Petroleum Economics and Management

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Module -10

Theories of Price Formation of Petroleum

Lecture - 50

Intertemporally Optimal Prices: Some observations

Hi everyone. Welcome to the NPTEL course, Petroleum Economics and Management and I am your instructor Dr. Anwesha Aditya. So, we have come to almost the last lecture of Module 10. So, in Module 10, we are discussing the Theories of Price Formation of Petroleum and this is our lecture number 50 in the course, where we will be discussing some Observations regarding Intertemporally Optimal Prices.

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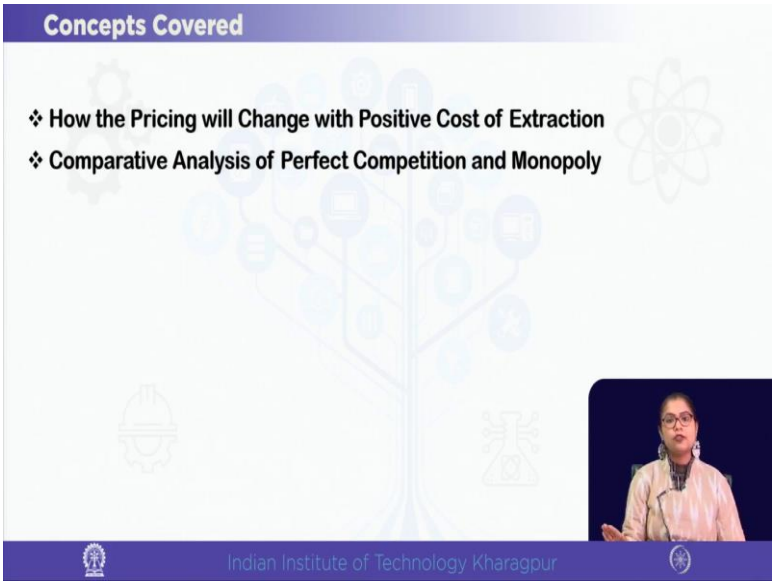

Now, if you remember in Module 10, we have discussed in detail a theoretical model about how the allocation and pricing of a given stock of a mineral resource can be done. So, this theoretical model can be applicable not only to oil, but other type of mineral

resources like coal, natural gas which we have in fixed supply at a given amount of at a given point of time.

So, these type of resources have to be used thus use is spread over time. So, at a given point of time say at the present we have a given endowment of the resource because the present rate of formation is very less. So, we can consider that in a given point of time the amount of resource endowment is almost fixed. So, how to spread the use of the resource over time?

And, without any intervention by the third party like any government or any institution, so, we will be leaving the optimal allocation rule to be governed by price and we see that it is the price which dictates how much to be used over time and we have already obtained the Hotelling's rule which says that the price of a given stock of a natural resource it should increase over time and the rate of increase is given by the market interest rate and this is the famous Hotelling's rule. Or it is also known as the R-% rule where r is the market interest rate.

Now, we have already discussed a very simple two period theoretical model – period 1 which is the present and period 2 which is the future, and we have discuss the how much of the oil or the natural resource is to be allocated between present and future and we saw that price in future will be greater than the price in present which discourages future consumption.

But, at the same time the owners of the resource will not sell everything in period 1 because the owner can make a return higher return by waiting till period 2 because period 2 price is greater. So, we have already studied this simple theoretical model which can be applicable to any type of natural resource. We have in detail discussed the Hotelling's rule, the derivation from the consumer side and we have validated the Hotelling's rule from the owner side.

Owner of the resource, how means the owner will also be indifferent between the two options of extracting the resource now and delaying the extraction to future. So, we have got the rule from the owner side also. Now, in today's class what we will be doing we will be addressing some of the limitations of the Hotelling's rule. Because if you remember in the previous lecture that is in lecture number 49, we have plotted the optimal pricing path following the Hotelling rule.

And, we saw that price increases over time if we plot price against time, so, over time price increases, but there are some criticism of the Hotelling's rule. So, even after 90 years almost the Hotelling rule is very much relevant, but it is not above any criticism. So, one of the criticism is that it does not consider any cost of extraction. So, we will see how with positive cost of extraction what will happen to the Hotelling's rule.

And, we will also study the optimal allocation of the resource in a in imperfectly competitive market because so far, we have considered perfect competition ok. Because in perfect competition we saw we assumed with that there is no cost of extraction or production, but even then, we saw that price was positive and it was also increasing at the market rate of interest.

Now, that is also we know by this time that perfect competition is quite unrealistic because in reality all the assumptions of perfect competition like for example, the complete and perfect information on part of all economic agent that is not satisfied. So, perfect competition is quite unrealistic.

So, we will be discussing how in imperfect competition the rule changes. And, here comes a very important a significant result in this framework if we deviate from perfect competition to monopoly, we will be discussing how our result will change or it will not change. So, as we proceed we will be discussing the implications.

