Energy Economics and Policy
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Week – 02
Energy Demand – Part I
Lecture – 02
Descriptive Analysis of Energy Demand

In the second lecture of week two, we are going to discuss some of the descriptive ways to analyze the energy demand. When we talk about energy demand, energy demand can be analyzed in various ways.

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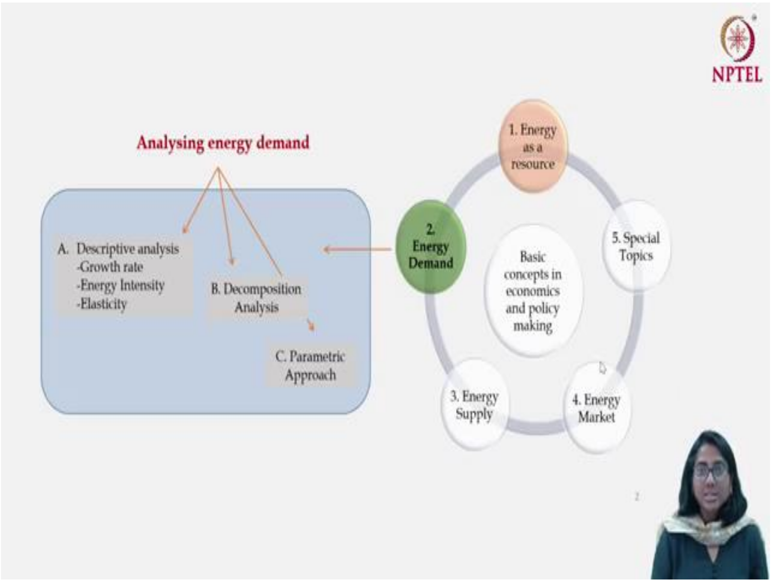

We are talking about three ways of that, one is the descriptive analysis, within which we will be discussing growth rate, energy intensity and the concept of elasticity. In the next lecture, we are going to talk about decomposition analysis and in the final lecture of this week, we are going to talk about the parametric approach that can be employed to understand the energy demand. So, let us begin with the descriptive analysis.

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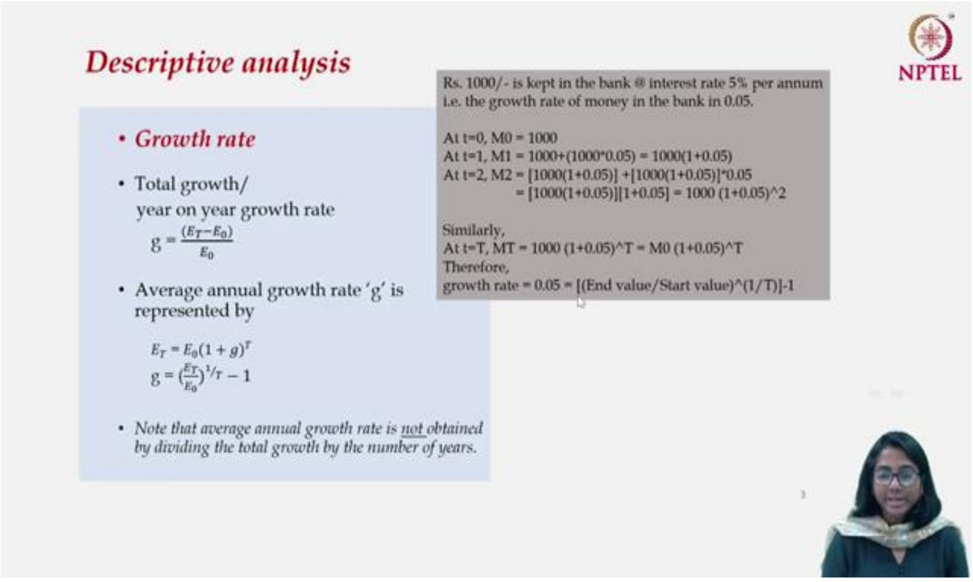

We start with the concept of growth rate, which is very-very important to understand the energy demand. You must have come across different figures that newspapers and different articles keep on mentioning, "what is the rate at which the energy demand is growing?" and "when the stock of fossil fuel will not be able to support that amount of growth in energy demand?" It also talks about the growth in the emission that is coming as a result of the use of energy and so on. So, the growth rate is one of the very important indicators and this is probably the first thing that you report when you are talking about an increase or decrease of probably various concepts, especially in the case of energy demand.

But the growth rate is not a single concept, there are different types of growth rates that you can think about and we are here going to discuss two such growth rates. The first one is very simple; this is the total growth or year-to-year growth rate. So, you think about one initial period and you think about one terminal period and you try to understand what is the total growth over this period?

Total growth/ year on year growth rate $g = (E_T - E_{0)}/E_0$

So, if you look at this formulation, you see that we are denoting this growth rate as 'g' and we are writing this as E_T minus E_0 divided by E_0. So, E_T is the time point at the end, this is the terminal time point or the final time point. E_T is the energy demand at the final time point and E_0 is the energy demand at the beginning.

You multiply this by 100 and you get the growth rate in percentage, so this is fairly simple.

The next rate of growth that we can consider is the average annual rate of growth, this is also again represented by ‘g’. Now, we can think about this formula:

The average annual growth rate ‘g’ is represented by $E_T = E_0(1+g)^T$

$where\ g = (E_T/E_0)^{1/T} - 1$

where E_T (terminal energy demand) $= E_0$ (initial energy demand) $*(1+g)\^T$. Energy demand is growing at the rate g, so that the initial demand becomes E_T. If the initial demand is E_0 and it grows at the rate of g, at some terminal point this becomes E_T. From this equation, you can derive what is the expression for g and that is going to be $(E_T/E_0)^{1/T} - 1$ E_T.

So, let us have a quick look at how we are deriving this particular formula or what do we exactly understand by the average annual growth rate. If you are thinking about a period of 10 years, you cannot simply divide this g by 10 and say that, that is the average annual growth rate, it’s a completely different formula of compounding all together.

And let us spend some 2-3 minutes to understand where the formula comes from. We take a simple example of putting some money in the bank, this is easier if you take this, because this is familiar to all of us. Suppose I have 1000 rupees, I want to keep it in the bank and the bank gives me an interest rate of 5 percent. So, I am saying is that I have some money which is growing at a rate of 5 percent. I know that this g is 5 percent or 0.05.

So, at the initial period, time point t = 0, the amount of money that I have is M_0 = 1000. Once I keep this money for 1 year in the bank, it has grown at a rate of 5%. So, how much money do I have?

$Rs. 1000/- \ is\ kept\ in\ the\ bank\ @5\%\ interest\ rate\ per\ annum$ i.e. the growth rate of money in the bank in 0.05.

