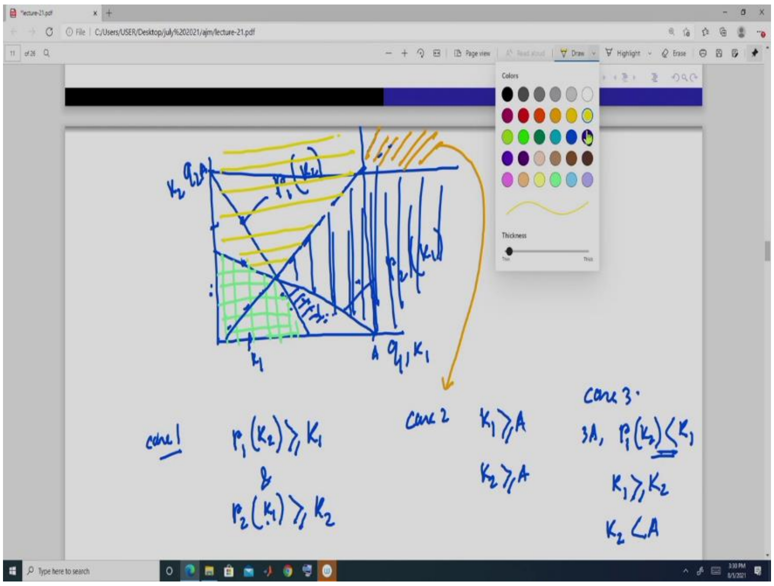

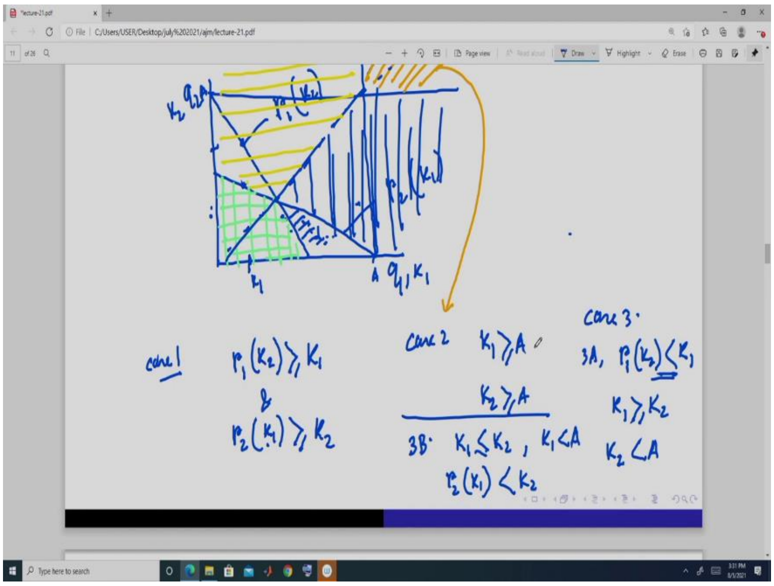

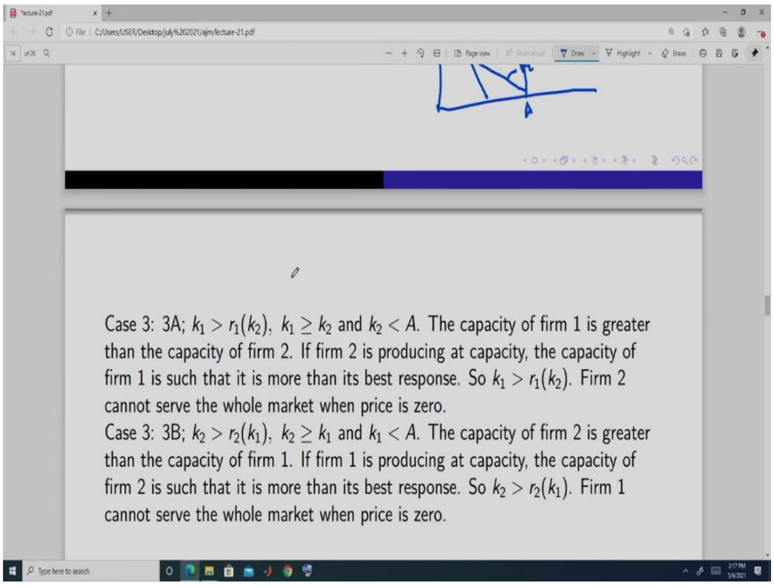

So, output of firm 1 here output of firm 2 our capacity of firm 1 capacity of firm 2 this we get as the reaction function of firm 1, this we get reaction function of firm 2. Now and in case 1 we have got this whole region and this whole region but when we combine these so, what is the case 1 saying? Case 1 says that r1, sorry, r1 k2 these reaction-$r_1(K_2) \geq K_1$ is greater than equal to k1 and this is k2- $r_2(K_1) \geq K_2$. So, if I fix this k1 then the reaction function from this we will get it should be here from this. So, k2 should be less than this.

So, here in this region and here if I fix suppose in here k2 then the reaction from this it should be in this line so, it should be less than this here. Now, if I specify k2 here then if we only have this then it should be here. But take this k1 k2 is should be less than this portion, so, that is why we will not include this portion and not include this portion only this portion is in case 1. So, suppose let us mark it with a different color this green color this region is actually the case 1 this, this green color, okay.