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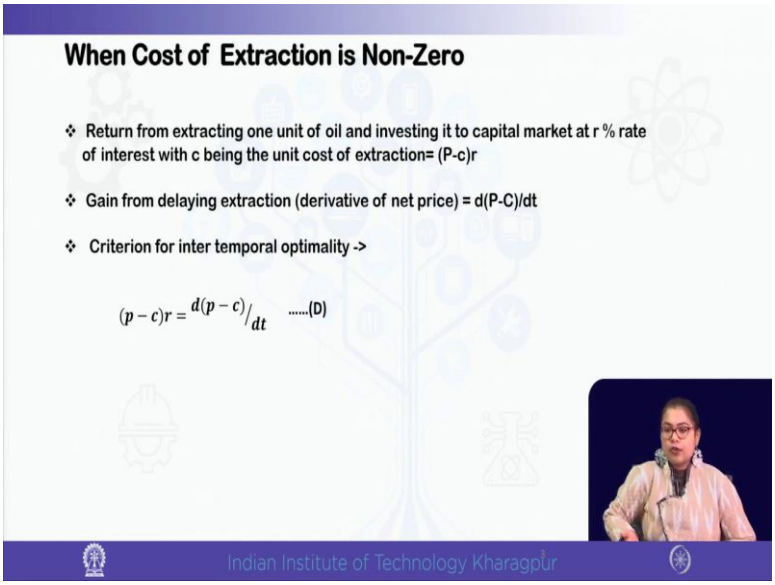

So, first let us start with positive cost of extraction. Now, suppose that c small c is the unit cost of extraction. So, one unit cost of extraction. So, then what will be the return from extracting one unit of oil? So, suppose the market price of one unit of oil is p. So, as I mentioned that this same model can be applicable to other resources, but for our purpose we are just taking the example of oil.

So, return from extracting one unit of oil and investing it to the capital market at r percent rate of interest will be what? (p – c)r because what is p minus c? This is the net price you can say. So, if the owner of the resource extracts one unit and the owner can sell the resource at the market but, now suppose we have a positive cost of extraction.

So, the if the owner extracts the resource and the owner has to pay for the positive cost of extraction, so, the owner can only invest the remaining amount the price minus the cost of extraction. So, (p - c)can be invested in the capital market. You remember in one of the classes earlier where we did not consider the you know cost of extraction. So, we consider that the return for the owner if the owner invest the means the resource wealth in the capital market so, the return would have been rp_1. So, rp_1 is the price in the present.

Now, we are just changing this by assuming a positive cost of extraction. So, then if the owner extracts one unit at the price p and sees the cost of extraction so, the for one unit extraction the profit is (p – c) and this profit is suppose invested in the capital market by the owner and the ongoing interest rate is r percent interest rate.

So, you see the return will be (p – c) r, ok. So, this is what the owner gains by extracting in the present period and investing the profit in the capital market at present. So, what is the other option of the owner? Other option of the owner is to gain is the gain from delaying the extraction ok.

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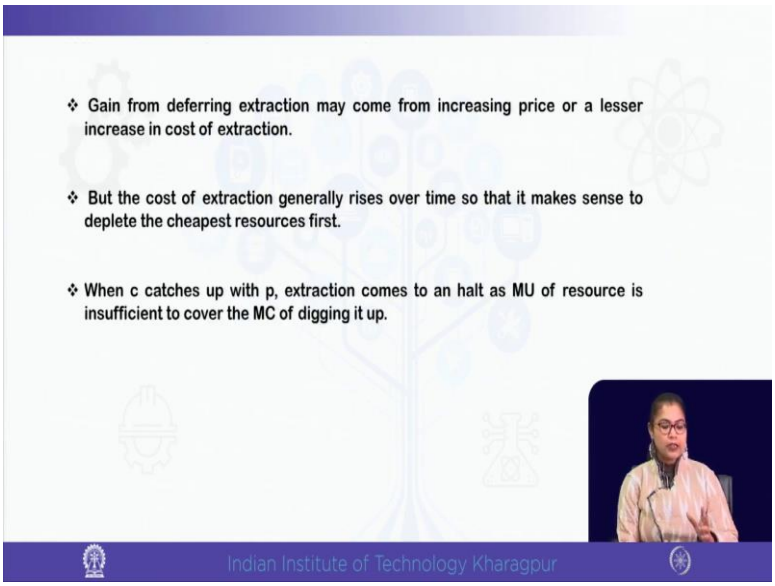

Now, you may think of what is the gain in delaying the extraction? Now, you see there can be two possible gains that may arise from delaying the extraction because we have already seen that price increases over time, ok. So, gain from delaying the extraction may come from increasing price, right. Because if future price increases the owner will be better off by delaying the extraction and selling the resource in the future because future price is increasing.

So, gain from delaying the extraction it can come from either increasing price or due to technological advancement the cost of extraction can increase at a slower rate in future ok. Because of technological upgradation what may happen cost of production we have assumed a positive cost of production extraction or production, but that can increase at a slower rate. So, these are the two possible gains from delaying extraction – one is increasing price and other is lesser increase in cost of production ok.

