Technology Forecasting for Strategic Decision Making
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Quantitative Forecasting

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Professor Dmitry Kucharavy: Welcome back to our course strategic technological forecasting and today we are going to discuss about logistic S-curve in particular in context of quantitative forecasting. So, today we are going to see, what are the logistic S-curve model and how can we use them for technological forecasting.

We are going to also see some examples about logistic substitution model which is essentially kind of extension of using logistic S-curve. And we can see advantages and limitation of those models and technology forecasting by itself in order of strategic decision making that lets us start gradually.

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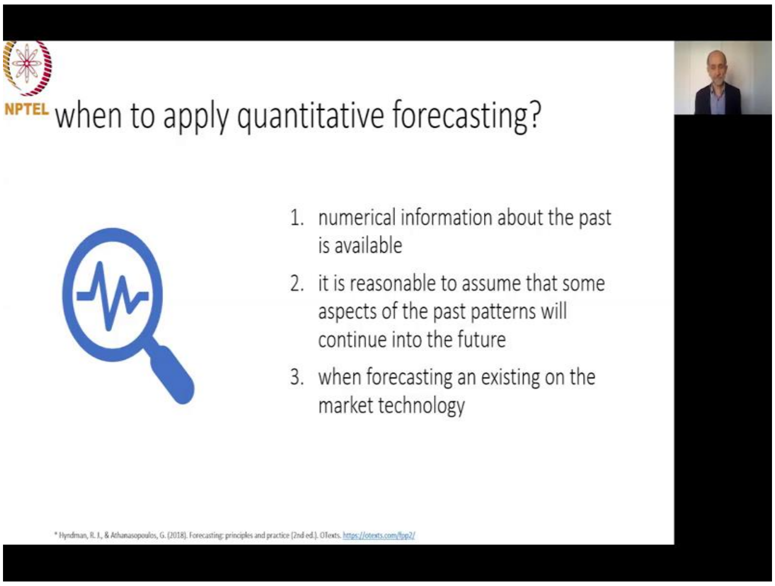

First of all, let us see, what are the area of application of quantitative forecasting. We use quantitative forecasting when we have numerical information about the past and this is very important, because if you have no, this data to use, quantitative model is not possible. The second - When it is reasonable to assume that some aspects of the past patterns will continue into the future. What does it mean?

It means that, when we have a data and we have our basic assumption that the patterns that we can learn from those data will continue in the future, we can use those patterns for the forecasting. And the third limitation, when we can use quantitative forecasting, it is when forecasting an existing on the market technology, I mean, the technology already exists on the market.

And this is kind of contradictory requirements for forecasting emerging technologies. And we are going to discuss how we can bypass and resolve this contradiction because from one point of view, we are mostly interested to predict emerging technology, evolution and diffusion. But, to have a data, we can have a data just from the technology which already exists on the market.

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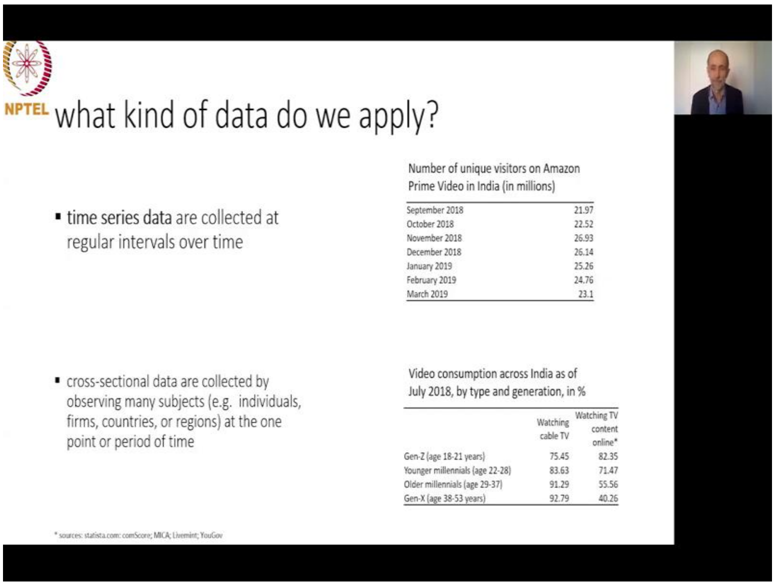

Well, what kind of data do we apply? What kind of data we can apply for the forecasting? We can split all data by two big categories. The first one is the time series data. This is a data which are collected at regular intervals all the time. For instance, if we have a number of unique visitors on Amazon Prime Video in India, and this is real data, just part of the data which is extracted from sources of data that you can find the bottom side of this slide.