Now, in case 2 we know that case 2 is this k1, k1 is greater than equal to A and k2 is greater than equal to A. So, here this point is A and this point is A so, this region is actually giving us is giving us case 2. So, case 2 is this-$K_1 \geq A, K_2 \geq A$. So, the market size is sufficiently big so, that both the firm can satisfy the or meet the whole market, okay. And this portion is given by this case this k1. So, suppose the capacity of firm 1 is greater than the capacity of firm 2 and if firm 2 is producing at capacity that is k2 the capacity of firm 1 is such that it is more than its best response.

It is like this-$k_1 > r_1(k_2)$ and firm 2 cannot serve the whole market when price is 0. So, case 3 is so, this line we will get this this is the 45 degree line. Now, here case 3 is we have defined that there are two part case 3A and case 3B. So, 3A is r1 k2 this is less than k1-$k_1 > r_1(k_2)$, k1 is greater than equal to k2 and k 2 is less than A. So, this portion is obviously and this portion is also part of it because this r1 if you fix k here it has to be greater than.

So, these points is satisfy this points. So, we get this, okay. This is case 3A and 3B is given by this this region. This region is 3B and 3B is it is this I am writing 3B here. So, it is k1 less than equal to k 2, k1 is less than A and r2 k1 this is less than k2-$k_2 > r_2(k_1)$. So, this portion. So this portion also comes. So, these are the three cases and in case 3 we have two sub cases.

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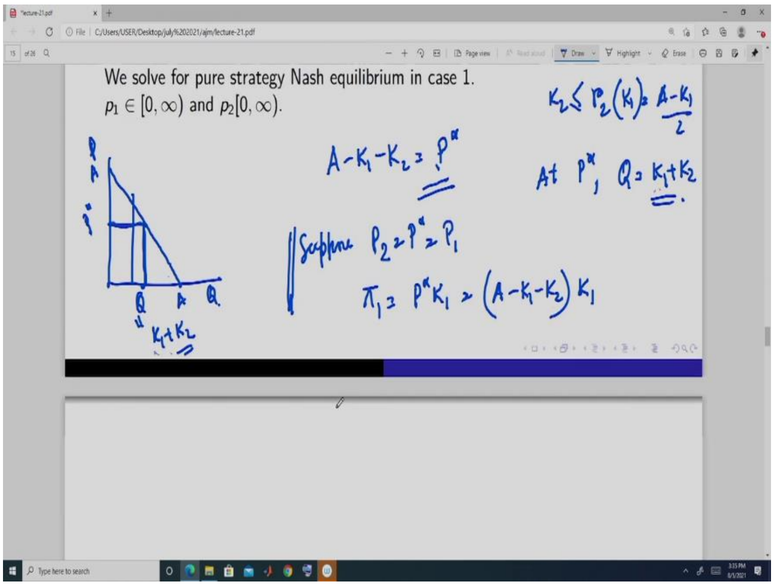