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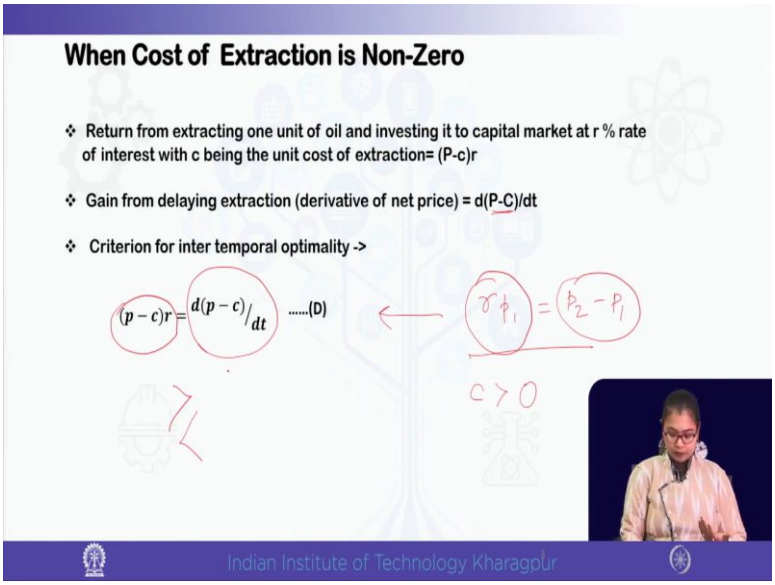

So, the other option so, the first option of the owner is to extract the resource and invest in the capital market and earning the return of (p-c)r and the other option is to wait till price increases and in the next period invest in the means wait until the next period. So, you make a return of (p-c), ok.

So, what is the gain from delaying the extraction which is a derivative of the net price (p-c)? So, this is $\frac{d(p-c)}{dt}$. So, what is the criteria for intertemporal allocation of the resource? Now, you see in the earlier model it was if you did not consider any cost of extraction, you remember it was rp_1 is equal to p_2 minus p_1. So, (p_2 - p_1) was the gain from delaying extraction because price is increasing over time. So, future price is p_2 and current price is p_1.

So, if the invest means the owner is extracting now and investing in the capital market, he or she will make a return of rp_1 and if the owner did not extract in period 1 and waited till period 2. So, he or she would make a return of (p_2 - p_1). Now, in this framework in this particular lecture we have incorporated a positive cost of extraction. So, you see how the rule change from this condition to this when we have a positive cost of extraction. The intuition is same.

So, this is now the left hand side is the return from extracting at present and the right hand side is the gain from delaying the extraction. So, the owner will be indifferent between these two choices and that correspond to the optimal price path and the

intertemporal allocation that is the optimal intertemporal allocation of the resource. So, (p-c)r is equal to $\frac{d(p-c)}{dt}$. So, condition d we have numbered it ok.

So, you see that the as we have already discussed the gain from delaying extraction may come from either increase in price or a lesser increase in cost of extraction. But, the cost of extraction in generally increases over time because we know that over time the price of raw material like labour. So, in extraction also you need some labour, you need machineries. So, this will increase over time. So, that makes sense that we should be depleting the cheapest oil fields first.

So, when in this way as c increases and c ultimately increases so that it matches the market price p. So, extraction will be stopped. Why? Because the marginal utility of the resource will not be sufficient to cover the marginal cost of digging the resource field, is not it? Because if you go on extracting the resource from the same field you are going deeper and the quality of the resource may also be deteriorating.

So, you your cost of refining oil may increase and cost of extraction can also increase. So, c increases. So, p is also increasing, but if c increases at a faster rate, so, c will catch up with p. So, then what will happen? The owner will stop extraction because then the marginal utility may not be sufficient to cover the marginal cost. So, the owner has to compare the marginal utility of extracting one more unit of the resource, with the marginal cost of extracting the resource.

So, if the marginal utility is not equal to the marginal cost it is less than the marginal cost the owner will stop, right. So, until and unless the marginal utility reaches the marginal cost of extraction, the owner will keep extracting the resource. But if marginal cost is greater than marginal utility the owner of the resource field will stop.