We have a monthly extraction of number of visitors those kinds of data we need time series data, because after the regular intervals, we have a data which show us certain information. And other kinds of data which is applied for quantitative study and it can be applied also for the forecast. This is a cross sectional data.

This kind of data is collected by observing several subjects at one point of a period of time, for instance, if I just show you the example, quite about similar topic, the video consumption across India for the fixed period of time in July 2018 and this data represent by types and generation for instance, who is watching cable TV, and who is watching content online and divided by generation.

So, those kinds of data is also interesting and useful, but in our case for the forecasting, we mostly use the time series data. And the logistic S-curve model that we are going to see today together they are based on using these kinds of data, time series data when we have a collection of the information our regular intervals over time.

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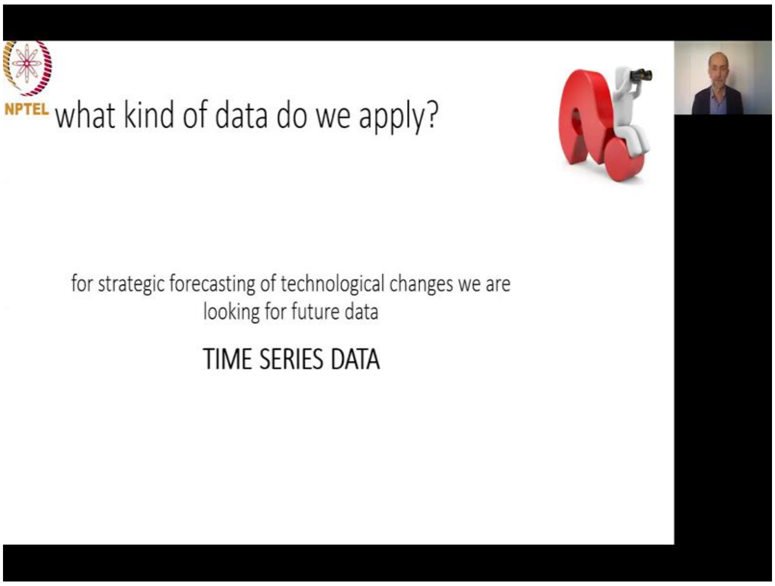

Well, what kind of data do we apply? For strategic forecasting and technological changes, we are looking for future data, in fact, what we are interested to know for instance, what will be in the future number of customers of Amazon Prime Video in India. So, for this purpose in order to answer such a question we are using time series data. We take available data, we use extrapolation technique using different functions and we can predict for instance, in 2022 how many these customers will be based on the pattern that we learnt from the past date.

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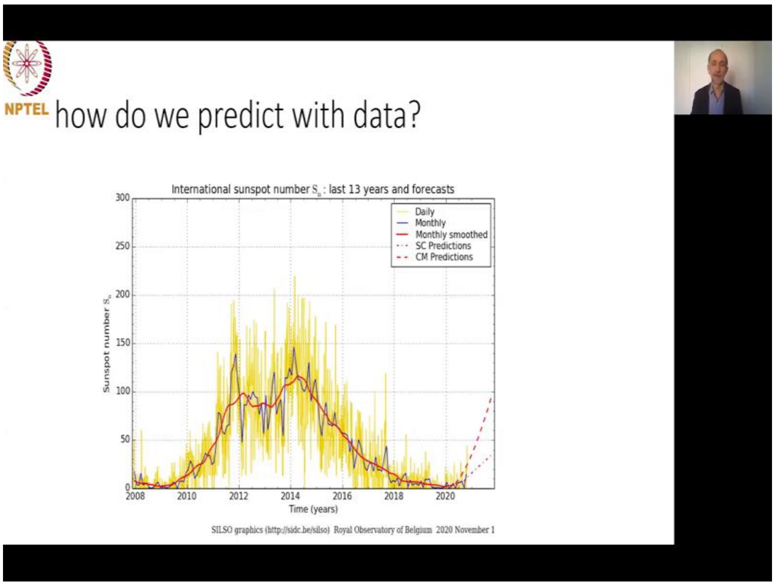

If I take this method very, very general, for instance, this is a fitting of curve. You can see on this slide the data over the long period of time about sunspot; this is a interesting data for the scientific, for scientist in order to start a magnetic activities of the sun. And you can see in the yellow, this is a daily data how many sunspots were observed.