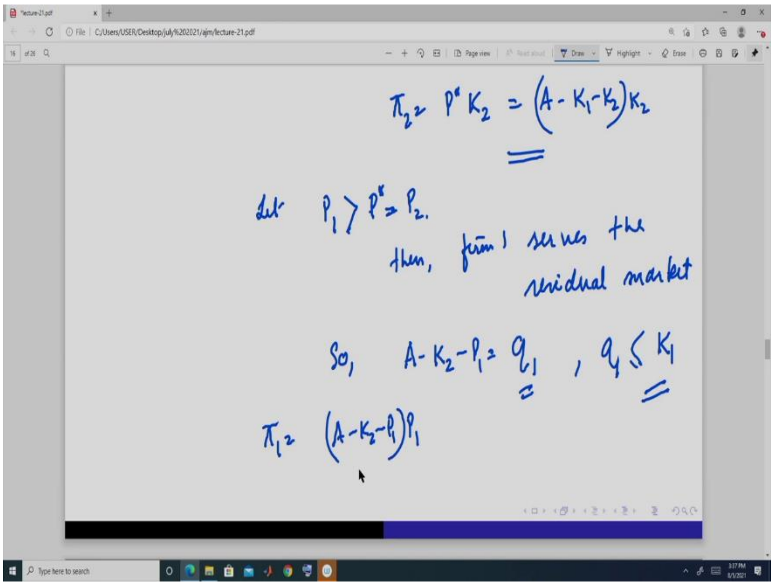

So, based on this we have got what we know the all the possible combinations of cases of k1 and k2 we have specified. Now, we have to find a pure strategy Nash equilibrium. So, that is what is going to be the p1 and what is going to be the p2 in this market p1 and p2. P1 the strategy set is this 0 to infinity, p2 strategy set is 0 to infinity. Suppose, we have this situation now, let us assume that there is a price and that is A minus this is P star we have a price like this-$A - K_1 - K_2 = P^*$. In this case we will definitely have a positive price like this.

Because in case 1 the capacity this is less than equal to this which is equal to this-$K_1 \leq P_1(K_2) = \frac{A-K_2}{2}$ and k2 is less than this-$K_2 \leq P_2(K_1) = \frac{A-K_1}{2}$. So, we will have a price like this. Now, we will show that this is the pure strategy Nash equilibrium in this case. Now, if suppose P2 is equal to P star, okay and suppose p1 is also equal to their price then the profit of firm 1 because it is selling k1 and price is this-$P_2 = P^* = P_1$. So, it is selling at this price and it is selling up to its capacity k1 and this is same as this, this-$\pi_1 = P^* K_1 = (A - K_1 - K_2)K_1$ and here mind this we will have a unique price here, why we will have a unique place?

Because our demand function is something like this it is A P Q it is A and this is A. So, it is a downward sloping straight name. So, if we fixed any fixed quantity here you will get a unique price if you fixed any quantity here we will get a unique price and at this price at P star demand Q is, equal to k1 plus k 2. So, if this is P star then this Q is equal to k 1 plus k2. So, it is such that both the firms can supply up to its capacity it is not less than that neither it is more than that, okay. And here we see that the profit of firm 1 is this- $\pi_1 = P^* K_1 = (A - K_1 - K_2)K_1$if it is.

And the profit of firm 2 profit of firm 2 is this and this is equal to this-$\pi_2 = P^* K_2 = (A - K_1 - K_2)K_2$. Now we have to show whether this we have to show that this is a pure strategy Nash equilibrium, okay. So, how do we proceed? Here let assume, lets suppose p1 is greater than P star and it is equal P2. So, if firm 2 sets a price P star then suppose firm 1, set a price higher than this, then this implies what? Then it will firm 1 serves the residual market so the demand curve of firm 1. So, the demand curve of firm 1 is- $A - K_2 - P_1 = q_1$, if $q_1 \leq K_1$ k2 q1 provided q1 is less than equal to, okay.