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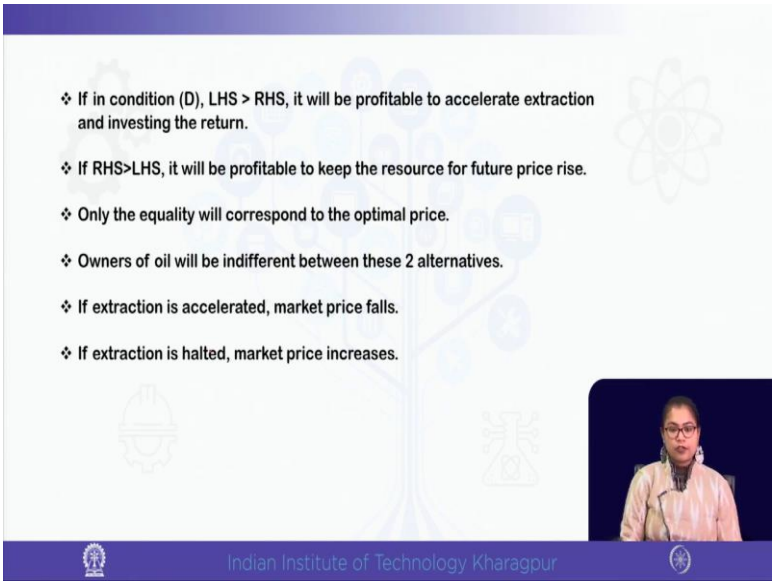

So, you see the condition D. Now, in condition D if the left hand side is greater than right hand side, it will be profitable to accelerate the extraction and investing the return in the capital market because the left hand side is this corresponds to the return that the owner will make by extracting at present and the right hand side is the return that the owner will make by delaying the extraction.

So, if as long as LHS the left hand side is greater than right hand side, it will be profitable to accelerate the extraction process, and if the right hand side is greater than left hand side it will be profitable to keep the resource means the owner will wait for price to appreciate in future.

So, only the equality will correspond to the optimal pricing criteria and the allocation rule. So, the owner of the resource or; that means, oil he or she will be indifferent between these two alternatives when the two returns from these two choices or options are just same. So, he or she will be just indifferent.

Now, you see if you accelerate the extraction what will happen? Supply will increase. If supply increases we already know from our simple knowledge of demand and supply that we studied in the basic economics part. So, if you speed up your acceleration means the extraction process. So, supply increases price will fall. If you delay the extraction means if the rate of extraction falls or you extraction is halted then supply falls then price will increase.

So, you see the only price path that is compatible with the intertemporal allocation rule that is the situation where the owner is indifferent between these two choices. So, the condition D will hold with equality because if there is means if it is does not hold with the equality sign, so, the owner will either accelerate extraction.

So, if LHS is greater than RHS, the owner will accelerate the extraction. So, there will be excess supply, price will fall again the equality will be achieved. If the right hand side is greater than left hand side, so, the owner will means stop extracting then supply will fall price will increase. So, you see in if LHS is greater, then you accelerate extraction, supply increases, price fall.

If RHS is greater then you delay extraction if you delay extraction if you stop extraction then what will happen you know that extraction will halted and market price will increase, right. So, the only price path compatible is when D holds with this equality sign, ok and this is the optimal allocation rule.

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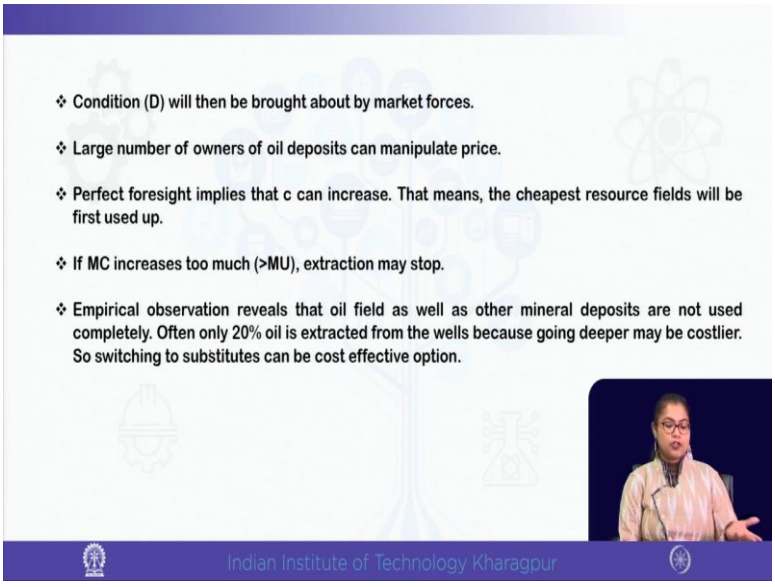

So, you can see that condition D will be brought by market forces. Again, you do not need any intervention by the any third party. So, it is a market forces of demand and supply, the pricing rule that will govern the intertemporal allocation of resource even if you introduce a positive cost of extraction.

So, large number of owner of oil deposits can manipulate the price if you assume that there are many owners instead of only one owner. So, they can manipulate the price accordingly because they can decide like the OPEC members do if they supply more we have seen the cases of great price collapse.

So, if they supply more they increase supply in 1985 – 86 and that led to a price fall. But, initially in 1977 and 79, they the OPEC members especially Saudi Arabia restricted their supply which increase the price. So, large number of owners of oil deposit can manipulate the price.