$At\ t = 0, M_0 = 1000$

$At\ t = 1, M_1 = 1000 + (1000 * 0.05) = 1000(1 + 0.05)$

$At\ t = 2, M_2 = [1000(1 + 0.05) + [1000(1 + 0.05) * 0.05]]$

$= [1000(1+0.05)][1+0.05] = 1000(1+0.05)^2$

Similarly,

$At\ t = T, M_T = 1000(1+0.05)^T = M_0(1+0.05)^T$

Therefore

$growth\ rate = 0.05 = [{End\ value}/{Start\ value})^(1/T)] - 1$

I have $1000\ (initial\ amount) + (1000 * 0.05)$. So, this is an accrual of a 5 percent rate of interest, this is representing the growth. So, if I take 1000 common from this expression, I get

$1000(1+0.05)$. This is the amount of money that I have at the end of the first year.

What will happen at the end of the second year?

I already had $M_1 = 1000 + (1000 * 0.05) = 1000(1+0.05)$. In addition to that, now I have a 5% interest accrual to M_1. So, the total money that I have after 2 years is

$1000(1+0.05) + [1000(1+0.05) * 0.05$.

Again, if I take $1000(1+0.05)$ common, then what I am left with is $(1+0.05)$. If I simplify it a bit, I can see that at the end of the second year the amount of money that I have after this 5% compound annual rate of growth, $1000(1+0.05)^2$. At the end of period 2, the power of this term $(1+g)$ is going to be equal to 2.

If we generalize it for some t period, at t=T i.e., T is my terminal point of time, the amount of money that the bank gives me back is M_T, which is the initial amount i.e. $1000(1+0.05)$. $The\ initial\ amount\ 1000(1+0.05)^T$. $This\ is\ essentially\ = M_0(1+0.05)^T$.

On the slide, E_T is the final amount of money that you are getting at the end of the term, E_0 is your initial investment, so this is the initial value (which is 1000 in your example);

$(1+g)\ is\ 0.05$ and T is the number of years that you are keeping the money for. This formula tells you that the energy demand is growing at the rate g. If that is the case, then at

$t = T, energy\ demand\ is\ going\ to\ become\ E_0(1+g)^t$ and from that, you are deriving the value of g which is like this.

$g = (E_T/E_0)^{1/T} - 1$

We will check with an example that $g = (E_T - E_0)/E_0$ is not equal to the $g = (E_T/E_0)^{1/T} - 1$. These two are two very different concepts. This is something you need to be careful about. Let us now try to explore, the implication of these growth rates with the help of some numerical examples.

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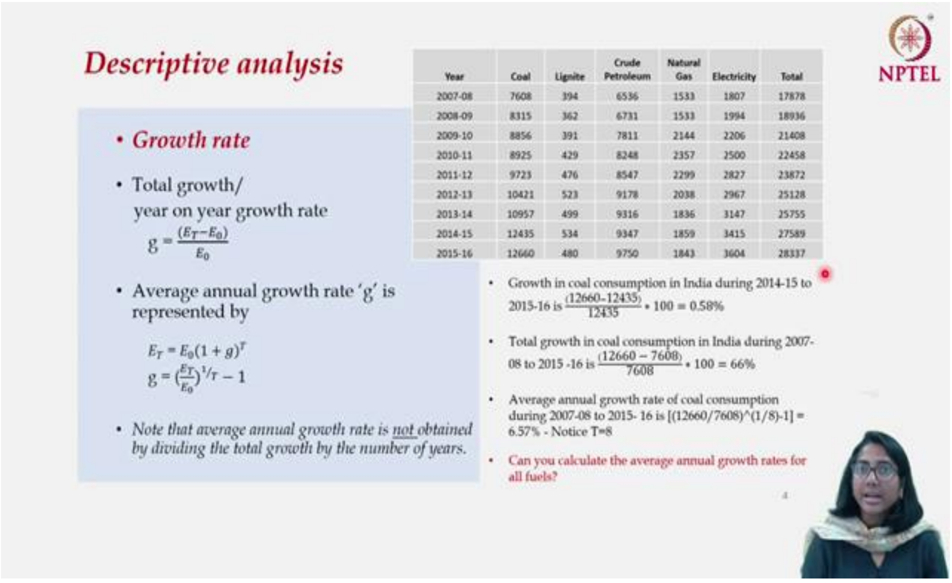

This table tells you the yearly consumption of different types of fuel in India, over the period 2007-08 to 2015-16 and we will be discussing the growth in demand for coal.

Year	Coal	Lignite	Crude Petroleum	Natural Gas	Electricity	Total
2007-08	7608	394	6536	1533	1807	17878
2008-09	8315	362	6731	1533	1994	18936
2009-10	8856	391	7811	2144	2206	21408
2010-11	8925	429	8248	2357	2500	22458
2011-12	9723	476	8547	2299	2827	23872
2012-13	10421	523	9178	2038	2967	25128
2013-14	10957	499	9316	1836	3147	25755
2014-15	12435	534	9347	1859	3415	27589
2015-16	12660	480	9750	1843	3604	28337

The first question that we are going to address: "what is the growth in coal consumption in India during 2014-15 and 2015-16?" Here we are talking about the year on year growth rate. How do we calculate that? This is the demand that you have in the year 2015-16 minus the demand that you have in the year 2014-15 divided by the demand of 2014-15. So, you can relate it to this particular formula $g = (E_T - E_0)/E_0$ and this gives you a 0.58 percent increase. If you ask me now what is the total growth in coal consumption during the period 2007-08 to 2015-16. The concept is pretty much the same, only your initial year will change; only the value of E_0 is going to change.

Instead of having 12435 in the initial year now, we are going to change the initial year to 2007. So, your initial demand is 7608, so the total growth that you have, that growth in demand that you have over this period 2007-08 to 2015-16 is $(12660 - 7608)/7608$. There is a 66 percent increase in demand over this particular period of time and here also we are making use of this particular formula $g = (E_T - E_0)/E_0$.

The next question relates to the average annual growth rate and what we are doing there. Here the question is that there is a total growth of 66% in demand during this period, what is the average annual rate of growth? So, this is something that we were discussing in the previous slide, which was analogous to this 5 percent rate of interest, so what is the average annual rate of growth.

Here what we are doing, we are relating to this particular formula $g = (E_T/E_0)^{1/T} - 1$. We are using this formula where $g = (E_T/E_0)^{1/8} - 1$. We are using this particular formula to understand, what is the growth rate? And we get that the average annual growth rate is 6.57. Two points of caution, once again, you should not divide 66 by the number of years to get the average annual growth rate. It's a different formula altogether and the second thing is that see, when we are choosing the value of T, this is 8, but if you see how many years are here this is 9. If you have information on 9 years, then your T will be equal to 8 because the growth is taking place for 8 years. And you see here what we are doing, we are saying E_0; we are not starting from E_1. We are putting the power as capital T, when we are starting with 0, right, E_0 to E_T. Therefore, the T that you are using should not be 9, but the T that you are using should be 8.

We have discussed the case of coal but you can try to calculate the average annual growth rates for the consumption of the rest of the fuel for India. And try to understand, for which fuel the growth rate is higher and for which fuel the growth rate is lower. It will also be interesting to understand whether the growth rate is increasing or declining over time and what could be the reasons behind that. Are there some economic reasons? Is it the case that the price is changing for that particular fuel, or are there some environmental concerns? Is it the case that there is a particular fuel that is causing a lot of pollution and the other is not, so what is going on behind that? So, these are the interesting things to study, when you think about the growth in energy demand or you can compare the growth of energy demand in terms of various fuels.