We can see also the blue line this is a monthly average of sunspots and what we are doing by fitting curves, we are trying to find the mathematical expression, the red one, which will explain this fluctuation, these changes over the time and based on this mathematical expression, based on the pattern that we learnt from the past data; we can predict the future number of sunspots. Why it is interesting to know?

Because in fact the magnetic activities of sun can have a lot of impact on the technologies, on the earth, like mobile communication, like navigation system, and other systems that are mostly based on using electric current and electromagnetic fields. So, that is why those kinds of forecast, this is very important. As a forecast, for instance, the weather forecast, the hurricane or earthquake forecast.

Well, on this slide, I would like to discuss the basic, very basic principle, we take the data, time series data, and we try to find the pattern, this is a very general method, which is on the basis of what we are going to do with logistic S-curve. The idea is to generalize. Yes, please. They have a question.

Professor Bala Ramadurai: I have a question on the modeling of this data itself. So, we have a plot along with the data. Now, the question is often what theoreticians or experimenters battle with? So, do we start with theory and then see if it fits the data or do we take data fit a model and see if it, can we generate a model? What do you recommend when it comes to looking at data like this?

Professor Dmitry Kucharavy: Yeah, in fact, first we take the data; we try to conclude the model out of the data. And of course, after we start to use a model, we try to check how our model is close to the reality.

Professor Bala Ramadurai: Okay.

Professor Dmitry Kucharavy: In fact, we provide the measurement, we continue to measure the real situation and we see how our model corresponds to what we predict. And this is exactly we are going to see with our logistic S-curve because when we are using logistic S-curve we already take their mathematical function what we are looking with logistic S-curve we try to see what will be the parameters of this function.

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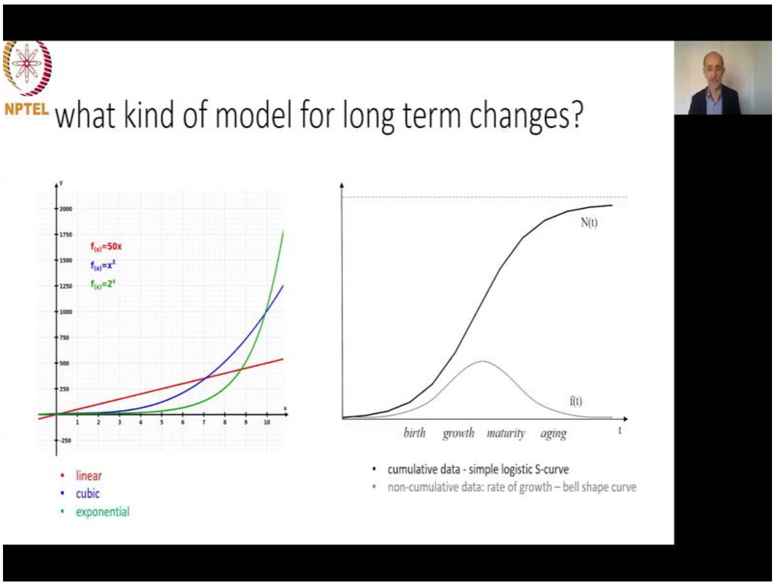

Let us see together starting from three different way to fit the data the simplest way to fit the data, this is a linear function, we can try to take the data points and try to see what are the linear function that can predict the future outputs the best way. Another way for instance, we can take simple function like cubic function and try to fit our data with this function.

And the most used, for instance, the function this is exponential growth because it was observed through many kinds of different system biological, technical system, that most of the processes they start to grow very slowly at a certain point, certain pivoting point, they start to grow very fast. From mathematical point of view, the three function both are interesting, but for real point of view, the exponential grows are most interesting.

Because it corresponds more to the real process observed, but what was also observed that there is no process, there is no diffusion, there is no any growth which can continue exponentially infinitely, and more realistic function, more interesting function for the practical point of view, this is a logistic function, which on certain period of time is very close to what we can observe with the exponential growth

But in the logistic function, we have the embedded idea that whatever growth we have it is always capped by certain limitation and it becomes from certain point of the in the time the system continued to grow not as fast as it was before and it approximate upper limit of growth. What is important also to discuss on this slide that this logistic S-curve usually represent the cumulative data.