And, also if we assume that there is perfect foresight so, we know the future with certainty. So, the cost of extraction the unit cost c can increase; that means, the cheaper oil fields will be first used up than going for a more costlier oil fields.

And, as we have already discussed if marginal cost increases and it exceeds the marginal utility of extraction, so, we may stop extraction right because that will not be making sense for the owner to extract. Because cost increases at a faster rate than the marginal utility or the return from extracting the fill, so, extraction will stop.

And, empirically one very interesting observation is that generally what we see that often we just use of only 20 to 15 percent of oil from the fields and before means we leave the oil field and we go for extracting another field. You see just only 20 percent of oil is extracted. Why? Because as I already mentioned that if more and more oil is extracted from the same field and price is increasing over time, but may be at a slower rate but, cost of extraction may increase if you are going deeper.

Because going deeper means your cost of extraction can increase. Cost of transportation will also increase and also if you are going deeper and the quality is not good your cost of refining will also increase. So, we often see that only 20 percent of oil is extracted from the oil fields because going deeper may be costlier. So, it will be more profitable for the profitable, also cost effective option for the owners to go for extracting a new fields.

Because if you remember, in our one of the module while we where we discussed the concept of proof reserve extractable resources, we have already started the steps of establishing the extractable resource and proof reserve. So, first the nationwide mapping

is done by the government agencies or by the government and in the second step the private firms they enter and they establish the proof reserve, right.

So, so, when you are actually extracting a particular field at the same time you are also looking for new fields. So, if you see that the cost of extraction of the existing field is very high, then you will stop extracting oil from that field and you switch to a new filled which will be less costly ok.

So, that is why we often see that not only oil for other type of mineral resources we do not use the entire resource in a particular field. We use only 15 to 20 percent and before we go deeper, we basically find that it is more cost effective to switch to a new field because then you do not need to go that deeper. So, cost of extraction may be less cost of refining is also less. So, this is the condition a condition D that we get when you consider a positive cost of extraction.

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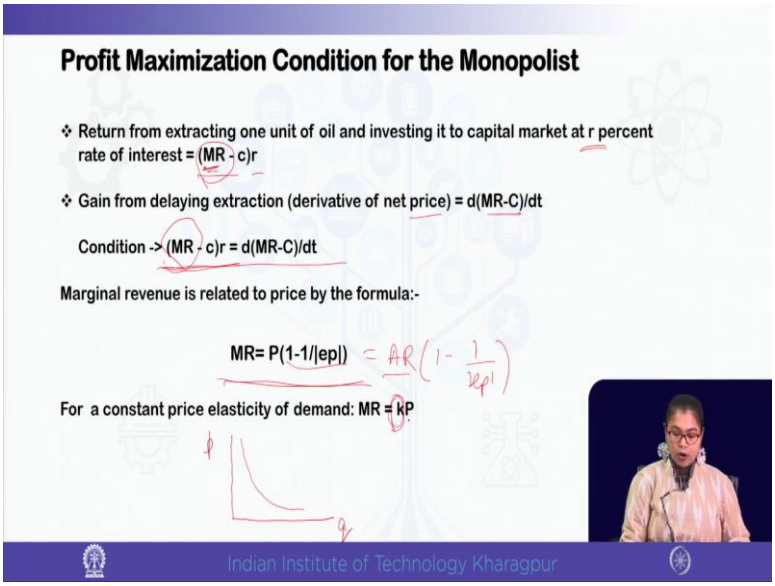

Now, the second limitation of Hotelling rule was the market structure was perfectly competitive. So, we will be relaxing this assumption also in the subsequent part of our lecture. Now, suppose we consider a single owner; that means, a monopolist resource owner, so, what will be the profit maximizing condition for the monopolist and we will be getting a very important result and with a very strong implication.

Now, see if the owner is a single owner of the resource, then what is the option for the owner. So, again we are assuming that the price is p and the unit cost of extraction is c and R is the market interest rate. So, again for the monopolist owner of the field, the monopolist will compare the return from extracting one unit of oil and investing that oil into the market capital market at the ongoing interest rate that is r ok.

So, that means, if the owner of the if the monopoly owner extracts the oil field currently, so, what will be the return? It will be the marginal revenue minus the unit cost of extraction into the return ok. So, (MR-c)r; so, margin MR is the marginal revenue. If you remember, we have already defined marginal revenue is the change in total revenue when one more unit is sold.

So, if the monopolist extracts now, so, what the monopolist will do? The monopolist will invest the profit in the capital market at the ongoing interest rate r. So, what will be the return from extracting the oil? So, that will be (MR – c). So, this MR minus c amount is extracted in the field and the other option for the monopolist is to defer the extraction.

So, the monopolist may not extract in the present and the monopolist can keep the resource for future extraction. So, then what is the gain from delaying extraction? So, we already know this is the derivative of the net price. So, how the net price will or the net return you can say. So, this is the net return is once again it is MR minus c. So, how that is increasing over time? So, it is d of MR minus C by dt.