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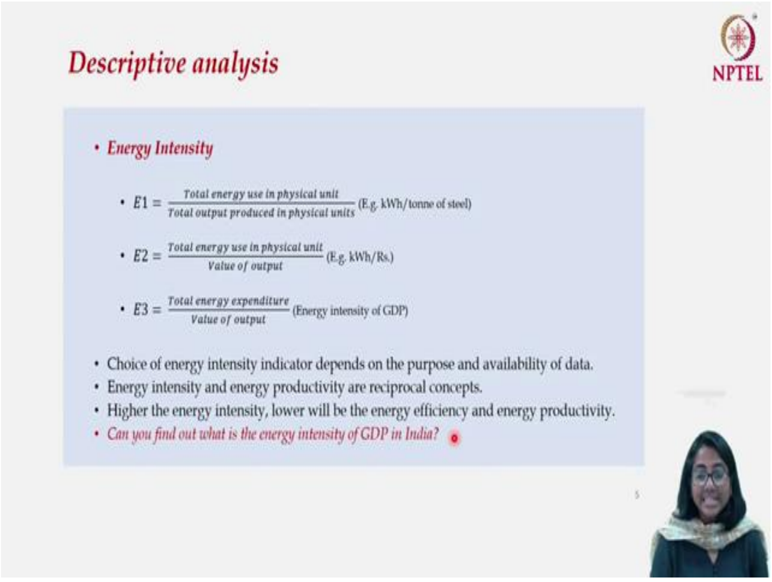

The second concept that comes handy, when you are talking about the analysis of energy demand, is the concept of energy intensity. Energy intensity is the amount of energy that you use to produce a particular amount of output divided by output. Again, depending on the data that you have or depending on the work that you are going to carry out, there are various ways in which you can measure energy intensity.

The first one, let us call it E_1, this is not some universal thing but we are just referring this to as E1. $E_1 = Total\ energy\ use\ in\ physical\ unit / Total\ output\ produced\ in\ physical\ unit$

That means I am measuring both energy and output in terms of their physical units. So, I am saying kilo Watt hour of energy required to produce one tonne of steel. Both energy and the steel are measured in their physical units.

This is a very technical way of measurement and in the engineering literature you come across the concept of energy intensity, this is how things are measured. But sometimes you may be interested in questions like what is the energy intensity of the manufacturing sector in India?

The moment you say ‘what is the energy intensity of the manufacturing sector in India?’, you cannot restrict yourselves to steel only. You have cement, you have fertilizer, you have chemical, and so on. So, there is a range of output that you are taking into consideration.

But you cannot add one tonne of coal with one tonne of cement and that too with one tonne of fertilizer to get the value of the denominator because they have different implications. In that case, what do you do? We just convert the denominator in the value of output. So, instead of saying what is the physical amount of output produced (which is kind of impossible to depict in this kind of situation), we say what is the value of output produced. If there are x tonne of steel produced, we will convert them into the value of steel by multiplying them by the market price. If there are y tonne of cement that is being produced, we will multiply it by the market price of cement and convert it to the value of cement produced.

Now, if you think about the manufacturing sector, each of the separate industries and their outputs are being converted to the monetary value. Now everything is measured in terms of the rupees. The value of output in the steel industry is x rupees, the value of output produced in the cement industry is y rupees and you can add up all these rupees. However, you can still keep the energy used in physical units. Because with energy the good thing is that when we were discussing the measurement, we already have come across the conversion factors.

Even if you have different forms of energy, different forms of fuel you can take out the heat content of that fuel and convert everything to something like kiloWatt hour or it can be Giga Joule or whatever you come across. It is possible to represent all energy in a single physical unit. However, for the output, we have changed everything to price, everything to the value of output. Once you move on from E1 to E2 kind of an indicator, you lose some kind of specifications that you had in the case of E1. However, you are being able to add some more new information because as I said for the entire industry or the manufacturing sector, you will never be able to come up with an indicator such as E1.

As you move towards aggregation, there are ways how you can lose the nitty-gritty and add more information by adding more macro figures, so this is the movement from E1 to E2. However, there might also be cases and this is mainly because of the data constraint, you don’t have the energy use data in physical units for all kinds of industries or all kinds of sectors in an economy. This is a little bit of difficult data to gather because you need to get this data from the industry itself, the production unit itself. Instead of doing that, what is the easier way? Since these all are commercial energy, so everything is being bought and sold in the market.

If I ask you what is the energy intensity of GDP, then I may not get the information on physical energy use for every sector of the economy but what I can come to know what is the value of the transaction that went on in the place. We can think about a measure where we are dividing the total energy expenditure by the total value of output. You are losing some specifications here. But again for a macro indicator like energy intensity of GDP, this is probably more useful and representative because there are various sectors in the economy for which you will not be able to get data on E1, you will not be able to get data on E2 because you don't have access to data on total energy use in physical units. But what you do have data on is the volume of or the value of the market transaction.

Now there is no clear distinction between E1, E2 and E3 and there is no guideline when you should choose one over the other. It depends on various things; it depends on what kind of data is available to you; it depends on what kind of analysis you want to do. Suppose, as I said, if you want to understand the energy intensity of the entire manufacturing sector of a country, then you can't use E1. And there is no reason why you should use E3 if you have the data on energy consumption in physical units. It depends on the purpose of your study that you are carrying out and it also depends on the availability of data.

One more thing, we just would like to take note that we are talking about energy intensity; this is energy use divided by the output produced. The other thing, which is a very important concept is called energy productivity. This is reciprocal and this is related to the concept of energy efficiency. Energy efficiency is just reciprocal to energy intensity; higher the energy intensity, lower will be the energy productivity and lower will be energy efficiency. The lower the energy intensity, the higher will be the energy production and the higher will be the energy efficiency.

Sometimes we get a little bit confused between these three concepts but this is the relationship between them, and all these three concepts are used when we are talking about the energy demand. In fact, in the next lecture when we discuss decomposition analysis, you will see that we talk a lot about energy efficiency and energy intensity.

Before we go to the next one, there is a quick question if you can find out from sources, what is the energy intensity of GDP in India? And you can track the energy intensity of India over a period of time and just check whether it’s declining, whether it’s increasing or whether it’s staying constant.

