Energy Economics and Policy
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Week - 4
Energy Supply - Part I
Lecture - 03
Economics of non-renewable resources

Welcome to the 3rd lecture of week 4. In this lecture we are going to discuss the economics of non-renewable resources and the economics of fossil fuel as part of energy supply.

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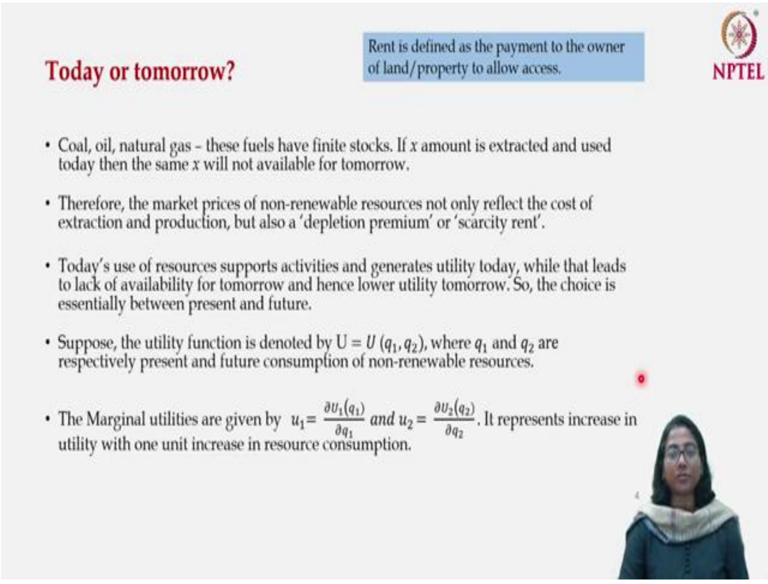

We begin with the economics of non-renewable resources. The main question that we ask in the context of non-renewable resources is today or tomorrow. Coal, oil, natural gas has a finite stock; which means, if you take some x amount and consume it for carrying out economic and other activities, it means that this particular x amount will not be available for use tomorrow.

Therefore, if you use the resource today, it will not be available for use tomorrow and therefore, we start with the question whether to extract and use it today or to extract and use it tomorrow? The market prices of these non-renewable resources, other than reflecting the cost of exploration and production, also reflect depletion premium or a scarcity rent.

What is depletion premium or scarcity rent? There is a finite stock of these non-renewable resources. If I use it today, it will not be available tomorrow, I am using it today at the cost of tomorrow or if I want to postpone my consumption in that case, I am using it tomorrow at the cost of today. There is a trade-off between today and tomorrow and this actually leads to a concept which is called the depletion premium or scarcity rent.

If more of non-renewable resources are consumed today, less amount will be left for tomorrow, resulting in scarcity for these resources. If there is scarcity of resources then the price is going to go up. The market price of these non-renewable resources not only reflects the cost but also reflects depletion premium.

The term rent in economic literature is used to define a payment to the owner of land or any other property to allow access. Scarcity rent is when you are paying rent because you are using non-renewable energy today at the cost of tomorrow. If you go into the literature of non-renewable resources, you will come across the concept of scarcity rent over and over again. And this kind determines the path of depletion and the price of non-renewable resources in the market.

Today's use of resources supports the activities and generates some kind of utility today. But if I am extracting and using it today, then my tomorrow's activities are going to go down and therefore it is going to affect tomorrow's utility. There is a tradeoff between today's utility and tomorrow's utility. If I extract and consume more today, my today's utility will be more. However, if I postpone my consumption and use it tomorrow, my tomorrow's utility is going to go up.

Therefore, if you think in the context of a consumer behavior framework where we discussed about demand for energy, the consumer is trying to sort of come to an equilibrium where she is deciding how much of q_1 and q_2 she wants to use or consume. Here the problem is also the same. The consumer or the economy is trying to decide, how much resources are to be extracted tomorrow and how much resources are to be extracted today. If I extract today, my today's utility is going to go up, if I extract the resource tomorrow, my tomorrow's utility is going to go up but at the cost of today.

Let us try to develop a basic fundamental theoretical model. Suppose the utility function of the economy or a consumer, is denoted as $U = U(q_1, q_2)$. q_1 is the present consumption of the non-renewable resources and q_2 is the future consumption of non-renewable resources and utility U is a function of both present consumption as well as future consumption.

We also define the term called marginal utility which denotes the gain in utility as you consume one additional unit of some commodity. Here we are defining u_1 which is $\frac{\partial U_1\,(q_1)}{\partial q_1}$ and u_2 which is $\frac{\partial U_2\,(q_2)}{\partial q_2}$. u_1 is the marginal utility derived from the consumption of non-renewable resources today and u_2 is the marginal utility derived from the consumption of non-renewable resources tomorrow.

We conceptualize the concept of marginal utility with an example. Suppose you are very thirsty and you need to drink water. The utility that you derive from the first glass of water is very high. Once you have had the first glass of water, you would still like to have a second glass of water but the utility that you derive from the second glass of water is going to be less than the first class of water because you already had the first class of water. If you keep on consuming one particular good or service or any resource, your marginal utility tends to fall. We will assume that both u_1, marginal utility derived out of the consumption of non-renewable resources today and u_2, marginal utility that is derived out of the consumption of non-renewable resources tomorrow, both are falling as you increase q_1 and q_2 respectively.

The intention behind developing this kind of a framework is to divide the finite stock of resources in two parts; the part that you are going to extract and use today and the part that you are going to extract and use tomorrow. Instead of thinking about today and tomorrow that is only two period of time, you can also think about some n period of time that will give you a continuous framework when you are dealing with multiple periods of time.

But for the sake of simplicity we are taking only two periods of time however you can develop the same model and framework for multiple periods of time. In fact, that is mostly what is available in the literature but we are starting with the most basic one. Before we go to the theory of resource extraction in case of the depletable resources, let us have a quick recap of the consumer equilibrium.