So, that means, the monopolist once again will be indifferent between accelerating the extraction and delaying the extraction. So, the optimal price path will be when we equate this two , (MR – c)* r = $\frac{d(MR-c)}{dt}$

. So, marginal revenue is related to price by the formula.

Now, see this is the marginal revenue. So, we already I have mentioned in earlier lectures that and we have we already devoted one lecture if you remember in our basic of economics part in the very initial module, I think in module 2 or 3. So, we establish the relationship between marginal revenue and price elasticity of demand, right.

So, MR is related to the price elasticity of demand in this way, right. MR =P (1- $1/e_p$), the absolute value of price elasticity or to be more specific this p is nothing but the average revenue say MR is AR (1- 1 / absolute value of elasticity), right and we know

that price is the average revenue average revenue is nothing but the per unit price. So, this is the relationship between price and the marginal revenue and the elasticity ok.

Now, if you assume a constant price elasticity suppose let us for the time being we assume that price elasticity e_p is constant. We know that in a rectangular hyperbola demand function, the elasticity is same. It take any point in this rectangular hyperbola demand function the elasticity value will be same ok. Now, what will happen?

So, this part is constant. So, we can write this part $(1 - 1/ |e_p|)$, this we can write as a constant k positive suppose k is positive. So, MR = kP, ok.

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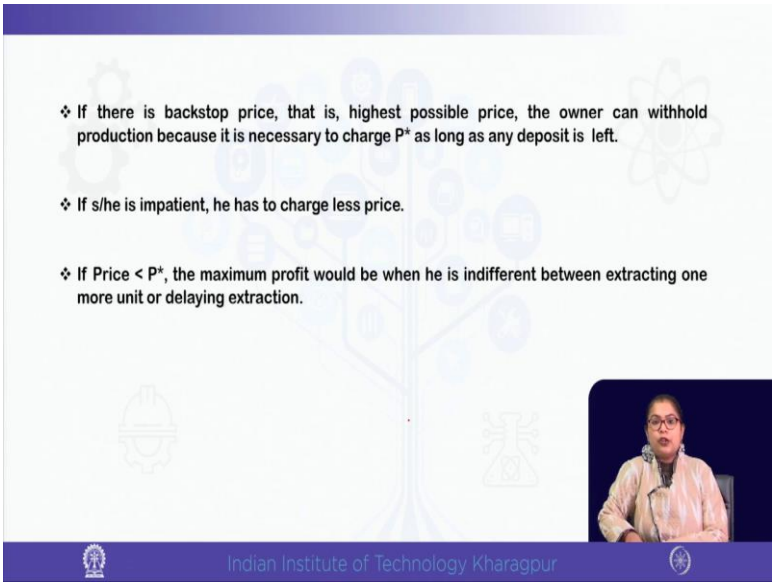

Now, you see if you remember what in one of the classes previous lectures, we have defined a backstop price. So, as the by the Hotelling rule price of the resource increases over time. Now, suppose the price of resource the oil becomes very high, so high that it becomes uncompetitive that means, it is no longer used. So, you consider the price which just before oil becomes uncompetitive, ok.

So, suppose this is the price at which oil becomes uncompetitive. So, you consider a price just before that price. So, this is the highest possible price of oil at which till that resource will be used. So, suppose this is P*. So, if there is a backstop price that means the highest possible price, so, what the monopolist owner can do? The monopolist owner

can withhold that means, it the monopoly owner may not supply the oil till the price becomes a very high price like P*.

So, the monopolist owner can withhold the production because if it may want to charge a very high price like the backstop price P* as long as any oil deposit is there in the field ok. But, if the owner is impatient then he or she has to charge a lower price because by charging a lower price, the owner can sell the resource now because this P* price will be achieved in future. So, it depends on the preference of the owner.

If the owner wants the return right now the owner has to invest currently means the owner has to extract the resource and invest the profit at present. So, this is the left hand side, but the if the owner can wait for the backstop price to be achieved. So, the owner has to wait for price to be increased till P*. So, if the price is less than P*, the maximum profit will occur when the owner will be indifferent between extracting one more unit or delaying the extraction.

That means, we get this condition (MR – c)* r = $\frac{d(MR-c)}{dt}$. So, this is the situation where the owner is indifferent between extracting one unit or delaying the extraction. So, the owner is comparing between the return that he or she can make by extracting one more unit now or delaying the extraction of that one unit for future and that is the situation where maximum profit will be earned by the owner.