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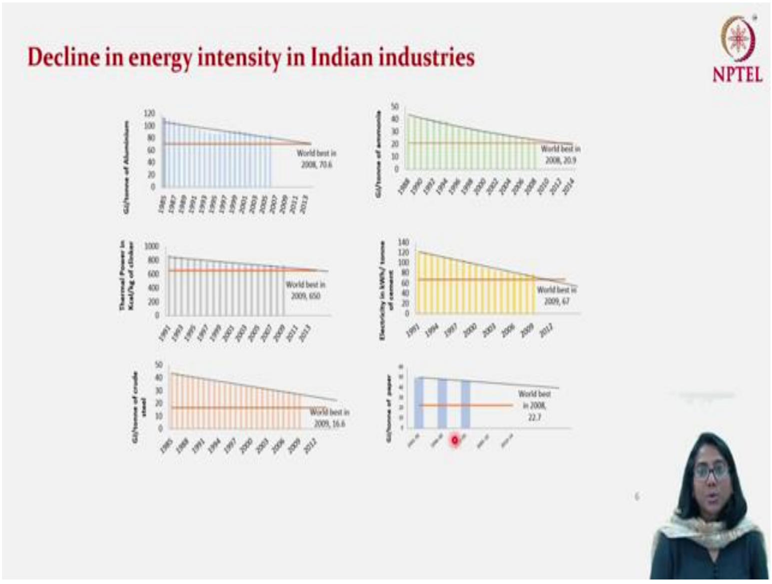

There is a quick look at the decline in the energy intensity trends in some of the energy-intensive industries in India. This is the data from a work that we carried out some years ago for all the basic industries, the energy-intensive industries, aluminum and ammonia fertilizer industry, these two correspond to the production of cement. This is the thermal power in the production of clinker and this is the electricity produced to manufacture in the next stage, that is the cement production. Then you have the production of steel and this is the production of paper.

And in all these industries what we have observed that the energy intensity of these industries has come down a lot over the years, during the past 20-30 years. It has come down a lot and for many of the industries you can see, they are very close to the world average. For example, the Indian production of cement, the energy intensity of the cement producing industries in India is one of the world's best. It’s also true in the case of fertilizer production and aluminum but the paper is not so close.

If you do this kind of analysis to understand what is the trend of energy intensity, this tells you where is the scope for policy intervention. If you think about cement, it’s already close to the world's best, it’s already close to the benchmark. But if you think about paper, there is a clear difference in terms of what is world best and where India is operating. Probably there is more scope for policy intervention in the paper industry to increase the rate of decline of energy intensity or to see how we can achieve the world best.

This is very important because a lion's share of energy consumption is going to these particular industries and to manage their demand is one of the biggest agendas of the government. In later lectures, we will explore what are the different policies that the government is taking to do that.

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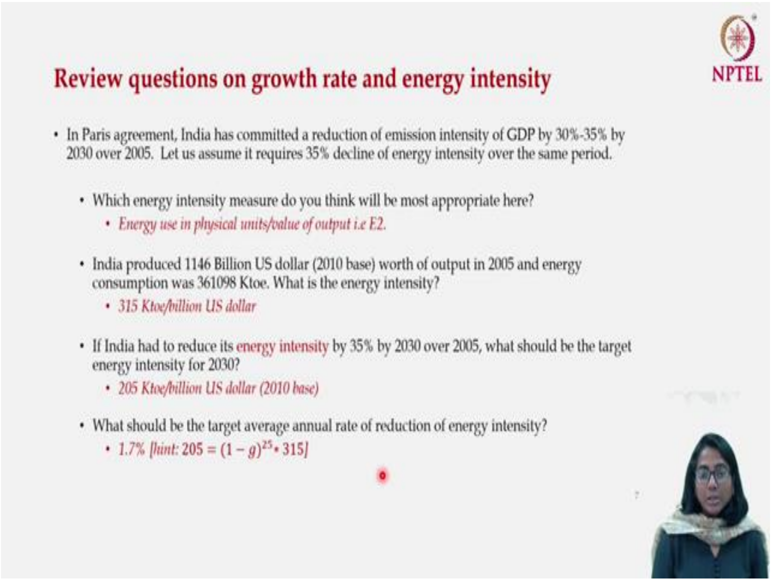

There are few quick questions on growth rate and energy intensity combined. We are going to talk about a scenario here. In the Paris agreement, India has committed a reduction of emission intensity of GDP, so notice this is not the energy intensity but this is the emission intensity of GDP by 30 to 35 percent by 2030 over 2005. Let us assume, this is a strong assumption but this is only for the analytical purpose, this is some kind of a back of the envelope calculation. Let us assume that to achieve a 30 to 35 percent decline in emission intensity of GDP, India requires reducing the energy intensity by 35 percent over the same period of time. The situation is that India has to reduce the energy intensity of its GDP by 30 percent by 2030 over 2005, so this is the scenario.

Now, the question is, which energy intensity measure do you think will be the most appropriate here? You had three options E1, E2, and E3. In the case of E1, both energy use as well as production are measured in physical quantities. In the case of E2, the energy use was measured in physical quantities whereas for the denominator we use the value of output. And in the case of E3, we use a value in the case of both numerator and denominator. One quick comment, you can see that the measure E3 for energy intensity becomes unit free because both the numerator and denominator are measured in terms of rupees or the monetary units. The question is what is going to be the most appropriate measure? I would say it's going to be E2 because you may have data on the physical units of energy consumption and you don't have to convert it to value. If you have data on E1, go for that, if you have data on E2, then you go for that, if you don't have data on E1 or E2, then it's better to go for E3.

The second question is: India produced 1146 billion US dollar worth of output in 2005 and the energy consumption in 2005 was 361098-kilo ton of oil equivalent. What is the energy intensity? If you take E2, you will see that the energy intensity is 35-kilo ton of oil equivalent per billion US dollars. I would like you to pay a little bit of attention here at the unit of measurement of energy intensity. Here the unit of measurement is kilo ton of oil equivalent per billion US dollar. In the case of E1, it would have been kilo ton of oil equivalent per ton of production of something but this is billion US dollars, this calculation you can come up with.

The next question is if you have to reduce the energy intensity by 30 percent over a period, from 2005 to 2030 that is for 25 years, what is going to be your target energy intensity? Again, you can do the calculation and check whether it's matching with your answer or not. If you have to reduce the energy intensity by 35 percent for 25 years, it has to become a 205-kilo ton of oil equivalent per billion US dollar, so this is your target energy intensity to be achieved.

The final question, this takes into account the average annual rate of growth. The question is what should be the target average annual rate of reduction of energy intensity? And this takes you to the formula, where you use that the average annual rate of growth is a function of the initial and the terminal year and also the time period that you are considering. A quick hint that is given, you can calculate it in this way and this should give you an answer that the average annual rate of decline to reach from 315 Ktoe per billion US dollar to 205 Ktoe per billion US dollar, is to have a reduction rate of 1.7 percent per annum.

One quick observation, when you are doing this calculation your g comes with a minus sign because we are not considering the increase in energy intensity, we are considering a reduction in the energy intensity. You have $[(1-g)^{\wedge}25 * 315]$, which would give you a value of 1.7 percent.