The cumulative data like population growth, like number of cars or number of kilometers constructed and something like that or number of articles published, the same time the growth process and we already discussed this within our course, can be also described with a bell shaped curve, which represent the rate of changes and whatever system we take, whatever system or biological or technological or societal system or political one, it always starts to grow with a slow speed, after that the speed of growth increase as a certain period of time and start to decrease.

Even the cumulative growth continues, we continue to accumulate more and more species or more and more participants on the market or more and more technical devices on the market. The population can continue to grow even the speed of growth and the bell-shaped curve represent more the changes of the speed of growth, rate of growth. So, from practical point of view for strategic decision making about technological diffusion and growing of new technologies, we are going to use this curve.

And, why we are going to use this curve? Because through many years of observation, how different system grows and decline, those curve was reinvented many times in different domain, in economic study, about in biological study, about population growths or in a certain domain or even growth of individual organism or individual technical system of performance growths, those mathematical expression, describe the real process growth and decline much better than exponential.

So, we are going to use this one. So, that is from one point of view, most generic from another point of view most exact. Yes, please.

Professor Bala Ramadurai: Okay.

Professor Dmitry Kucharavy: What is the question?

Professor Bala Ramadurai: Question is regarding two systems say, one system depends on the other. And I will give you an example that I am thinking of, is the mobile phone and the camera. So, when they were put together, before they were put together, they were independent systems. So, I can imagine them fitting onto this curve. But now that they are together, does it make, does one influence the other? Does it change anything in terms of the population, the birth growth, maturity and aging itself? Will it make a difference?

Professor Dmitry Kucharavy: Yeah, thank you, thank you for this question. Because it helps us to disclose also that within a growing, the system they whenever they arrive to the upper limit of growth, they continue the evolution by integration with another system. This was exactly the question about the camera. If you look, for instance, to the process of growth on the certain market of digital camera, it was arrived to the plug tool dozens of years ago; it did not continue to grow.

But the number of cameras continued to grow as a part of smartphones. And today in our smartphones, we can observe that we have not only one camera, but we have even two cameras, the front camera and back camera, which are different resolution. And in order to improve functionality of back camera, for instance, in order to improve quality of images, we have also some kinds of combination of two or three, what can be named camera because those are the lenses and the sensors.

So, this is exactly how our system goes from one curve to another one and how they are substituted. And we will see today, the how can we use this logistic S-curve in order to describe and predict the substitution of one system by another one. But the question when system arrived to the upper limit of growth, it continued its evolution is a part of another system. And this is one of the very fundamental law of technology simulation.

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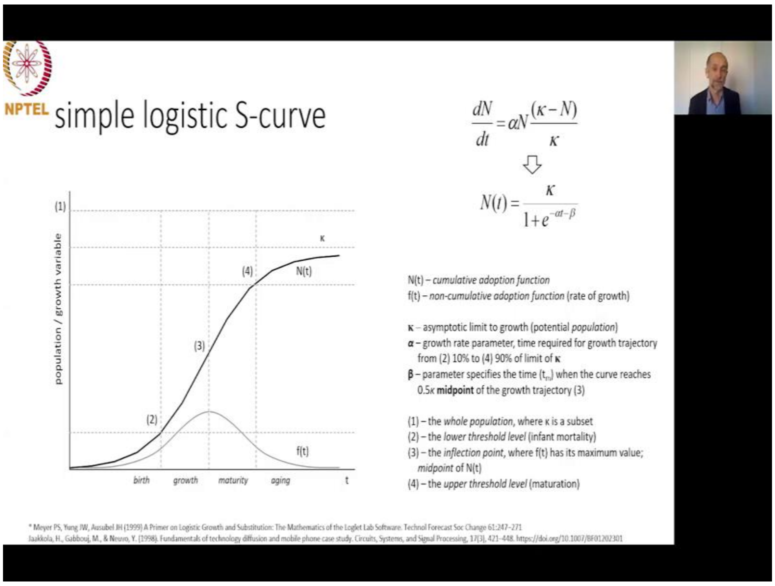

But lets us go a bit more detail about logistic curve function and what can we learn from practice. In fact, the first time this function was derived by a Belgian mathematician in 1835, in 19th century after the study in economic, after the study about growth of population in Europe. In fact, this curve is based on the following differential equation.