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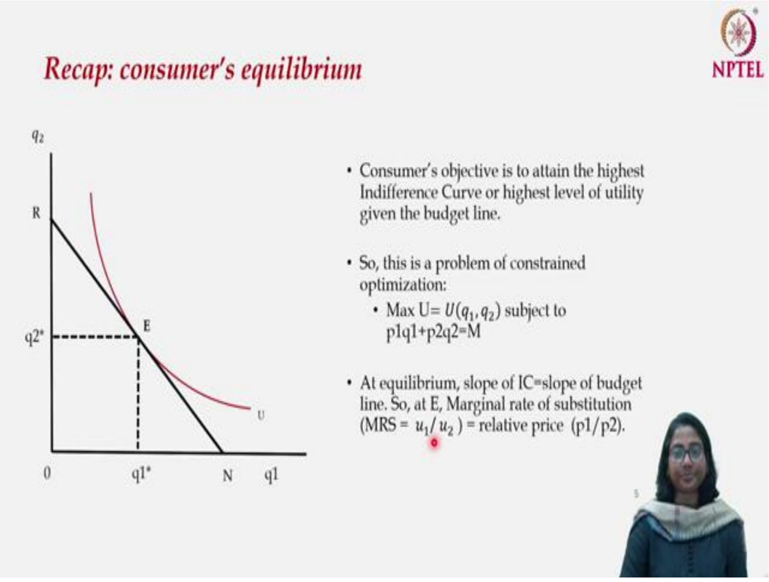

The equilibrium of the consumer is attained at the point where the slope of the budget line that is the slope of RN line is equal to the slope of the indifference curve that is at point E. At point E, the slope of the budget line is equal to slope of the indifference curve or what we can say is the absolute slope of the indifference curve is equal to the absolute slope of budget line.

We know that the absolute slope of the budget line is given by the price ratio $\frac{p_1}{p_2}$ and the absolute slope of the indifference curve is given by the marginal rate of substitution which is $\frac{u_1}{u_2}$. Therefore, at point E what we basically have is $\frac{u_1}{u_2} = \frac{p_1}{p_2}$ or what you can say this u_1 is the marginal utility derived from q_1 and u_2 is the marginal utility derived from q_2. The ratio of marginal utilities is equal to the price ratio.

One note of caution is that, if you look at the latest consumer behavior theory, the theory of ordinal utility, it's not mandatory that the marginal utilities are declining, it is mandatory that the marginal rate of substitution actually declines as you increase consumption of one particular commodity. But here we are assuming that the marginal utilities are also declining and the ratio of the marginal utilities are actually equal to the ratio of prices. In this framework we consider q_1 as the present consumption of the non-renewable resources and q_2 as the future consumption of non-renewable resources. You are likely to get a similar kind of equilibrium, if you decide how much to use today and how much to use tomorrow.

We are replacing the concept of q_1 and q_2 to be more specific. Instead of saying q_1 is one particular commodity and q_2 is some other commodity; what we are saying here is q_1 is the present consumption of the depletable or non-renewable resource and q_2 is the future consumption of the same non-renewable resource and the price that is invoking in the present period is p_1 and the price that is invoking in the future period in p_2.

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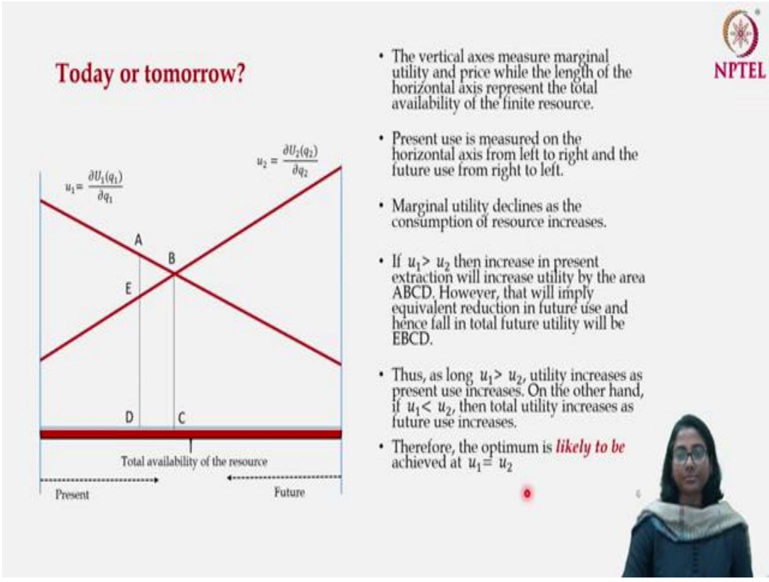

Let us come back to the question of whether today or tomorrow? How much do we use today and how much do we keep for tomorrow's consumption? In the diagram the two vertical axes are going to measure the marginal utility. On the left-hand side vertical axis, we will measure the utility derived from the present consumption and on the right-hand side we are going to plot the utility that is derived from future consumption. The horizontal line, the length of the horizontal line represents the amount of resource that is available.

This is not actually reserved but the total amount of resource that is available in case of depletable resources or total stock of the resource represented by the length of horizontal line. How are we measuring the present consumption and future consumption? The present consumption is measured from left to right and the future consumption is measured from right to left and where the present and future consumption meets that point gives us the division between the present use and the future use of the non-renewable resource. As we have said that the marginal utility declines as the consumption of resources increases, this is true both in the context of today as well as in the context of tomorrow.

The marginal utility curves are derived for the consumption of non-renewable resources as shown in the diagram. On the left axis u_1 is plotted, that is the marginal utility derived from the consumption of the depletable resources today and on the right-hand side the marginal utility is plotted which is derived from tomorrow's consumption. This is how the marginal utility curves look like and both of them are falling that is u_1 is falling as the present consumption is increasing and u_2 is also falling as future consumption is increasing.

The next question; how do we know about the division of the resources between today and tomorrow. Suppose point D is chosen which means using the part for present consumption up to D from my left and up to D from my right for the future consumption; what is the specification of this point? At this point, $u_1 > u_2$ that is the marginal utility derived from today's consumption is higher than the marginal utility derived from the future consumption.

At a point where $u_1 > u_2$, if you increase the consumption of today that is if you increase today's consumption and leave less for tomorrow then what happens. Then you move to a point like C. CD is the increase in today's consumption and decline in future consumption. As you move on from D to C present consumption is increasing. As a result, total utility is increasing by amount ABCD. The area ABCD represents the integration under the curve u_1 between two points C and D.

As present consumption increases from D to C, total utility is going to increase by the amount ABCD. Increasing present consumption means reducing future consumption. The amount of reduction in future consumption is DC and the reduction in your total utility will be the area under the curve u_2 between D and C. The loss in utility because of reduction in future consumption is denoted by the area EBCD.