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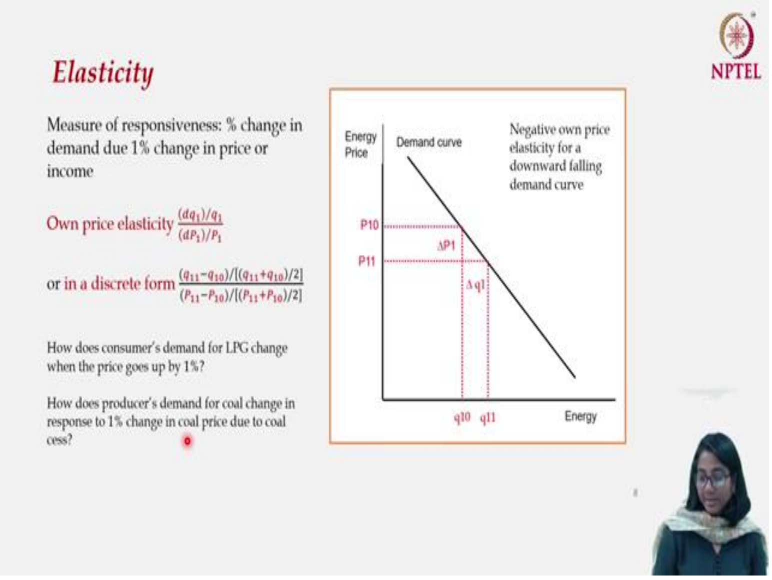

This was the discussion on energy intensity and the growth rate. The third topic that we said, we will cover under analytical tools is the concept of elasticity. And this takes us back to the discussion that we had in the previous lecture on how to determine the demand for energy for consumers as well as for the producers?

Let us have a quick look at the theoretical understanding of elasticity. We have already said that we can link the idea of elasticity with the slope of the demand curve. The slope of the demand curve tells, what is the change in the quantity demanded, when there is a change in the price of that particular product and we are going to bring that concept in here.

Elasticity is a measure of the percentage change in demand, when there is a 1 percent change in price or income. Now, I am generally saying price, this can be the price of different commodities that we are going to discuss here. Let us begin with the concept of own-price elasticity. This is a case where we are trying to understand, what is the change in energy demand, if there is a change in energy price, other things remaining constant.

This own price elasticity, this is a percentage change in demand due to a percentage change in price. The numerator here captures the percentage change in quantity demanded, so this is $dq_1/_{q_1}$ and the denominator captures percentage change in price $dp_1/_{p_1}$. This is the percentage change in demand and this is the percentage change in price. Now, this kind of formulation is possible when you have a continuous demand curve with you and you have a continuous framework.

However, if you do not have a continuous framework, in a discrete analysis you can also calculate the own-price elasticity in this manner. Instead of δ q, you have $(q_{11} - q_{10})$, so the change in demand is q_{10}. And here you have the change in price that is δ p, so this is δ q and δ p. And see the problem in case of a discrete framework is what do you take as q_1 or p_1 because you have two data points.

Instead of taking one particular data point, the best way is to take the average of q_{11} and q_{10} and for the price take the average of p_{11} and p_{10}. It looks as follows, so suppose you have plotted your demand curve for energy and the price. This gives you the correspondence between energy price and energy demand. Suppose, the price of energy falls from p_{10} to p_{11}, so this is δ p_1; this is the change in the price. As a result, the quantity demanded changes from q_{10} to q_{11}. So, this is δp_1 and this is δq_1.

Now, the question is what is the elasticity of demand if you think about this particular demand curve? What we do here is that you can take δq. Put the value of δq_1 here, and put the value of δp_1 here and then you take the average of the initial and terminal quantity and an average of the initial and terminal price. This should be able to tell you what is the own-price elasticity of energy demand for a particular consumer, it can be for the producer or it can be for the consumer.

One point to notice here is that since your demand curve is negatively sloped, the value of elasticity will also be negative because the change in price it's from higher to lower, so p_{11} minus p_{10} this is going to give you a negative quantity, whereas q_{11} minus q_{10} this is going to give you a positive quantity. When you do the calculation, it should come with a negative sign.

Own-price elasticity for most of the commodities come with a negative sign. If there is an increase in price, there will be a decline in the quantity demanded. What kind of questions are answered with the help of the concept of price elasticity? They are like this, suppose, I ask the question and these are very important policy questions; how do the consumers demand LPG when the price of LPG goes up by 1 percent or you can say what is the change in the consumer demand of LPG when the price of LPG goes down by 1 percent.

Now, why is it a very important policy question? It is so because, in countries like India, LPG is highly subsidized. If you want to increase the subsidy on LPG that will imply price, which will eventually reduce the price of LPG. Why is there a subsidy on LPG? Because we want a higher uptake of LPG and that should replace the traditional fuel that is used in cooking and causes a lot of indoor air pollution.

Now, if I want to give the subsidy to reduce the price, I need to understand what is the repercussion on the demand? Is the demand responsive to price? Is the elasticity high, or is it not so high? If the elasticity of demand is not so high, then only by giving subsidy it will not be possible to increase the uptake of LPG. If the elasticity of demand is high, then by giving subsidy, and therefore, reducing the price the government can penetrate a lot of LPG uptake in the whole system.

The second kind of question which is also very important is about the producers. How do producers demand coal change in response to 1 percent change in coal price, for example, the coal cess? What is coal cess? Coal cess is the price that one has to pay for using the coal. Some additional money that you are paying for using the coal on the top of the market price of coal. Why is it so, because coal is a polluting fuel as compared to the rest of the fuel and therefore, you are collecting this money to adjust for that pollution. Why is this coal cess imposed? The logic is that if coal cess is imposed then the price of coal is going to go up and therefore the producers will be discouraged to use coal.

Now, this is true only if the own-price elasticity of coal is very high, then only by inserting this cess in the whole process, one can reduce or one can expect a greater reduction in the demand for coal. However, if the coal demand is not so responsive, that is if the elasticity is not so high then even after the imposition of coal cess, you may not expect too much of a decline in the demand for coal. These are the kind of questions that are addressed through the concept of own-price elasticity.

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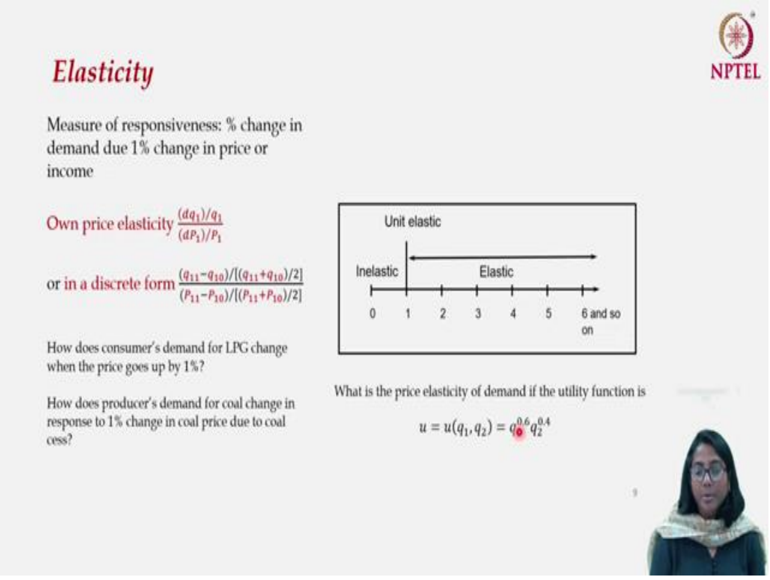

Now, as I said that it is very important to understand whether the demand is elastic or inelastic. If there is a price change, whether there is going to be high responsiveness in terms of demand or not. To understand that let us look at this scale. This is a scale which starts from 0 and goes to any positive number, this is the scale for elasticity. Now, let us begin at the point 0.