When we describe the ratio between the population over the time as this differential equation and this differential equation can be solved one of the solution the following way, when the population over the time is represented as a ratio of upper limits of growth divided by 1 plus exponent, exponential you know you know this, yeah wait.

But let us see, little by little the meaning the Nt on this slide, this is a cumulative adoption function, it means the cumulative rate of growth how it is cumulative growth, how it is changed when ft this is no cumulative production, it means our bell-shaped curve. The K, this is an upper limit of growth usually our system grow and never close this upper limit of growth, it is substituted by another system.

And in for different system this upper limit can depend on different kind of limitation usually it is capped by available resources. The alpha this is a growth rate parameter, which should represent time required for growth trajectory within this period of time from 2 to 4. In fact, this is a time of exponential growth. And parameter b in this equation, beta sorry, parameter beta in this equation.

(dN by dt equals to alpha multiplied by N multiplied by (K-N) divided by K which implies N(t) equals to K divided by one plus exponential of minus alpha t minus beta)

This is a specific time, this is a midpoint of growth when we arrived to the population, which is a half off upper limit of growth and usually it is interesting to know this point because it indicates us very clearly the time and the time of growth when we arrive to the highest rate of changes, you see this point three on this diagram correspond to the highest rate of changes the point one on this diagram.

This is a war population it means the capacity of the market if you are talking about technology, this is when the upper limit of growth is always the subset of this world population. The point to this is a lower threshold, in fact the all invention before they arrive to the innovation, they have to pass this, so called infant personality threshold, usually it correspond to the 10 percent on the market.

When system pass through this threshold, it starts to grow exponentially and it is very interesting to predict this point. This is a lower threshold. The point three this is exactly our the inflection point where our function of non-cumulative growth, rate of growth has its maximum value. This is a midpoint of growth and the point four this is an upper threshold after which our exponential growth change its nature and stop and our growth continue non exponential way of approaching our upper limit of growth.

And usually when the system of business after this point, it has to change the rules and policies which were used on the period of exponential growth otherwise it will be not completed because basically that curve that we are discussing now, we will see the basic assumption just a bit later, this is a curve we should represent the growth under the competition, the growth of system under the competition.

So, I would like us to see that really interesting to see that the history of this curve is interesting because it was rediscovered. So many times, even in different countries, it is named differently. For instance, in the US, it is named Pearl Corker because it was discovered by a mister whose name is Pearl, in it is named also sigmoid curve, S curve.

It has many names for different domains, because it was already discovered but what is interesting that mathematically, finally, it is the same, the same function we should have present the behavior of system when it grows, when it grows under the competition. Well, let us see for what can we measure or what can we study is not just a question.

Today, there are so many so many different application that we use this curve, even the knowledge, your knowledge is growing also logistically, just recall your own experience when you started to learn foreign language the beginning you spent a lot of time to memorize new words, but after that, then you would start to grow exponentially, so, that you become more or less familiar with the new language, when at a certain point you did not add too many words to your dictionary.

And when we run whatever we are running, this is also can be described logistic function or for instance number of scientific publication or number of smartphones on the market or number of cars on the certain market or number of population. Population growth is also very well described and predicted with this, this function. Let me share with you a few examples.

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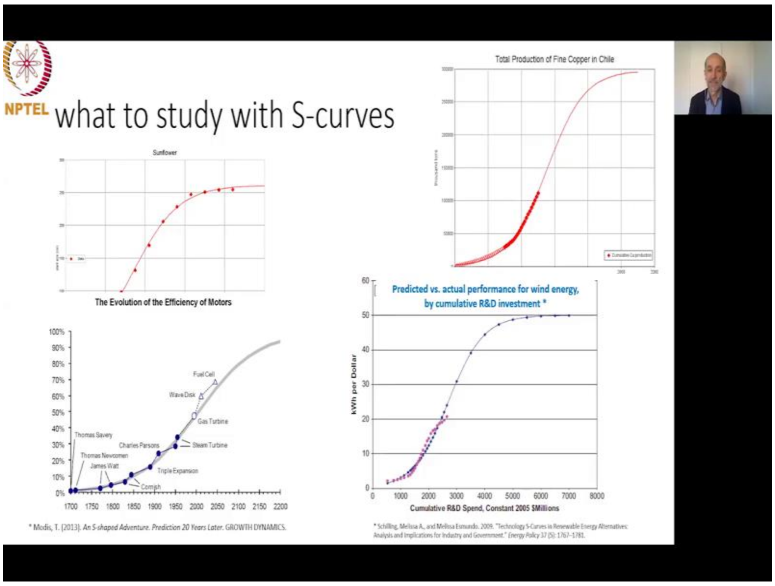

And let us at this time discuss why this term is so universal for instance, the size of any plants which grows can be well predicted the maximum size can be well predicted, when we have several data points about beginning of the growth why our sunflower does not grow taller, if you look to the process of growth, we will easily arrive to the conclusion that it is always limited by available resources.