What is the gain in your utility? The gain in terms of utility is because of increasing present consumption and loss of utility is because of reduction in future consumption. However, this diagram shows, that $u_1 > u_2$, that is the marginal utility of q_1 is greater than the marginal utility of q_2. In that case, it's probably a wise decision to increase the present consumption because as you move from D to C there is a net increase in utility captured by the area ABE.

As a result of the increase in present consumption from D to C utility increases by ABCD. However, this leads to a reduction in consumption for the future by the amount DC. As a result, reduction in utility is EBCD which leads to a net gain of utility of the amount ABE. This shows that if your marginal utility from today's consumption is greater than the marginal utility of tomorrow's consumption then it's better to increase today's consumption and reduce tomorrow's consumption.

In the similar manner, if today's consumption is such that $u_1 < u_2$, then it's probably a wise decision to move to point B which results in decrease in present consumption and increase in future consumption. Whether you are to the left of point B or to the right of point B, the tendency should be to come to point B where marginal utility of q_1= marginal utility of q_2. The marginal utility that you are deriving out of the consumption at the present period is equal to the marginal utility that you are deriving from the future consumption.

If B is the point, then from the left to C is your present consumption and from right to C will be your future consumption. However, this is more or less the guiding principle but this is exactly not what happens and therefore optimum is likely to be achieved at $u_1 = u_2$ but we need to do a little modification in order to come to the optimum allocation of this resource over two periods of time.

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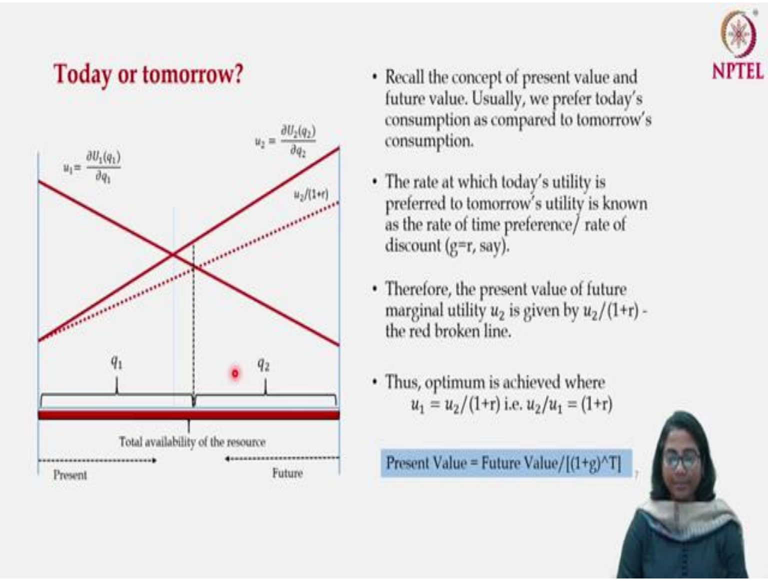

Why $u_1 = u_2$will not guide you to take the optimal decision? The reason can be explained by the concept of present value and future value. Usually what we discuss under present value and future value is that we prefer today's consumption as compared to tomorrow's consumption. Again, taking the example of 100 rupees note, if put in bank accrues 5 percent rate of interest per annum so that at the end of the year the money that I have is 105 rupees. Today's 100 rupees is equal to tomorrow's 105 rupees. The present value of the money that I have is 100 rupees whereas the future value of the money that I have is 105 rupees.

Instead if I have100 rupees in the next year, the future value of that money is 100 rupees and the present value of that money is going to be less than 100 rupees. In the diagram same thing is happening, u_1 is defined in the context of today and u_2 is defined in the context of tomorrow. But we cannot compare u_1 *and* u_2 or the consumption of the same resources today and tomorrow on a one to one basis because today's consumption is likely to give more utility as compared to tomorrow's consumption. This is what is called the rate of time preference. Also called the rate of discounting that is the rate at which you prefer today's consumption as compared to tomorrow's consumption.

The formula for the present value and future value is given as $Present\ value = Future\ value/(1+g)^T$ where g is the rate of growth and the T is the period. Here we have T is equal to 1 because we have the time period 0 and 1 only. g is equivalent to rate of time preference, the rate at which preference is growing or preference is falling with respect to the consumption. This is denoted as r but it plays the same role as g. If we have to compare today's marginal utility and tomorrow's marginal utility, rate of time preference is taken into consideration.

The present value of today's marginal utility is given by u_1 however u_2 is the future value of tomorrow's consumption. u_2 is the marginal utility that I am deriving in future. If the present value of the marginal utility of future is to be calculated it has to be divided by $(1+r)$ where T is becoming 1 and the g is becoming r.

The present value of $u_1 = \frac{u_2}{(1+r)^1}$. The optimum is not really achieved at this point where $u_1 = u_2$ but rather the optimum is achieved at a point where $u_1 = \frac{u_2}{(1+r)^1}$. The present value of future marginal utility is equal to today's marginal utility.

To incorporate the same in the diagram, instead of going by the line u_2, we will construct a new line which will denote $\frac{u_2}{(1+r)^1}$. The u_2 is rotating as it is divided by a factor $(1+r)^1$. Instead of going by this point, we are now looking for intersection between u_1 and $\frac{u_2}{(1+r)^1}$. The new equilibrium will give the optimum result at this point. The interaction between the red broken line representing $\frac{u_2}{(1+r)^1}$ and the solid line of u_1 gives the point of optimality or tells how the resource needs to be divided between today and tomorrow.

This is the point of equality between u_1 and $\frac{u_2}{(1+r)^1}$, q_1 amount measured from the left-hand side is the amount that can be extracted and used today and q_2 is the amount measured from the right, should be extracted and used tomorrow. The present value of the marginal utility of both the periods remain the same.