So, if this is the case then what is the profit of firm 1. Profit of firm1 is this-$\pi_1 = (A - K_2 - P_1)P_1$. Now, so, there can be many such prices which satisfy this we have to find that price which is the maximizing this.

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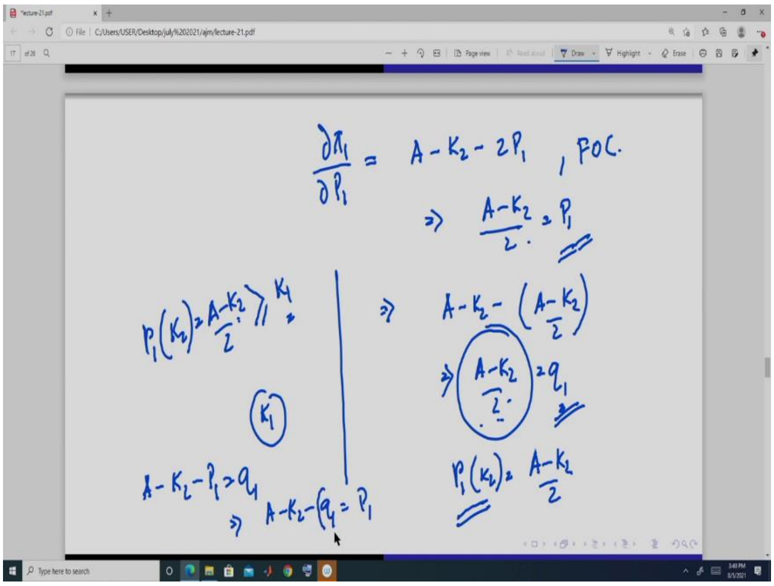

So, what we do let us we are taking partial because in this case there is a strategic interaction. So, price this profit is also a function of p2, okay although it is not appearing explicitly but it is appearing based on the condition, right? So, that is why because this is the condition, right? This-$P_1 > P^* = P_2$. So, that is why I am taking a partial. So, this is this first order condition will imply that it is this-$\frac{d\pi_1}{dP_1} = A - K_2 - 2P_1, \frac{A-K_2}{2} = P_1$. So, if you plug in this price in the demand function of firm 1 that is the residual demand function if this.

Now, this- $\frac{A-K_2}{2}$ is equal to q1 now, we know that this is r1 is given by this form. So, if firm 2 is supplying up to its capacity then what is the best response of firm 1 it is given by this-$r_1 (K_2) = \frac{A-K_2}{2}$ and if firm 1 suppose charges a higher price and it is charges a higher price so, it is serving the residual market in that case what is the optimal price? it will set optimal price is this-$\frac{A-K_2}{2} = P_1$ an optimal quantity to sell is this much, right?

So, this is when it is acting as a monopolist in the residual market and this when it is given a capacity of firm 2, what is the optimal output of firm 1 it is given by this-$r_1 (K_2) = \frac{A-K_2}{2}$. Now, in case 1 we know that this which is equal to this this is greater than or equal to k1-$r_1 (K_2) = \frac{A-K_2}{2} \geq K_1$. So, in this case what is happening if our firm 1 sets a price think initially thinking that his price is going to be higher than the price set by firm 2 that is P star then it is acting as a monopolist in the residual market.

In that case, if it wants to maximize or it wants to set the monopoly price in the residual market, it sets a price this- $\frac{A-K_2}{2} = P_1$and the output itself is this-$\frac{A-K_2}{2}$. Now, this output is actually greater than equal to its capacity. So, it means what, even if it wants to sell this much amount of output, it cannot sell this much. So, it will sell k1. Now, remember this the demand function is of firm 2 firm 1 is this one- $A - K_2 - P_1$and this you can get this- $A - K_2 - q_1 = p_1$.