For instance, if I take another example, which is evolution of efficiency of different motors, we can see that here we are not measuring population, but we are measuring efficiency mechanical efficiency of different kinds of motors and we can see that when we substitute one motor by another one we can see that each time the efficiency grows with us which is what is interesting that if you look at through the time is grows according to the logistic S-curve.

On this diagram, the triangles, this is a prediction and the circle points this is the recent estimate of most advanced gas turbines. The next example of logistical S-curve that they would like to share with you this is a for instance prediction of total production of fine copper in Chile.

We took the data point those red nodes, this is a data point when the curve is a prediction and what we can learn, we can learn how the production of fine copper will grow in this particular country within a time and when it will stop to grow exponentially start to and start to approximate on the basis of this extrapolation, we can build our strategic decision about technologies to use or not to use a mining industry and how many resources we will have in order to invest in our new technologies. Yes, please.

Professor Bala Ramadurai: So, question is regarding what we covered earlier, concerning the drivers and barriers, so is it reasonable to assume that along this s shaped curve, when we go, are we solving or overcoming these barriers and that is why it moves along that that that line? Is it a reasonable way to look at it?

Professor Dmitry Kucharavy: Yeah, absolutely. Thank you for this comment. Just In fact, when we said that our logistical S-curve describe the process of competition of our system, for the resources, they are how we bypass the different barriers, usually represented in most synthetic way, by the trajectory of evolution of our system over the time.

And this is exactly, but when we have a lot of several barriers to see, it is from time to time, it is difficult to synthesize out of them trajectory, but the knowledge of barriers knowledge of problems, allow us to understand what are the resources, which shall limit the evolution of our system, what are the resources, which shall limit efficiency of our motors, what are the resources which are limited, which are limiting the production of fine copper.

It is not only explored sources of fine copper, it is also different kinds of resources that can limit. Another example that we would like to share with you, it is interesting to share because on the horizontal line, you can see that we use not a time dimension, but we use kind of time series, but in the horizontal line, we have a community research and development span which is a constant to 2005.

And what is interesting to see that if we have this kind of measurement, and if you look how the efficiency of our energy producing technology grows, the trajectory is also can be described by logistic S curve. On this diagram, you can see the pink point those are data point and the blue one, those are the prediction using the logistic function and we can see that the prediction is very close to the data point. So, we can we can use this model in order to predict how our efficiency of wind energy by community friendly investments will increase.

In most of the cases we use the time as an expenses, the time as expenses on our logistic S-curve, but it can be also used not only time, if this is regular, regular changes according to the regular intervals of the resource and very essential that this is a resource that we spend the time it is most generic resources we spent for evolution of any system.

So that is why most of the cases, we plot our logistic S-curve in a time and we already discussed that, for that we use time series, but this as you can see through this example, there are some exception from the rule

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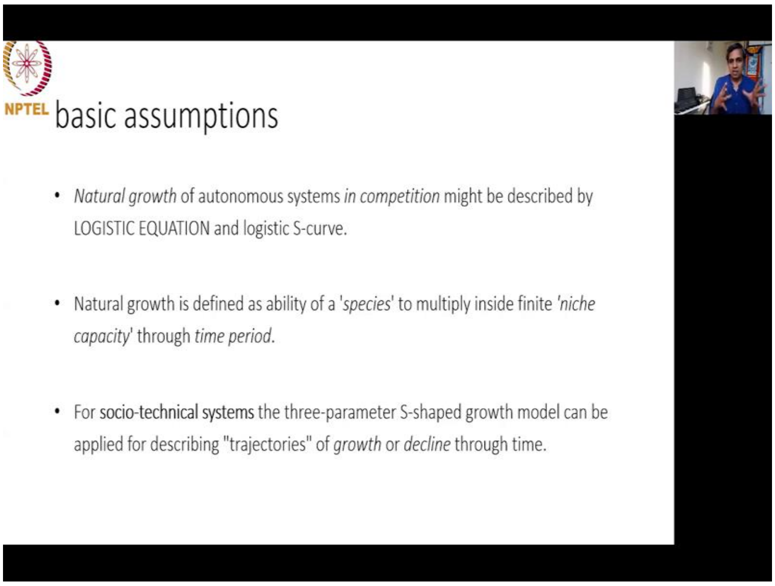