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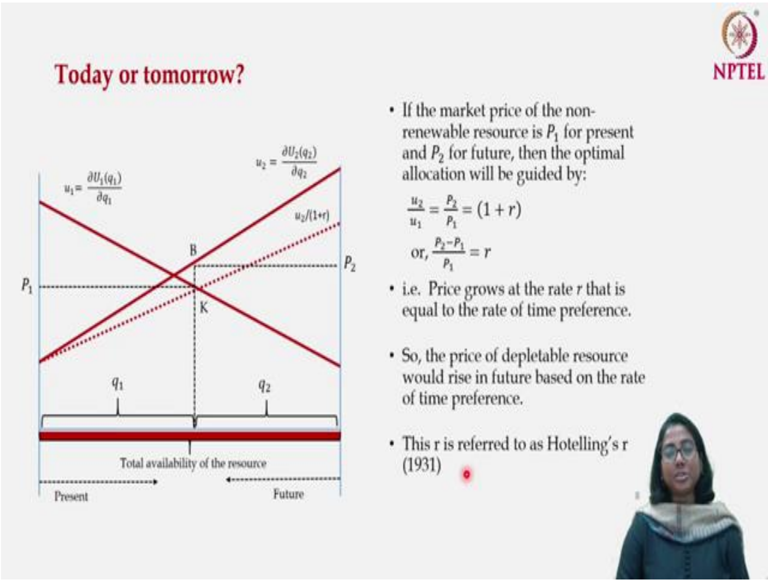

What is the price that needs to be charged for these two periods? There is a scarcity rent that one needs to pay as the resource becomes more and more scarce, this means that the price should go up. The price should go up even if the cost of extraction and production remains unchanged and that is the scarcity rent. That is again determined by the concept of the rate of time preference or the discount rate. The proportion in which the price should increase in future as the scarcity increases, is actually determined by the rate of time preference or the r that we have been discussing.

How is that happening? In consumer behavior theory equilibrium takes place where the indifference curve is tangential to the budget line that is $\frac{u_1}{u_2} = \frac{p_1}{p_2}$ or we can write $\frac{u_2}{u_1} = \frac{p_2}{p_1}$. We have already seen that $\frac{u_1}{u_2} = (1+r)$, r is the rate of time preference. It is be written as $\frac{u_2}{u_1} = \frac{p_2}{p_1}$ in case of market determined price, which is $= (1+r)$, r being the rate of time preference.

If you look at the distance BK between these two lines, the red line representing u_2 and the red broken line representing $\frac{u_2}{(1+r)^1}$, this is actually reducing u_2 by a factor $(1+r)$. If point K is multiplied by $(1+r)$ we get the point B. If point A is multiplied by $(1+r)$, we should be at point B. This distance BK is representing the multiplicative factor $(1+r)$.

How do we determine the price? Again, we say $\frac{u_2}{u_1} = \frac{p_2}{p_1} = (1+r)$. After manipulation we get $\frac{p_2}{p_1} = (1+r)$; which means, $r = \frac{p_2}{p_1} - 1$, which is $\frac{p_2 - p_1}{p_1} = r$. What is $\frac{p_2 - p_1}{p_1}$? This is the rate at which the price is growing from today to tomorrow. We are talking about two time points; this is the annual growth rate.

The growth rate in price is equal to your rate of time preference. The rate at which you prefer today's consumption as compared to tomorrow's consumption determines the rate of time preference, that determines discount rate and that again determines the rate at which price is going to increase in future in case of non-renewable resources.

How do I point out p_1 and p_2 in this diagram? Clearly point K this denotes the intersection between u_1 and $\frac{u_2}{(1+r)^1}$. This is the point of equilibrium and q_1 is the amount of non-renewable resources supplied and used tomorrow. q_1 is the quantity of non-renewable resources supplied and used today and not tomorrow. So, the price that the market is going to charge today will be p_1. This is the price charged and this is the quantity consumed, this is determined by u_1 curve.

What is the price that is going to be charged tomorrow? Tomorrow's price is going to go up at the rate r. Tomorrow's price that is p_2 is nothing but $(1+r)\ p_1$. If I need to multiply p_1 by $(1+r)$, we end up with price p_2 because this BK is actually giving the factor $(1+r)$. We multiply p_1 by $(1+r)$ in order to get p_2. The rate at which price increases is equal to the rate of time preference.

Instead of making it a two-period analysis, you can also make it a multiperiod analysis and you will get a step diagram here, where you will see $p_1 < p_2$ which is again less than some p_3 and so on as you move on in the time. This explains why the price of depletable resources or the non-renewable resources increases over time. This increase is not due to increase in the exploration or increase in the production, this is simply reflecting the rate of time preference and therefore, the scarcity rent that you are paying in terms of price.

This rate at which it is increasing is captured by Hotelling in his 1931 work, this is often called the Hotelling's r or Hotelling's rule by which you can explain the pathway of resource extraction in case of non-renewable resources and can also identify the optimal price path. If you are interested, you can go back to Hotelling's writing, even today it is very relevant and often this theory is used in the context of the non-renewable resources and to explain its depletion and the resource rent and the price.

We are going to stop here with respect to the depletion perspective of the non-renewable resources and what we are going to move on is to the economics of fossil fuel. Here we are going to talk very briefly about exploration, field development and the production with special focus on the cost aspect. We are not going to go into depth of all these notions but we are simply going to understand them a little bit such that if you want to gather more knowledge about it in future, you have a starting point.

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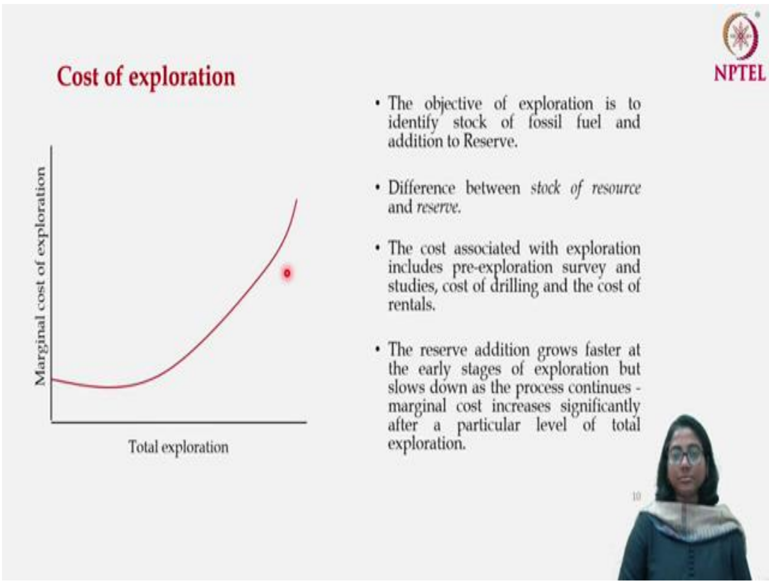

Starting with the cost of exploration, it is the first stage of the production of fossil fuel. The objective of the exploration is to identify the stock of fossil fuel and to add it to the reserve. There are two things that we are talking about; one is the stock of resources and the other is the reserve. The stock of resources is not equal to the reserve.