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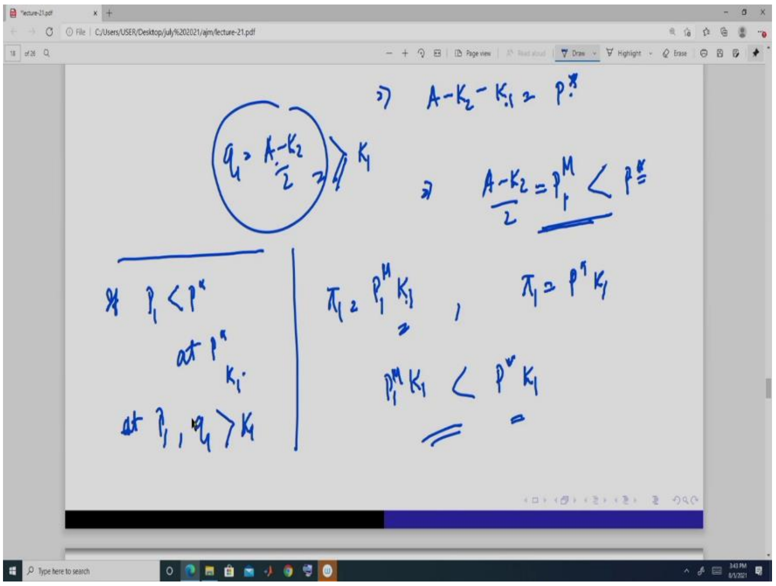

Now, here, when we plug in k1 here, when we plug in k1 we get the price P star. So, this means what and here the monopoly in the residual market if this is equal to this firm should be selling this much amount should be producing this. So, and this is actually greater than k1. Now if we plug in this here, we will get a price which is less than this. So, this means this means which is the this which is the you can I am writing this Pm.

This is supposed to P1m, okay this is less than star-$\frac{A-K_2}{2} = P_1^M < P^*$. Now, so, here profit because it will sell if it is acting as a monopolist in the residual market this, this is the profit of firm 1-$P_1^M K_1$ because it cannot sell this much. So, this is less than greater than equal to this here. So, it will be able to sell only this and if it sets P star its profit is this-$P^* K_1$ and we have shown that this is less than this. So, that is why we get this-$P_1^M K_1 < P^* K_1$.

So, this means that profit up firm 1 is higher if it sets a sets the price P star rather than trying to act as a monopolist in the residual market. Because if it wants to act as a monopolist in the residual market, it will end up charging a price which is less than this P star. So, that is why this is not optimal. So, this strategy of firm 1 is not optimal-$P_1 > P^* = P_2$. Now, if suppose firm 1 sets a price which is less than q if P1 is less than P star. So, at P star it sells k1. So, at P1 q 1 this will be greater than this will be greater than, k1.

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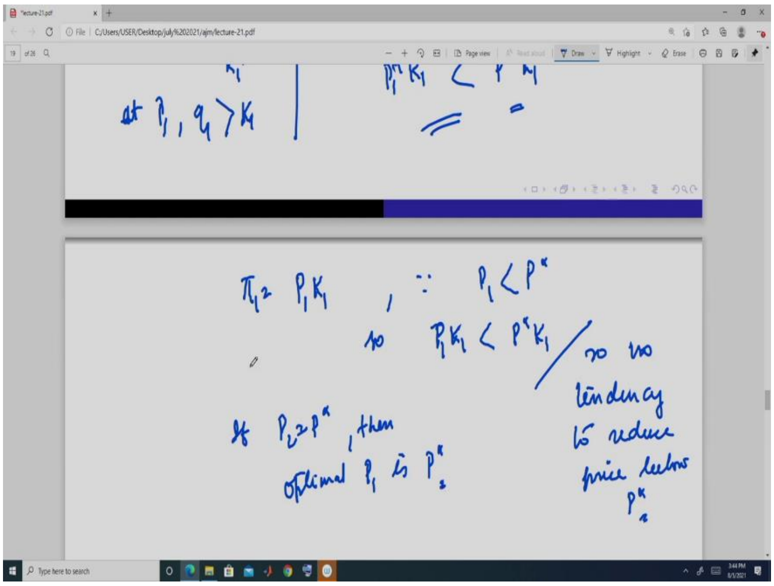