What is happening at point 0? If you look at this formula for own-price elasticity, it says that δ q1 is equal to 0. This says, even if there is a change in price, there is going to be no change in demand because the change in demand is equal to 0 which is leading to the own-price elasticity to be equal to 0. This is the situation where you have inelastic demand.

When do you have inelastic demand? When something is very necessary for you. Even if the price increases, you do not change the quantity demanded, or sometimes you are saturated with the use of that particular commodity and even if the price declines, you do not increase the consumption of that particular commodity. When you have the quantity then there is kind of less responsiveness in terms of demand even if there is a change in the price.

Second, we will discuss unit elastic demand. What is unit elastic demand? Here the own-price elasticity is equal to 1 which means, the percentage change in price will be exactly equal to the percentage change in demand. If there is a 1 percent change in price, it will lead to a 1 percent change in demand. Now, if that is the case, one quick thing to reconcile and you can think about it later. If 1 percent increase in price leads to 1 percent reduction in demand, you can imagine that the expenditure remains constant. A 1 percent increase in price is reducing your demand by 1 percent, expenditure remaining constant. So, unit elastic demand also implies that your expenditure is constant.

We are talking about the absolute value of elasticity which is why we are not going beyond 0. We are not taking any minus signs as we are discussing the absolute value of elasticity.

As we move on from 1 to the higher value of elasticity, we move on to the elastic demand region. What is happening here if the demand is elastic? A 1 percent increase in price will lead to more than 1 percent reduction in demand. Then you have an elastic demand curve. When will that kind of situation happen? This is a situation where you have a lot of unsatiated demand. If you want to consume a lot of one particular form of energy, however, the price is restrictive and if there is a reduction in price suddenly your demand goes up a lot. So, a 1 percent decline in price will lead to more than 1 percent increase in demand. This is the elastic zone.

Now we are going to discuss a couple of examples to understand what are the implications of inelastic, elastic and unit elastic demand curve and what are the other concepts of demand. This is a small exercise that you can do, we already have discussed the utility function, this is the Cobb Douglas utility function, where you have $q_1^{0.6}$ as your energy consumption and $q_2^{0.4}$ is your consumption for pizza. And you solve for the equilibrium and you also draw what is going to be the demand curve for q_1 and q_2.

Here the task is to derive the own-price elasticity of demand for both the commodities q_1 and q_2 and the hint is that you can start from the equation of the demand curve. Before we move on to the example that I have mentioned, we can have a quick look at the other concepts of elasticity.

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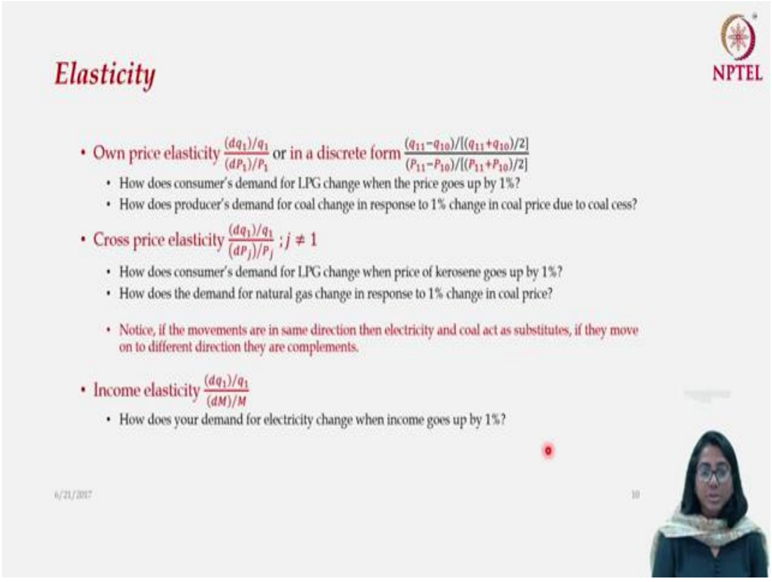

There are two more concepts. Own-price elasticity we have already discussed. There are two more concepts, one is called the cross-price elasticity and the other is income elasticity. What is cross-price elasticity? We are still interested in the change in energy demand. We are taking $\frac{\partial q}{q_1}$. However, we are no longer interested in the change in the price of energy. We are considering the change in the price of any commodity other than energy. So, your j is not equal to 1, this is the cross-price elasticity.

What kind of questions do we address with the help of cross-price elasticity? How do consumers demand LPG when the price of kerosene goes up by 1 percent? Think about a household who is using both kerosene and LPG as cooking fuel. Now, the price of kerosene goes up by 1 percent, what is going to be the impact on the use of LPG? Or think about a producer. For the producer, the question is how does the demand for natural gas change in response to 1 percent increase in coal price? You are thinking about the cross repercussions, you are considering the change in the price of one commodity and you are talking about the demand change in the other commodity.

The final one is the concept of income elasticity. What happens in the case of income elasticity? Sometimes if we have more money, we tend to buy something more, and also if you have more money you may buy something less. This is the concept of income elasticity. If your income goes up by 1 percent, what is going to be the repercussion on the demand of a particular fuel?

We started with the example of the electric vehicle. Probably if the income level goes up, then you may think about using electricity as your fuel for mobility and discard petrol as your fuel for mobility but that can be determined by your level of income. This is the responsiveness of demand to change in income. In the next few slides, we are going to talk about a couple of examples that are related to these concepts.

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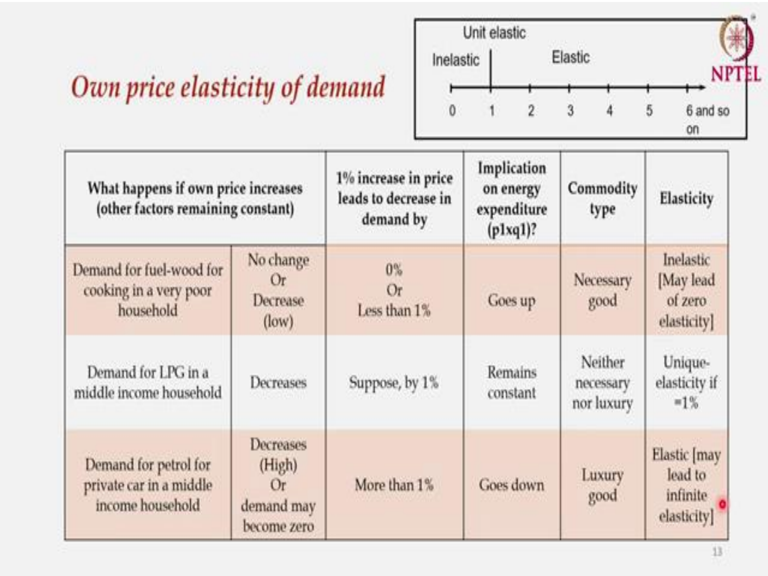