What is the stock of resources? This is the entire amount which is available, it may or may not be explored, it doesn't matter, it is a stock of resource. The stock that is the amount of resource which is available is actually unknown to us but what is known to us is what has been confirmed through exploration activities. Whatever availability of this resource has been confirmed that is called the reserve. Reserve is something where exploration activity has led to identification of the stock of resource.

The cost of exploration for any project related to extraction or exploration or extraction or production of fossil fuel is a very cost intensive process. There are three stages; the first one is exploration, the second one is extraction and the third one is production. Even before exploration, there are a lot of things that need to be done including the pre-exploration survey and studies, the cost of drilling and the cost of rentals and so on.

There is a large amount of money that is involved. What is the nature of the cost if you think about the exploration activity with respect to fossil fuel? In the initial phases, when the reserve is established that is when the result of the exploration activity is positive and suppose oil well has been found and you want to drill it. In the initial phase, it’s easier to take this fossil fuel out as in the initial stage of exploration there is faster addition to the reserve, however, as time goes on it becomes difficult to add to the reserve and it becomes more costly.

The exploration can be compared with the groundwater, as you want to keep on taking the groundwater out initially it’s very easy. The water can be taken out from a shallow depth; however, as you keep on taking out this groundwater, you have to keep on moving deeper and deeper and therefore, the cost of extracting the groundwater will increase.

The same thing happens in the context of fossil fuel. Initially it’s not very costly and relatively easy to add to the reserve. However, as you move to higher volume or increase exploration activities; the marginal cost is going to increase. The additional cost needed for exploration is going to go up. It leads to a given shape of the marginal cost curve for the exploration activities. Initially, the marginal cost of exploration is low however, as the exploration goes on, the cost is going to go up and after a point the cost is going to be very steep. Maybe beyond a certain point, it is not very economical to take up the activity of exploration.

When we think about fossil fuel; one part is the geological availability, whether fossil fuel is available and how much is available? The second important part as the exploration activity is cost intensive is whether it is economically feasible to take fossil fuel out or not.

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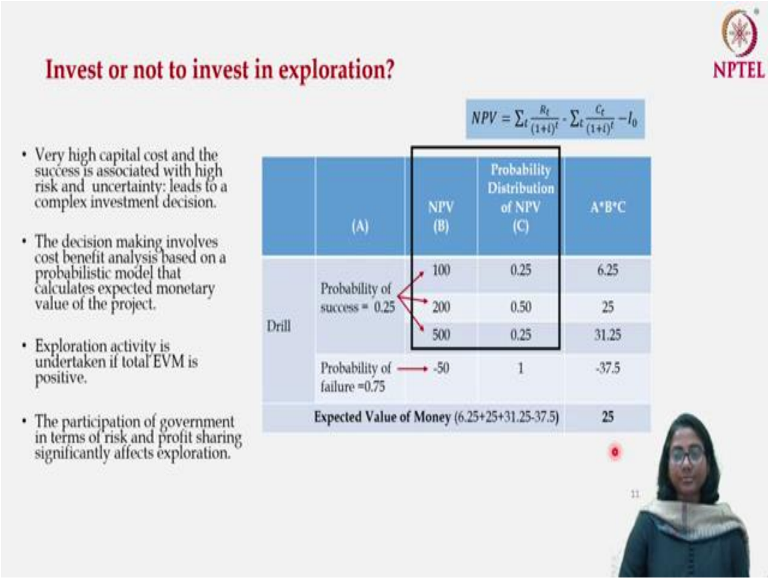

The decision that is to be made is whether to invest or not to invest in exploration activities. If you can recall we discussed the concept of Net Present Value and the concept rate of annual return. Here we are going to make use of these kinds of concepts. The question is, how do I decide whether to invest or not? Why is this a crucial decision? This is so because the capital cost is very high if you want to go for exploration activities.

The variable cost associated with exploration activity is also very high however, the capital cost is higher and there is an element of uncertainty associated. The element of uncertainty is because even if an exploration activity is undertaken, there is no guarantee that we are going to find fossil fuel. It may result in a failure where a lot of investment is made but fossil fuel is not found.

The decision making actually involves a cost benefit analysis based on a probabilistic model and where expected monetary value of the project is calculated. What do we understand by the probabilistic model? There is no one Net Present Value of a particular project and just looking at the Net Present Value the decision on whether to invest or not to invest is not going to be taken. There can be multiple Net Present Values associated with different probabilities and therefore we come up with the expected monetary value of the project.

This will be clearer with a small exercise with few numbers. Before that, a quick recap about the Net Present Value. The formula of Net Present Value, where we said that $\sum_t \frac{R_t}{(1+i)^t}$ is the present value of the revenue stream. $\sum_{t} \frac{C_t}{(1+i)^t}$ is the present value of the cost stream. And, I_0 is the investment which is already in terms of present value. This is the present value of the net revenue being generated during the lifetime of the project. This is the NPV.

Let us now have a look at this table. It's like a decision tree. The decision to be taken is in favor of or against drilling that is whether or not to invest in drilling. Suppose the probability of finding the fossil fuel is say 0.25. The probability of success is low, the probability of failure is relatively high that is 0.75.

If there is success in finding the fossil fuel, we move one step further to the conditional probability where we say if there is success in finding the fossil fuel, the Net Present Value that will be derived out of the project is not confirmed. The project can derive a Net Present Value worth of 100 in some suitable units may be crores of rupees with a low probability of 0.25.

The probability of a small Net Present Value of 100 is low at 0.25. The probability of a decent Net Present Value of 200 is 0.5 and the probability of a high Net Present Value of 500 is also 0.25. This will give the probability distribution of the Net Present Value. The probability distribution is the probability of getting Net Present Value equal to 100 is 0.25, probability of NPV equal to 200 is 0.5 and the probability of NPV of 500 is 0.25.

What is the expected NPV? The expected NPV is $100 * 0.25 + 200 * 0.5 + 500 * 0.25$. However, this number is not actually representing $100 * 0.25$. This is $100 * 0.25 * 0.25$ because we are talking about the expected Net Present Value; this is contingent upon the fact that there is success.