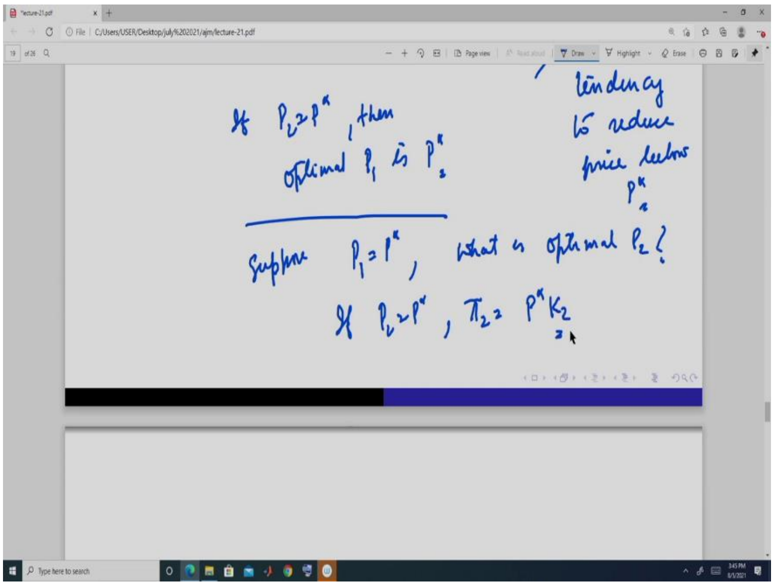

So, if this is the case then profit of firm 1 is going to be P1 into k1 and since P1 is less than P star. So, is less than P star k1. So, to know tendency to reduce price below P star. So, we get that if P2 is equal to P star then optimal P1 is P star, right? Now, we have to show the whether it is a Nash equilibrium or not. So, again suppose P1 is equal to P star, okay when P1 is equal to P star we have to find what is optimal P2. So, we know if P2 is also equal to P star then profit of firm 2 is P star into k2.

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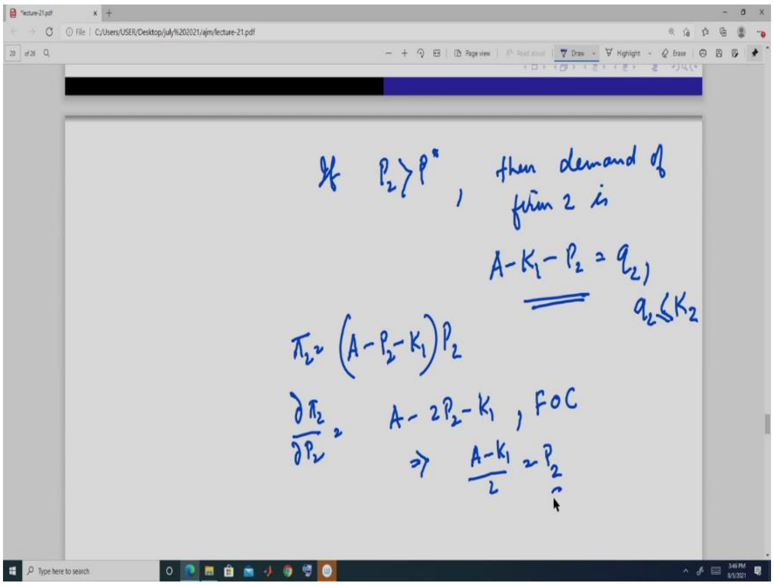