What happens if own price increases (other factors remaining constant)		1% increase in price leads to decrease in demand by	Implication on energy expenditure (p1xq1)?	Commodity type	Elasticity
Demand for fuel-wood for cooking in a very poor household	No change Or Decrease (low)	0% Or Less than 1%	Goes up	Necessary good	Inelastic [May lead of zero elasticity]
Demand for LPG in a middle income household	Decreases	Suppose, by 1%	Remains constant	Neither necessary nor luxury	Unique-elasticity if =1%
Demand for petrol for private car in a middle income household	Decreases (High) Or demand may become zero	More than 1%	Goes down	Luxury good	Elastic [may lead to infinite elasticity]

The examples go on like this. We spend some time understanding what is there in the rows. Different columns say different thing. In the first and the second column we are saying what happens if own price increases, other factors remaining constant and below we are going to state the events that we are interested in. What happens if your price increases? The second is, we are talking only about the direction whether something is changing or not changing. Here we are talking about the magnitude. We are saying if there is one percent increase in price, what is the impact on demand?

Next column, we are saying that we know what is the change in price and in quantity demanded, what is the implication for total expenditure? And depending on the previous information, can we come up with some commodity type, and can we comment on the elasticity?

We begin with this particular example, demand for fuelwood for cooking in a very poor household. What happens to the demand for fuelwood for cooking in a very poor household if the price of fuelwood increases? Imagine you have to set the context so you have to understand the context. There is no one specific answer to this question. The context is defined by the fact that it is a very poor household and they cannot afford to move up the energy ladder. If they stop using fuelwood because the price has increased, they can't move on to, for example, LPG as it is not available.

Even if there is a change in price, you can assume there is hardly any change in the demand for fuelwood in this poor household for cooking. What is the impact on demand if there is a 1 percent change in price, you can think that the change in demand is almost 0. If change in demand is 0; even if there is an increase in the price of fuelwood, you are positioned here, so this is the absolute inelastic demand, where your elasticity is equal to 0 because the change in demand is equal to 0 or you can say that it might change the demand a little bit so it might lower the demand but the magnitude is not going to be high.

A 1 percent increase in price will never lead to a fall in demand by more than 1 percent because this fuelwood is kind of a necessary commodity for this particular household and you don't have any cheap substitute available. What is the implication on energy expenditure? The percentage increase in p_1 is greater than the percentage decrease in q_1. And therefore, $p * q$ that is your expenditure on cooking fuel is going to go up because the increase dominates the decline. This kind of a commodity is called a necessary good.

In the case of a necessary good, you typically see an inelastic demand curve which is you can have absolutely inelasticity in demand, where own-price elasticity is equal to 0. This helps you to understand what kind of policy will work here. To discourage the use of fuelwood in a particular region which is poor, one cannot think about increasing the price of fuelwood as it is not going to help.

Coming to the second example, this is a middle-income urban household and we are talking about the demand for LPG when the own price increases. The price of LPG increases, what is happening to the demand for LPG? Here you can think that the quantity demanded, the LPG demand may decrease because this is a middle-income household as they also have the option of using kerosene. The moment the LPG price goes up, they can switch a part of cooking from LPG to kerosene. Now, if that is the case, then a one percent increase in the price of LPG is going to lead to a decline in LPG demand by 1 percent. This is the unitary elastic demand and the value of elasticity is equal to 1.

What happens to the expenditure? The expenditure remains constant. Probably the household sets aside some x amount of money per month to spend on LPG. If the LPG price goes up by

1 percent, they reduce the consumption of LPG by 1 percent, the expenditure remains constant. What kind of commodity is that? This kind of energy commodity are neither necessary nor luxury, there is a little bit of flexibility in the demand but not very high flexibility in demand. And in this case, if both change by 1 percent, then you have a unitary elastic demand curve.

Coming to the third example; here we are considering the demand for petrol for private cars in a middle-income household. The demand for petrol is definitely for mobility service. And what happens if the price of petrol goes up by 1 percent. There is much cheaper alternative available if you think about private vehicles, there are public transport system available. If there is a well-functioning public transport sector, then an increase in the demand for petrol may lead to a high decline in the demand for petrol because you have some very cheap alternatives and you can switch.

For example, I was taking the car every day to my office, the moment the price of petrol goes up, I decide, I am going to take the car for 3 days and rest of the 3 days, I am just going to use the public transport or the demand may become 0. If you think about the household who is a low middle-income household, they can tend to stop using the car because there is a hike in the petrol price. This may not go down exactly to 0 but this may tend to be close to 0. Now, you can see that this one percent increase in the price of petrol leads to more than a 1 percent decline in the demand for petrol. So, the demand for petrol in this context is highly responsive.

What happens in the case of energy expenditure? Because, 1 percent increase in price is leading to more than 1 percent decline in energy, your energy expenditure tends to go down. What kind of good do we call it? It’s usually called a luxury good. Even if you stop the consumption or reduce the consumption drastically there is not a big impact on your quality of life. This kind of commodity is called a luxury good. And what is the value of elasticity? The value of elasticity is going to be very high and far away from 1, it may also tend to infinity. You get it to tend to infinity when the value suddenly declines a lot as compared to the change in price.

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The next one is about cross-price elasticity of demand. Here we are considering the change in the price of one particular type of fuel and change in demand in the other type of fuel.

The first example is about the demand for LPG for cooking if the price of electricity or kerosene increases. We are considering the price of electricity or kerosene and we are considering the demand for LPG. If the demand for LPG for cooking increases, when the price of electricity or kerosene increases, then we say that kerosene and LPG are substitutes.

What is the channel through which this mechanism is working? Suppose the price of kerosene increases, if the price of kerosene increases the demand for kerosene will go down. If the demand for kerosene goes down and this reduced demand is met by LPG, then you can use either LPG or kerosene for your cooking purpose and your budget allows you to do that. So, kerosene and LPG are considered to be substitutes. If you think about a high-income household, then we are saying if the LPG price goes up, then the household is consuming more electricity. Why? Because the LPG price has gone up, the LPG demand has gone down and this vacuum that is created in the demand for cooking fuel is being met by electricity. Therefore, LPG and electricity are substitutes.

The sign of cross-price elasticity tells you whether two different types of fuels are substitutes or complements or unrelated. If you see that the cross-price elasticity is positive, the two fuels are substitutes.

In the second example, we are talking about the demand for electricity in the cement plant, if the price of coal increases. Now, this is a little bit tricky. We are considering the demand for electricity and coal price. Now, you have to understand that coal and electricity are used at two different stages of production of cement. When clinker is being produced from limestone, it's the coal that is used. When from clinker, cement is being produced then you are using electricity.

If the price of coal goes up and the industry reduces the use of coal, that means; less amount of clinker is being produced. If less amount of clinker is being produced, then your consumption of electricity to produce cement from the clinker also goes down. So, in this kind of a production process cross-price elasticity is negative. When the price of coal goes up, the demand for electricity goes down. The negative cross-price elasticity is telling you that in the process of production of cement, electricity and coal are complements.