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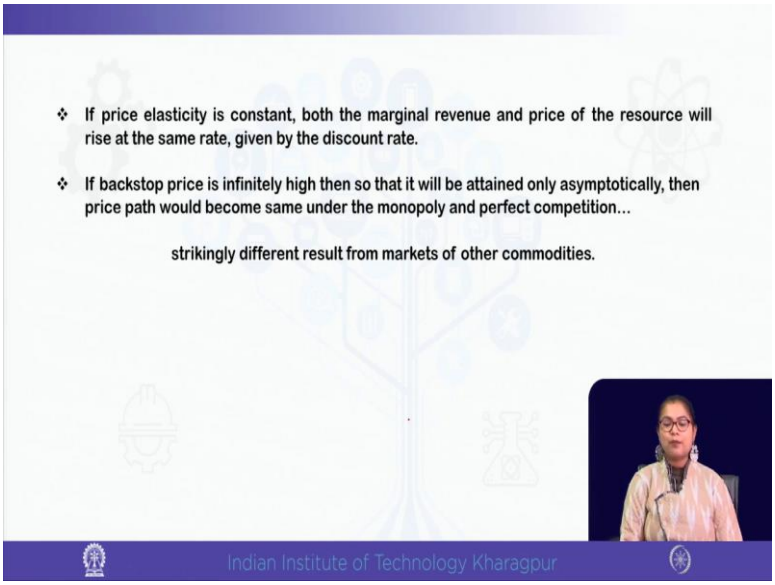

Now, so, if we just assumed a constant price elasticity of demands or rectangular hyperbola demand curve; so, the marginal revenue and the price of the resource will increase at the same rate because you can see over here. So, MR and P will increase at the same rate, right if you assume this ep to be constant throughout the demand curve and this is given by the discount rate. So, both MR and price of the resource will increase and the rate of increase is given by the discount rate.

And, if suppose the backstop price is very high, it is infinitely high so that it will be attained only asymptotically. Then the only option left with us will be what? The price path would become the same under the monopoly and perfect competition. So, this is the price path that you get which is also the one you got earlier you see. Just now in place of p you have MR, but it is the same, the owner comparing between extracting now or the delaying the extraction to future ok.

So, this is the only compatible price path. So, you are comparing if you extract now and you invest the your profit in the capital market, what you the return you earn and if you delay the extraction then how your return will change over time. So, under constant elasticity of demand you see such an interesting result we are getting that the monopolist does not gain by choosing any different price path.

The price path or the allocation rule for the monopoly and perfectly competitive market structure are same. And, this result is completely different from market of other commodities because you see we know in other markets in you have already we have devoted a lectures in module 8, module 9 we have studied market structure we have compared different types of market and we have many times we have mentioned that in monopoly the output supply is less than perfect competition.

Monopoly price is also highest possible price monopoly profit is also unique monopoly profit is highest possible profit and in oligopoly also the firms earn profit, but oligopoly firms can collude and can make a higher profit like a monopolist, right. So, you see that in other markets in where the supply is renewed ok supply is based on flow of inputs; like we took the example of agriculture. Agriculture production happens period after period.

Industrial production or manufacturing production also takes place over time. So, you collect the raw material you combine the raw material into the factory using human

capital, physical capital you produce the product in each period. Even services are also provided by human capital it can be skilled labour, unskilled labour period after period like education, health services, saloon services, tourism, hotel.

So, you see and all the markets what we can show is that a monopoly output will be less than perfectly competitive output, but here we get a very interesting result that the monopolist does not gain by choosing any different price path. So, the monopolist will also charge the same means the monopolist will also follow the same pricing rule that we got in perfect competition and that does not happen in other type of markets.

So, it is because in the natural resource for cases of natural resource in which we have a fixed and given supply we see that the pricing path of monopolist and perfectly competitive market structure are same because the monopolist does not gain any further. Because if the monopolist wants to wait for the price to become P*, but as we already discussed that there is lot of uncertainty because due to technological advancement, technological breakthrough, the resource can become useless.

So, the monopolist may not be taking that much of risk, right and if the monopolist is impatient, he or she has to extract the resource right now and sell the profit and invest the profit at present. The monopolist can wait and can delay the extraction, but by delaying also the monopolist will again will get this return that we have mentioned in the right hand side.

So, we see that the optimal pricing will be the situation where the monopolist is indifferent between extracting one more unit or delaying the extraction as long as price is less than the backstop price. So, that means, you may think that the monopolist why does not the monopolist wait till the price P*.

But then again you see there is lot of uncertainty regarding achieving P* because we have already discussed that the peak oil hypothesis also predicted a very high price of oil, so that the oil use can be stopped, but that did not happen because of the Shell oil revolution.

So, waiting up to the that the price increases to P* will be quite risky for the monopolist, right. So, the monopolist will also supply at present. So, the monopolist the optimal pricing path or optimal allocation of the resource between present and future for the

monopolist will also be the one that is compatible with this condition that the return from extracting at present, extracting one more unit at present should be equal to the return from delaying one more unit of extraction to future.

So, this is the only compatible price path in monopoly also. So, you see that here the monopolist does not gain by choosing any different price path than a perfectly competitive market. So, this result we are getting under constant price elasticity of demand, but even you see in other markets also even if you assume constant price elasticity of demand in other goods or services in industrial production or even in agriculture, we do not get this result.