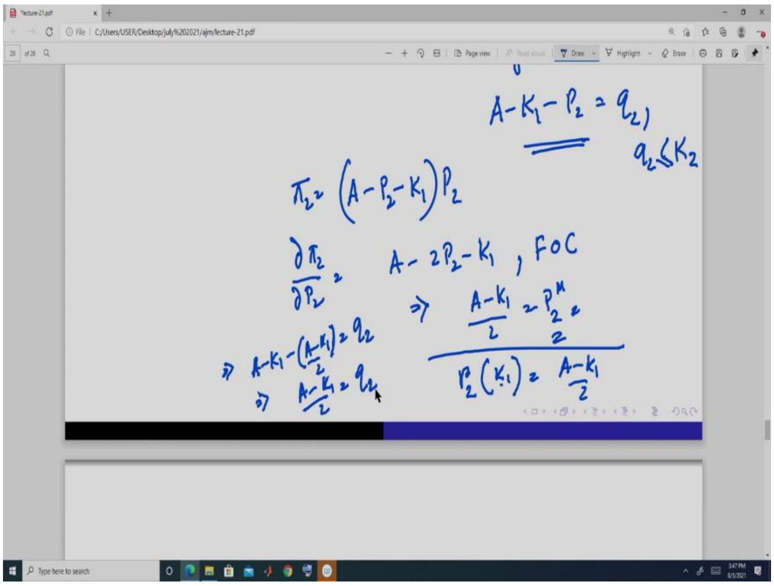

Now, if P2 is suppose greater than P star then of firm 2 is A minus k1 minus p2 this-$A - K_1 - P_2 = q_2$ it will start the residual market provided k2 is less than equal to k2. So, we have to find a price p2 such that it is greater than P star and also it is maximizing its profit. Because there can be many such p2s. So, P2 profit function of firm 2 now is this-$\pi_2 = (A - P_2 - K_1)P_2$. So, again optimizing with respect to P2, we get this first order condition gives this-$\frac{d\pi_2}{dP_2} = A - 2P_2 - K_1$.

So, this is what? So, this is again the Cournot reaction output. So, if r1 is producing up to its capacity that is k1 what is the optimal output of firm 2 it is given by this a which is equal to this-$P_2(K_1) = \frac{A-K_1}{2}$. So, let us this is M, so we get this. And from here we get so, we get this, it is this-$A - K_1 - \frac{A-K_1}{2} = q_2$.

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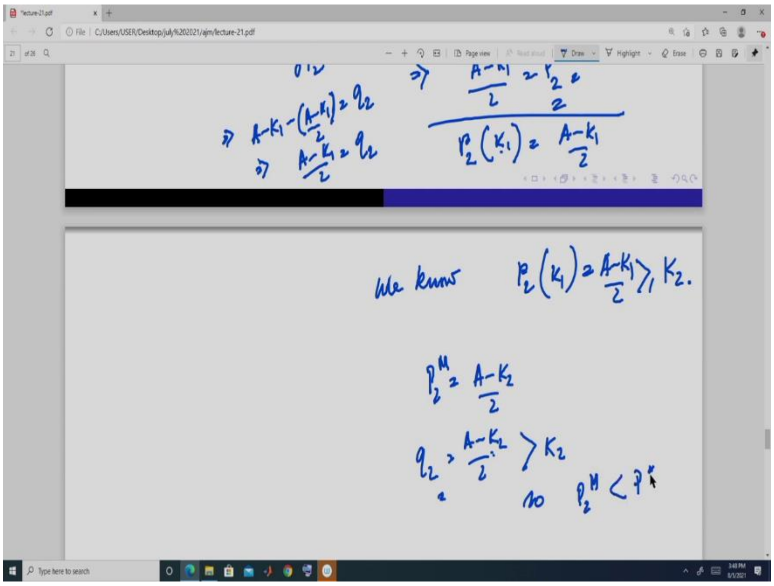