If conditional probability is accounted in calculation, the expected net value is going to be $100 * 0.25 * 0.25$, which is 6.25 plus $200 * 0.5 * 0.25$, which is 25 and $500 * 0.25 * 0.25$ which is 31.25. The expected Net Present Value is arising out of a conditional probability which is $6.25 + 25 + 31.25$.

However, coming back to the probability of failure which is very high that is 0.75 is the probability of failure. If the project fails, then the Net Present Value is going to be negative. The revenue is going to be much less than the present value of the cost and investment. The NPV is going to be negative.

If NPV is negative, there is only one option as there is no probability distribution of negative NPV. This is only one event which is happening with a chance occurrence of 0.75. In case of failure the expected loss is $-50 * 0.75 = 37.5$.

How is the decision taken? If 6.25, 25 and 31.25 are added up we get net expected present value or expected Net Present Value. This is the expected gain. What is the expected loss? My expected loss is -37.5. What is the expected monetary value of the project? This is the expected value of NPV minus expected loss. This is $6.25 + 25 + 31.25 - 37.5 = 25$.

In that case the expected value of money is equal to 25 is positive. The expected gain is actually greater than the expected loss. If you get the expected value of money to be positive, then it is wise to take the decision in favor of investment. However, this is not the only criteria, but this is the first step where one can begin.

The Expected Value of Money (EVM) is associated with a lot of uncertainty and risk. And therefore, comes the role of the government especially given the fact that the government owns all these resources and one needs a permission to explore and extract this kind of resources.

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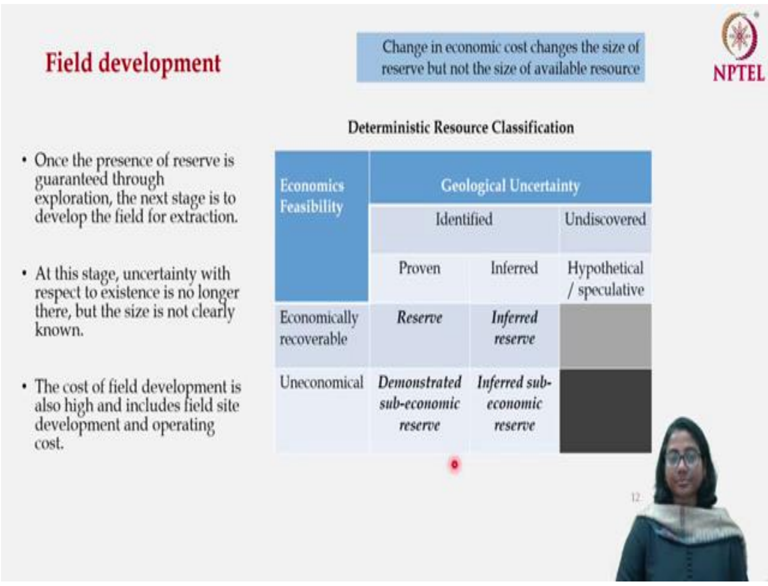

Once the exploration activity is done the next is field development that is development of the field in order to extract the natural resource. Once the presence of the reserve is guaranteed, then field development is undertaken for extraction. If the result of exploration is positive that does not necessarily provide an idea about how much fossil fuel is available on the ground. All that is known is that fossil fuel is available there but the exact amount is again unknown. Even at the stage of field development, there are certain uncertainties involved.

The cost of field development is again very high as this involves field site development and all kinds of operating costs. The whole business of exploration, extraction and production of fossil fuel-based energy is very costly. Depending on the economic feasibility and geographical certainty or uncertainty the resources can be classified in the following manner. Under the economic feasibility there are two categories; one is economically recoverable that is the reserves that can be recovered economically. In case of uneconomical reserve, the reserve is in place that is the result of the exploration activity is positive however, it is not economically feasible to take that resource out of the ground. In case of geological uncertainty two classifications are possible; one the resource is identified and second the resource is undiscovered or yet to be discovered.

If a resource is identified, then it can be proven. In case of proven reserve, the amount of resource available is known, that is we know the resource is available and we also know the amount of resource available. We understand that the resource is available however, we are not very sure about the amount of resource which is available there.

If a particular stock of non-renewable or fossil fuel has been proven and it is also possible to recover it economically then it is called a reserve. When we use the term reserve it usually has two characteristics, one the resource has been proven and the second is, it is economically viable to recover that reserve.

However, there can be other economically viable recoverable reserves which are inferred and are called the inferred reserve. But the interesting thing is that, even if there are proven reserves or inferred reserves, it may happen that it is not economically feasible to take these things out. The uneconomical reserve is called a demonstrated sub-economic reserve, if they are proven and inferred sub-economic reserve. And in case of undiscovered reserves or in case of undiscovered stock, some of them are hypothetical and some of them are speculative. However, in future we may see that the undiscovered reserve may be economically recoverable or it may not be economically recoverable.

These classifications are not very rigid, that is they are not written on the stone. This is so because the economic feasibility which is actually putting a line between economically recoverable and uneconomical, with the advancement of technology if efficiency increases the recovery becomes less costly. Then some of the reserves which are now identified as demonstrated sub-economic reserve may come into the category of reserve which can be economically recoverable.

Also, technological progress actually shifts the line between identified and undiscovered reserve. With technological advancement, it is possible to go for more sophisticated exploration techniques and identify more and more reserves. This is the soft category that is available, the boundaries between these categories are kind of flexible in terms of economic availability and the technology and so on.