Coming to the last example this is where we are discussing the demand for natural gas. It is a feedstock demand, the demand for natural gas in the fertilizer industry if the price of fuelwood goes up. If the price of fuelwood goes up, probably it's not going to affect the fertilizer industry anyway. These two are unrelated commodities. And in this kind of situation, you are likely to get the cross-price elasticity equal to or close to 0. The change in the price of one type of fuel is not affecting the demand for any other type of fuel. These three examples clarify how you can use the sign and the magnitude of cross-price elasticity to understand the relationship between different fuel types.

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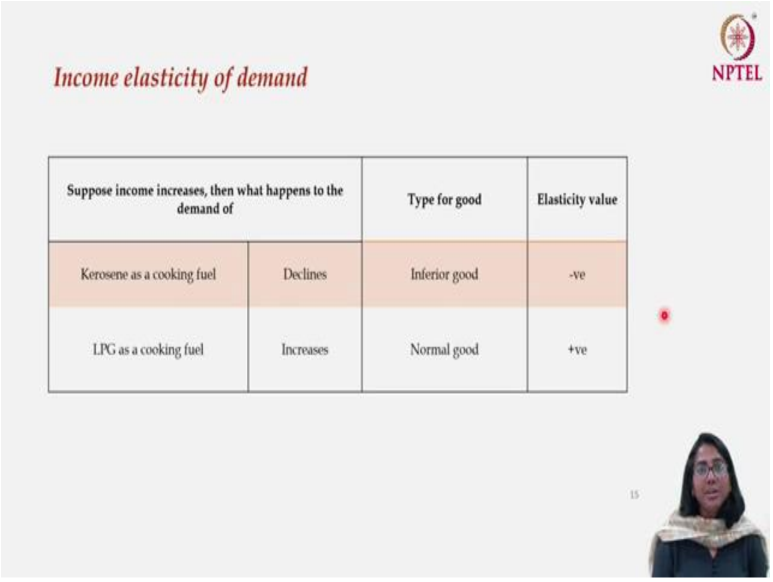

Suppose income increases, then what happens to the demand of		Type for good	Elasticity value
Kerosene as a cooking fuel	Declines	Inferior good	-ve
LPG as a cooking fuel	Increases	Normal good	+ve

The final one that we are going to discuss is two examples that make use of the concept of income elasticity of energy demand. The first example, we suppose the income of a particular family increases, then what happens to the demand for kerosene as cooking fuel. If you think about the range of cooking fuel starting from cow dung, biomass-based fuel to kerosene, to LPG, then kerosene is sort of an inferior form of cooking fuel. The moment your income increases, probably you tend to move towards LPG and then towards electricity. When income increases, the demand for kerosene as cooking fuel is likely to decline. If the demand for a particular fuel decreases when the money income increases then this is called an inferior commodity. The inferior good is something from which you always want to shift away that is elasticity value is negative.

On the other hand, if you take the example of LPG as a cooking fuel, if your income increases, probably your consumption of LPG also increases because you are moving away from kerosene and you are going towards LPG. This will give a positive value for income elasticity. And this kind of commodity is called a normal good. And this fuel is a kind of normal fuel.

Now, one has to be careful about the context, I mean it’s not that empirically everywhere you will find a positive income elasticity for LPG. If you think about the very well to do household, who can afford to buy sort of an induction oven and all induction oven usable crockery, then they can move away from LPG and can move towards electricity.

In that case, if your money income increases, you may have a situation where your demand for LPG is declining instead of increasing. It all depends on the context, that is where comes the usefulness of the empirical study. This is what theory tells us and then when you have empirical data, you make use of that empirical data to understand whether this is in line with the theory; if yes, then why; and if not, then why.

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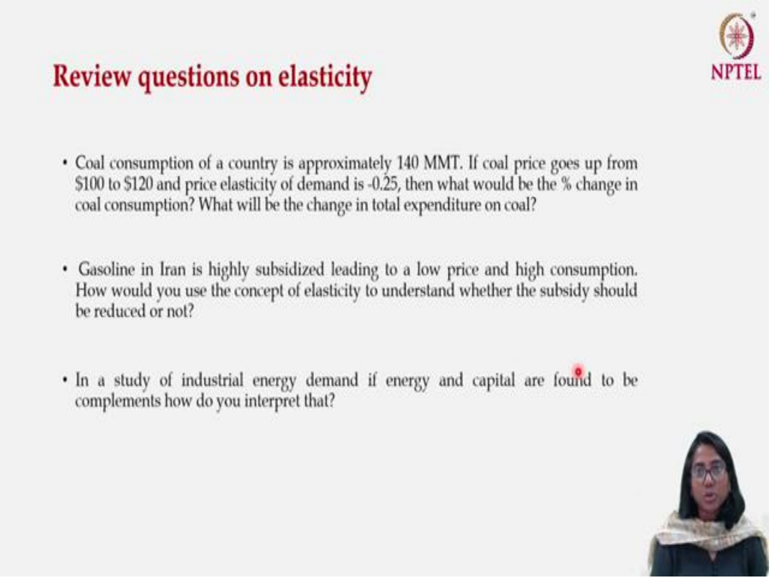

This is the end of the discussion on energy intensity, growth rate and elasticity, three very important analytical frameworks that we use. And there are some the review questions. I am just going to briefly discuss but this is more like a food for thought. You can think about it once you go through these slides, and think about the answers to these questions.

The first question, coal consumption of a country is approximately 140 MMT. If coal price goes up from 100 dollars to 120 dollars and the price elasticity of demand is minus 0.25, then what could be the percentage change in coal consumption? This question pertains to own-price demand elasticity. You can see the hint is like this, you can see that the increase in price is 20 percent, so 100 to 120. So, a 20 percent increase in price is leading to some x percent decrease in the demand for coal, so that the resultant elasticity is 0.025. So, you have to figure out what is this x, what is the percentage decline in coal. The sign is negative. One thing you know when the price is increasing, the demand is decreasing and that is pretty much usual when you are talking about own-price elasticity.

The second question is relevant to policymaking. Gasoline in Iran is highly subsidized leading to a low price of gasoline and very high consumption. But if you have a high consumption of gasoline, this leads to environmental pollution and the emission of carbon dioxide. Now, the question is how do you reduce the consumption of gasoline in Iran? Do you think that if there is a removal of subsidy that is going to sort of reduce the consumption as well? Because if the subsidy is removed, then there will be an increase in price and whether you feel that is going to reduce the demand or not. Now, you can use the concept of elasticity to understand this particular issue. You can explain how this problem can be dealt with if you understand the concept of elasticity.

The third example is about study of industrial energy demand if energy and capital are found to be complements, how do you interpret the result? You can go back to the discussion in the previous lecture when we were talking about the substitution between capital and energy when you are installing energy-inefficient technologies or you are reducing your energy intensity and that can give you a direction how to answer this particular question.

So, we are going to stop here for this lecture. In the next lecture, we are going to discuss the decomposition analysis that is again another very useful analytical tool to understand the energy demand.

Thank you.