What are the basic assumption on which our logistic S-curve is based? Why it is so generic because if you looked at the basic assumption, we can see that those basic assumption can be applied not only for biological system, not only for societal system, but also for the technical system. The first one, that the natural growth of autonomous system in competition might be described by logistic equation and logistic is good, but if you look, essentially whatever system you take, it grows always in competition.

It grows always in a competition for certain resources. It can be resources of water, it can be resources of land, it can be resources of air, it can be resources, as a market niche of clients, but it is always grows the system always grows in competition. The next assumption that we use when we use logistic S-curve that natural growth is defined as an ability of species which are growing to multiply to increase the numbers inside finite 'niche capacity,' niche capacity means upper limit of growth through the time period.

Let us see what can be the example of upper limit of growth. For instance, if you are talking about personal mobility, technologies and if we use for instance, motorbikes which are most popular technological solution in India for personal mobility, more than 80 percent of the market , you cannot put on the streets more motorbikes then you have a space, you have a space, is the same as a parking, you cannot park, the motorbikes if there is no space even you can produce those motorbikes, you can stock them and people can afford them to buy, they cannot use it if there is no space.

So, how the space is reducing within a time as more people are using for instance, motorbikes represent the trajectory of evolution for instance, motorbikes under certain, certain mark the niche capacity, this is an upper limit of growths, but what shall we remember, we are on our slide about logistic. So, we had line number one, line number one, this is all available space, but all available space does not change a lot, because we have to have available space for moving on a motorbike you cannot use motorbike to move if you have no road condition. So, we are talking about space, which is representative to the road condition.

And the 3rd assumption that we use that for socio technical system, the three parameters, S-shaped rows model can be applied for designing trajectories of growth and decline through the time. In fact, there are many different mathematical expression, we should use not only three parameters, five parameters and more parameters, they have more sophisticated nature and they show in a very specific condition, higher accuracy of prediction.

But we are going to use the three parameters, simple logistic S-curve which is symmetrical according to the point of inflection point three, if you recall the diagram that we discussed just one slide before, why because these logistic S-curve resolve the tradeoff between simplicity of model and predictive capacity of the model. If we increase the complexity of the model, we can achieve much more detailed results for more particular cases.

But what we are looking for, we are looking at the models which are generic enough and accurate enough to support strategic decision making. If you are interested in a quantitative model at the end of our today's session, we will share with you the list of the references and there are some books which are available even for free for through the internet. But we are we are going in order of our course we are going to use logistic S-shaped growth model. Yes, please. What is your question?

Professor Bala Ramadurai: Thank you for the example from Indian roads that I understood for competition definitely not only motorbikes, but also in auto rickshaw that took. And the other vehicles also compete for the same available space. So, I understood the first assumption. Can you or can you give us an example of the 2nd assumption the species? What do you mean by species? In this I am not able to relate to that perhaps through an example.

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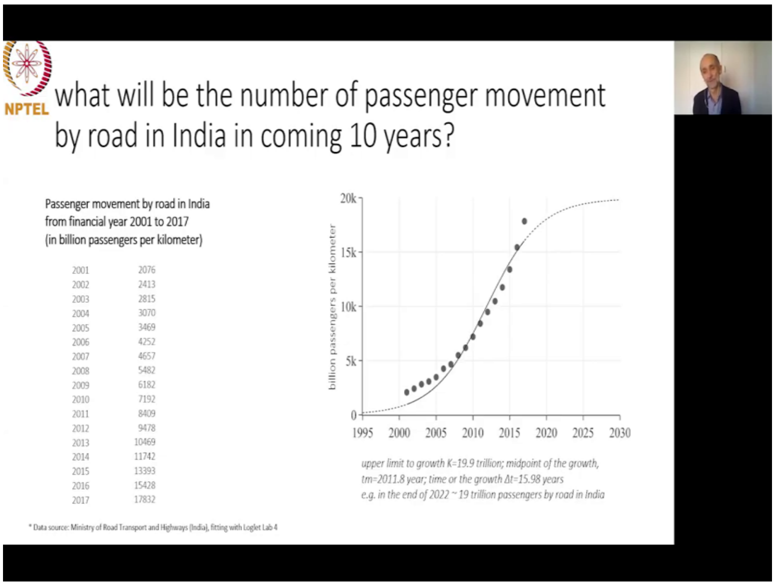

Professor Dmitry Kucharavy: Yeah, let us see just next slide. Thank you very much for this question. Let us try to understand this question through the following example. For instance, if you for the question, what will be the number of passenger movement by roads in India in common 10 years.