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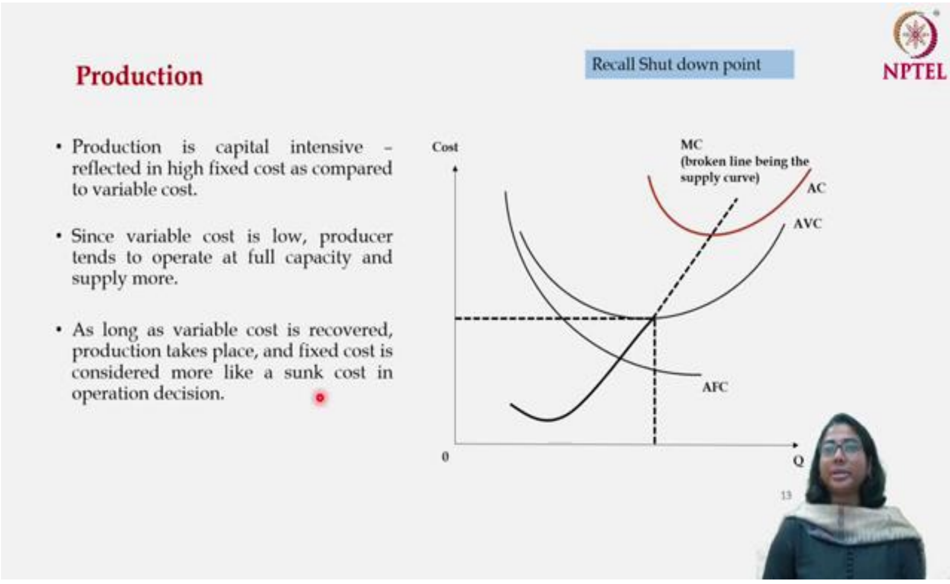

The final stage is production. The production follows more or less the similar pattern as we have seen in the case of other production and supply behavior of the producer. The diagram shows the quantity being produced and the cost associated. Fixed cost is the amount of money that you need to put in irrespective of the level of activity and we have been discussing that the level of fixed cost is very high in case of exploration, extraction, and production. The average fixed cost represented by rectangular hyperbola is very high in case of the production of the non-fossil fuel-based resources.

The second is the average variable cost and the third here is the average cost which is an aggregation of average fixed cost and average variable cost and then we have the marginal cost curve. Marginal cost is the addition in cost as production increases by one unit and marginal cost is determined only by the variable cost. The fixed cost has no role to play in the context of supply.

We said that the production of fossil fuel is capital intensive and that is reflected in very high fixed cost as compared to variable cost. However, this is not to say that the variable cost is low. Since the variable cost is relatively low, the producer tends to operate at full capacity and supply more. A lot of money has been put for development of the capacity and as compared to that the production cost is less. The objective is to utilize the full capacity otherwise the investment is going to lie idle.

In case of fossil fuel, the producers will try to produce as much as possible to go to their full capacity utilization as long as the variable cost is recovered. It cannot go into a situation where the variable cost is not being recovered. Recall the concept of shutdown point where we said the shutdown is the minimum point of the average variable cost where the marginal cost cuts the average variable cost from below.

Why was it called the shutdown point? Suppose given is the price that the market is paying to the producer, this is the price of the fossil fuel and profit maximizing equilibrium from this producer will be generated where this price is equal to marginal cost. The point is the minimum point of AVC that is giving the equilibrium point for the producer.

The diagram shows how much the producer is producing and supplying. $P * Q$, the rectangular area is giving the revenue and this area is also giving the total average variable cost. The revenue is recovering just average variable cost and as long as average variable cost is being recovered, the producer keeps on producing. However, if the price falls below average variable cost, the total revenue is less than the total variable cost. Therefore, you are not able to pay the variable inputs and the production has to be stopped.

In case of fossil fuel or any other product, the producer and the supplier keep on producing as long as it can recover the variable cost that is being incurred. What is the role of average fixed cost? It is often considered as a sunk cost. Something that has already been there and is not taken into consideration when you are talking about the economic cost or the economic decision making.

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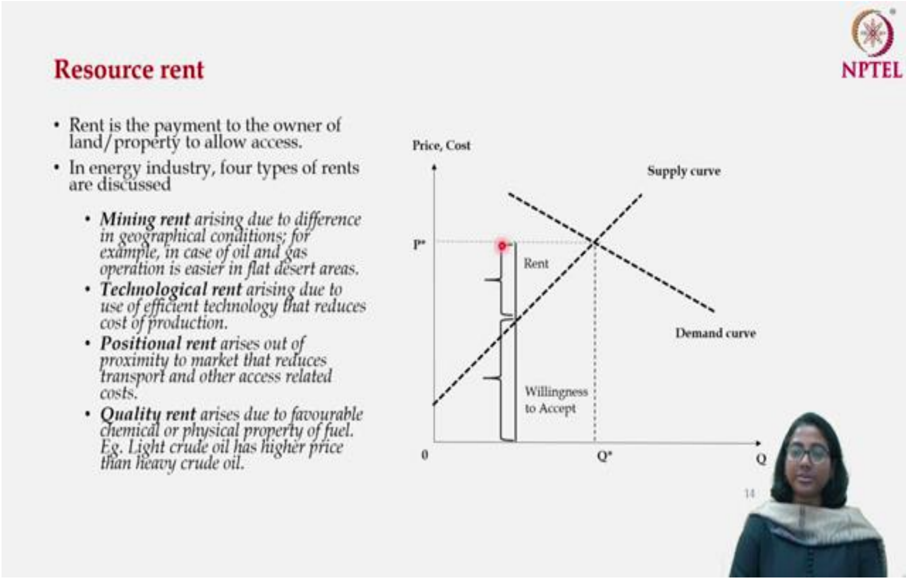

That last part that we are going to discuss is the resource rent. We have already said that the resource rent is a payment to the owner of a land or the property to allow access. What kind of rent do we see in the context of energy? We have already discussed one kind of rent, the depletion rent or the scarcity rent or depletion premium. We are not going to bring that into this literature, this is more sort of a rent that accrues to a producer because it has certain advantages with respect to the production of fossil fuel.

There are four types of rents; the mining rent, technological rent, positional rent and the quality rent. Let us begin with the diagram where in the price quantity space, we are plotting the quantity and the price and the supply curve. The supply curve essentially is the upward rising part of the marginal cost curve that you have and suppose this is the market demand curve. The equilibrium is determined at a, the point of intersection between supply curve and demand curve, $Q*$ is the quantity produced and $P*$ is the price charged. If you take any quantity for example call it Q'. The supply curve says if the producer has to supply a given amount of fossil fuel or produce a given amount of fossil fuel, then the producer has to be given at least an amount of money sufficient to recover his costs. This is the minimum willingness to accept for a producer.