Because nowhere the monopoly output is same as perfectly competitive output, but this interesting result we are getting in this framework it is because of the scarcity of the resource the limited stock of the resource that the monopolist will also not take a risk of increasing the price to P*, rather the monopolist will compare the gain from extracting now and the gain from delaying the extraction.

And, the monopolist will compare the return from this to and, the monopolist will be just indifferent between supplying now and future as long as the two returns are just equal. So, this is the same price path that would have been chosen by a perfectly competitive market.

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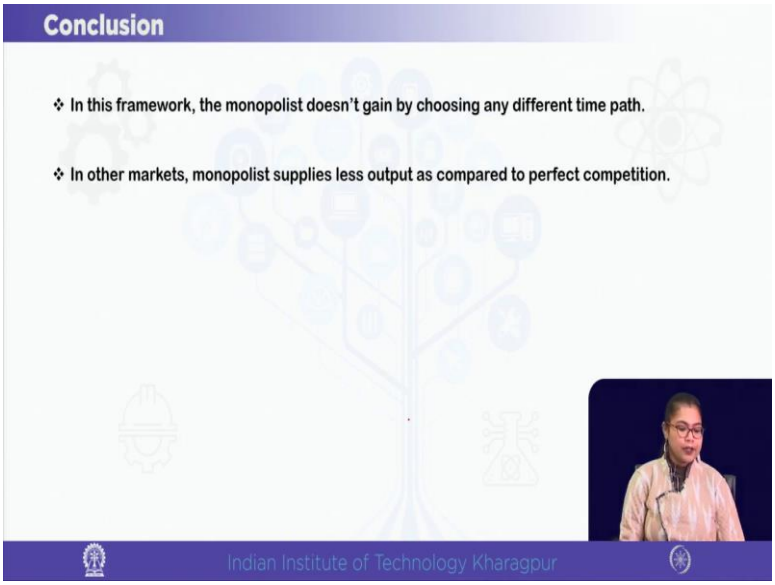

So, you see we conclude that the monopolist does not gain by choosing any different time path in other markets the monopolist supplies less output as compared to perfectly competitive market. So, that means, in today's lecture what we did in this particular lecture we have relaxed the two assumptions in the original Hotelling's framework.

So, we introduced a positive cost of extraction, but then again, we saw that price increases by the rate of interest. So, we got this condition D, if you remember. So, first in the first part of the lecture we consider a positive cost of extraction and then we are also deviated from the assumption of perfect competition.

But very interesting result we got that under the condition of constant price elasticity of demand we see that the optimal pricing rule and the optimal allocation rule for monopolist supplier as well as perfectly competitive market are just same, which is a very striking result because it does not happen in any other type of market.

So, the monopolist does not gain by choosing any different time path. So, in a theoretical model we have studied this intertemporal allocation and pricing rule by a monopolist as well as a perfectly competitive market and under the condition of constant price elasticity of demand, we are getting the same result.

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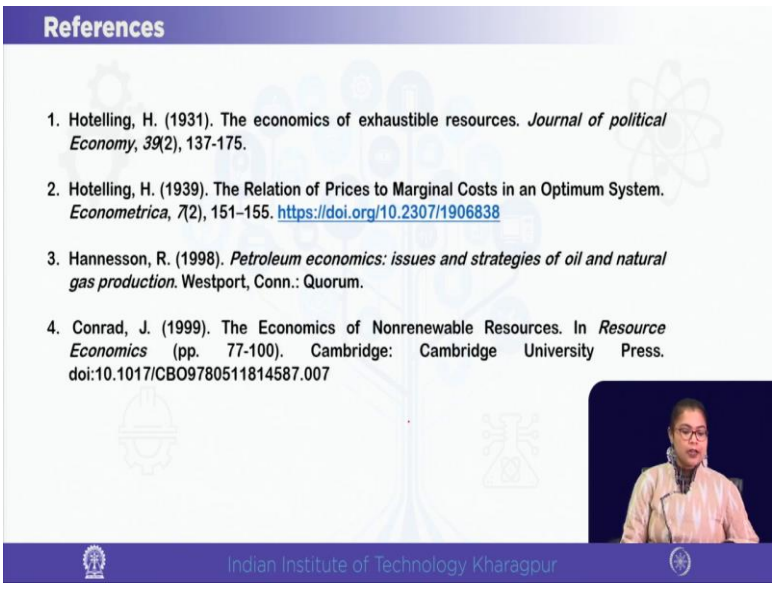

So, we have followed the original papers of Hotelling and the paper of Conrad on Economics of Non-renewable Resources, but mainly our discussion is based on the

Petroleum economics book by Hannesson. So, we have just due to time constraint, we have presented a very brief overview of the theoretical model.

Those who want a more in-depth analysis should look into the book of Hannesson for studying this theoretical models in detail because there are lot of examples with the particular form of the utility function. So, you may and there are numerical examples also. So, you should look into the relevant chapter in the book of Hannesson.

So, thank you very much. See you in the next module.