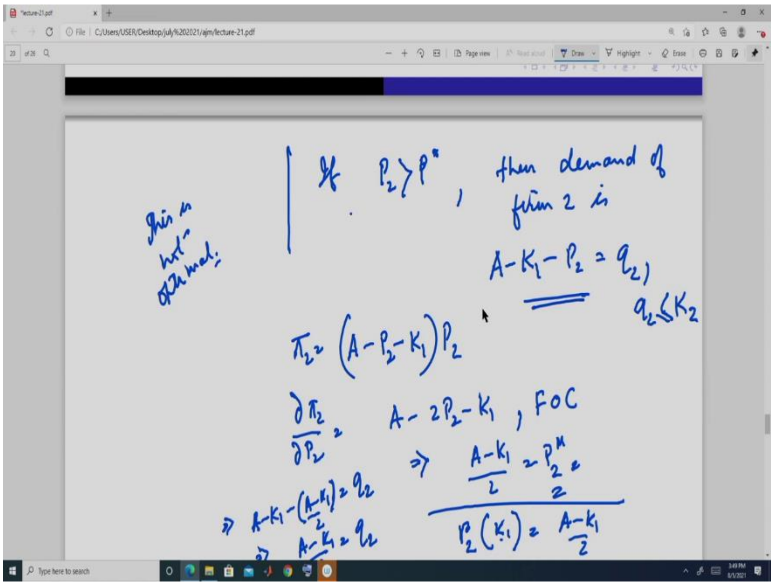

So, and we know that r2 k1 which is equal to A minus this is greater than equal to k2, i.e. $P_2\ (K_1) = \frac{A-K_1}{2} \geq K_2$. So, even if firm 2 wants to sell this it will not be able to sell it will only be able to sell k2. Now, if it wants to sell this it sets a price which is p2M. And p2 M is equal to $\frac{A-K_2}{2}$. So, at this price quantity is it sales is it can it wants to sell is this- $\frac{A-K_2}{2}$ since it is a downward sloping demand curve the residual demand curve is also downward sloping.

So, these since this is greater than k2, so, p2 M is actually less than P star here. So, if that is the case then profit of firm 2 when it sets P2 M and k2 this is going to be less than P star k2. So, this is not optimal $P_2 > P^*$.

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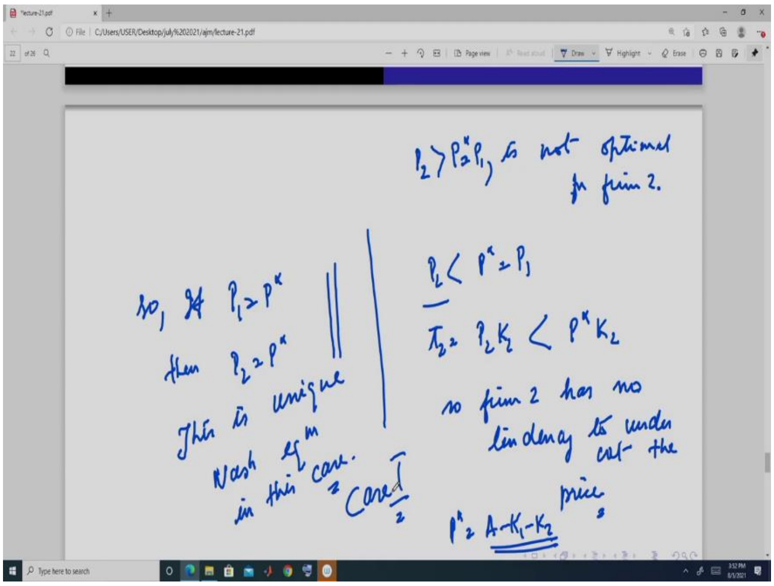

So, we get that P 2 greater p star than is not optimal for firm 2. Now, if p2 is less than P star which is equal to P1 say firm 1 sets that price in this case profit of firm 2 is P2 into k2 this is definitely less than p start k2- $P_2K_2 < P^*K_2$. So, firm 2 has no tendency to undercut the price. So, from here we get that. So, if p1 is equal to P star then P2 is also equal to P star. So, therefore, this is unique Nash equilibrium in this case and this is case 1.

So, in case 1 we get that there is going to be a unique Nash equilibrium and that Nash equilibrium is given by this case this here. So, it is such that the price is equal to prices such that it is the firms are producing at their capacity. So, P star is equal to this-$P^* = A - K_1 - K_2$. So, this is P star. So, when both the firms are going to set a common price that is P star and at that P star the demand is such that both the firms produce up to its capacity.

And this is the unique thing because we have seen that there is no tendency of any firm to set a price higher than P star neither there is a tendency to lower the price, okay. And for the other cases that is in case 2 and case 3 we will do later in the next class. Thank you.