If you pay the producer below this amount, then the producer will not produce because in that case the producer is unable to recover the cost. However, you see the market price is actually higher than the cost that is incurred by the producer. This difference between the market price and the cost that the producer is incurring is called the rent. For this particular producer there is a positive rent which will accrue if the production is $P*$. Why do you think that the price that the market is paying is much higher than the cost that a producer is actually facing? This may arise because of different rents. Mining rent arises due to difference in the geological, geographical or geological condition. For example, in case of oil and gas, the operation is easier and less expensive in the flat desert in the area.

However, for oil there is one particular price. There are no differential prices for differential producers, there is one market price however if you are operating in a flat area, marginal cost is going to go down and the rent component is going to be higher. There can be technological rent as well if you are using more advanced technology. Then it is expected that marginal cost is going to be lower and the rent is higher.

Similar is the positional rent that is if oil well has a proximity to the market that reduces the transport cost and it also gives access to certain kinds of information and other amenities. Final one is the quality rent. For example, the light crude oil actually fetches a higher premium or higher market price as compared to heavy crude oil, although the supply curve or the cost curve may be quite similar. Here, given the supply curve at every point of production there is one component which covers the cost of the supplier and there is another component which gives the supplier something over and above the cost which we are calling as rent. If there is integration of the whole part of rent, the rectangular area, this is called producer's surplus.

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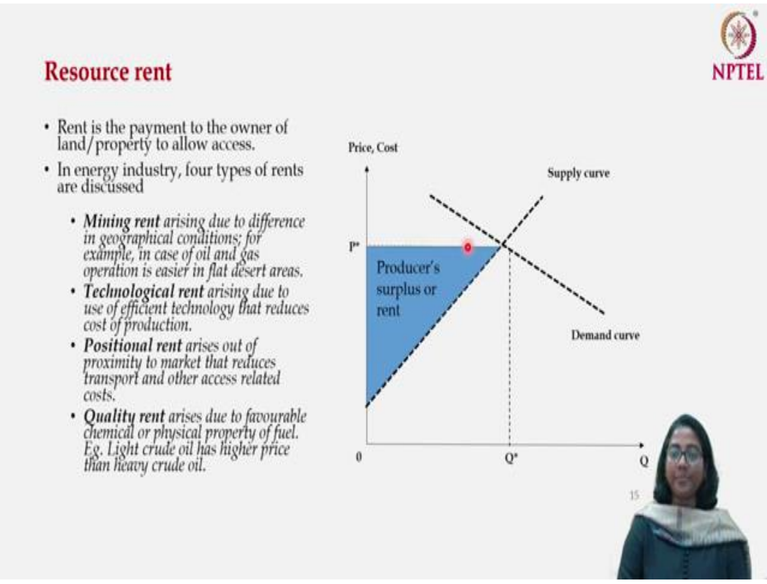

This is the producer's surplus because if the producer is applying at $Q*$, the blue triangular area is the amount that the producer is getting over and above the cost that the producer is incurring. More the producer's surplus more will be the benefit accruing to the producer.

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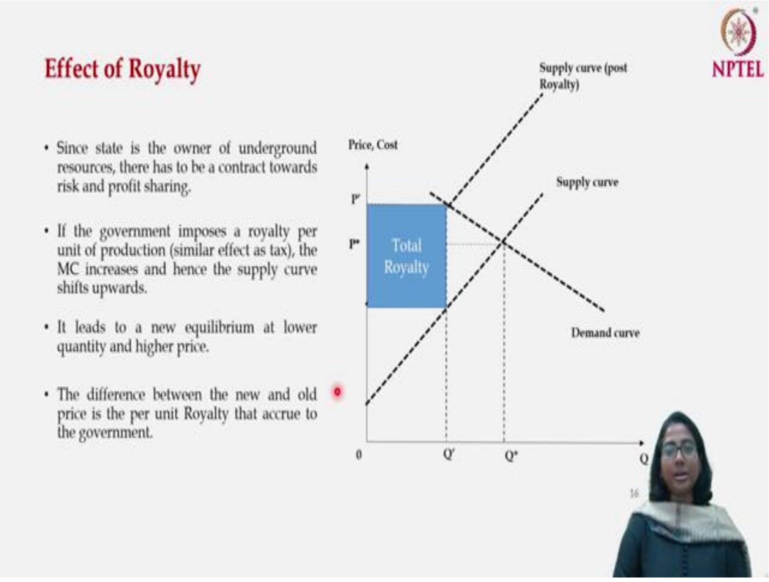

Where does the role of government come? It follows the concept of producer's surplus. When we think about fossil fuel, the state is the owner of the underground resources. If you want to extract and produce fossil fuel-based energy, you have to sign a contract with the state where you get the land on lease and then you carry on exploration activities and so on. There has to be a contract. The contract talks about sharing of risk and profit. If the government is willing to share both risk and profit, then more and more private investors will come and invest in the fossil fuel industry.

However, if the government tries to share the profit in terms of taking the rent back but does not share the risk then it is less likely to have higher investment. Let us look at the mechanism the government deploys to implement tax or royalty in order to get profit sharing as the underground resources are actually owned by the government. The government is asking for some rent because it is signing a contract. Once tax or royalty is imposed then for each unit of production the supplier has to pay something to the government. As a result, there is an increase in the per unit cost of the supplier and the supply curve of this fossil fuel supplier moves to the left. It goes up, which means that if you still want to continue with $Q*$ amount of production the marginal cost has gone up.

However, if the demand curve remains unchanged, then you no longer stick to the old equilibrium and equilibrium shifts and now you are producing Q' which is less than $Q*$ and the price that you are asking from the market is higher, which is P'. The new equilibrium is P' Q', higher price and lower quantity supplied.

If you look at the distance between the new supply curve and old supply curve, it gives the amount of money charged by the government as a royalty per unit of production. If production is Q', then the total money that is going to the government in the form of royalty is represented by the blue box. This is the distance between the new supply curve and the old supply curve multiplied by the new quantity that the supplier is supplying in the market at equilibrium. This is how the government can take a royalty or take a part of the profit or take a part of the producer's surplus to the government account.

This is a very simple model and here the underlying assumption is that the market is competitive. However, in most of the cases we will see that the market for fossil fuel is not at all competitive. It's either monopolistic in nature, monopoly can be the state monopoly as well or in some cases this is oligopolistic as nature. The nature of rent and royalty and how it applies is going to change as the market set up or the market framework changes. But this is the beginning, if you are interested you can always go back to the textbook and study more about this.

We are going to stop here, next week we will come up with some new topics for discussion.

Thank you.