We have a population of the country and those population is moving within every day that people move using the roads and using not only roads, but let us see what will be number of passengers which are moving by roads, by roads this is an infrastructure, which we do not include by railroad and we do not include by airplanes, those are the people who are moving by the roads and the species those are our passengers.

Our passengers, this is a population and if you just look to the available data from Ministry of road Transportation of Highway in India, we can say the following statistics from 2001 until 2017 and this is in billion passengers per kilometer it means in 2017, 17 trillion, 17.8 trillion passengers per kilometer moved within this year, this is a cumulative data, this is how it grows within a term and it represent the mobility of people in the population growth and mobility of people all together.

And if you try to use these numbers and with our logistic curve in order to predict for instance how many passengers per kilometer we will have in India in 2022, we can arrive to that following the result. We take data points, we tried to fit those data points using logistic S-curve model and to what we arrive, we arrive to the conclusion that the upper limit of growth, the niche capacity for the road, for movement of people by road in India is about 19.9 trillion.

It means in the future it will not bypass this upper limit of growth, in the coming 10 years even, even more years ahead. The main point of these growth using this extrapolation is about almost 2012. We shall we are talking about financial years here not years in European calendar financial years in India start in April and finish in March. So, in order to have approximation by numbers, we can be more precise. In 2012, we already reached the midpoint half of the niche capacity when the time of exponential growth is almost 16 years.

So, 2012 plus 8 years we arrive to the end 2020 we arrive to the end of exponential growth. Before just be the beginning of 2020 we arrived to the end of exponential growth of passenger movement by road in India. So, we can answer for the question with a high precision that in 2022, we will have about 19 trillion passengers for road in India, this is how it works based on the data available. Yes, please. What is the question?

Professor Bala Ramadurai: Okay, the question is that now, the ministry of road transport and highways looks at this data and a recommendation for them say is, I am going to build more highways and more roads, because now I can see that this is an opportunity to make to extend it to connect to places where roads were not there, highways, were not there, will our prediction change or will it remain the same when external conditions like this, the environment changes like that? Will it make any changes in this or will it stay the same?

Professor Dmitry Kucharavy: Yeah, it seems that situation in India infrastructure of the road in India, the pattern of evolution is similar that we experienced in other countries. And what happened really is that in order to build new highways, we have to use the space, in fact, today the network of roads in India, this is 2nd largest in the world already. And if we try to build more roads, it means we are going to reduce the cropland.

If we are going to reduce cropland, we have less food or if you are going to build more roads, we are going to take another resources from another domains. So, what is interesting to see that with logistic S-curve even we do not know all the causes, even we do not know all the why it happens like that, we can catch the pattern, we can catch the pattern of evolution and we can indicate the upper limit of growths.

In order to answer for this for the question of Bala straightforward, I would like to say that it is a very unprobable that there number of passengers movement by roads in India will increase and will be more than 19 and 20, 20 trillion whatever year we are taking into account because those are the competition and if you look for instance, if you try to forecast for to answer question for India's on alternative markets, we need to take for instance into account what are the two wheelers that passengers use?

What are the three wheelers and what are the four wheelers, small and middle-sized cars. And what is interesting to see that today, according to the data, the two-wheeler sales on the hand share is our 80 percent of all vehicles, which is used in India, it shows us that we already use the existing infrastructure, very, very efficient if I compare for instance, the same situation with European country where most of the vehicles they are four wheelers means the one vehicle take more space on the road.

So, the logistic S-curve, they are kind of interesting models also because they touch essentially, the essential limitations of any kind of growth and those are the limitations of the resources, the limitation of the resources under the competition of resources why they are so universal. Years ago, when I started to use those logistic curves in practice, I was really astonished how it is possible that they can be applied, so universal, what is the root cause of the models are so efficient, and they have so predictive power.

In fact, because of the foundation of those models, the really basic engineering idea of limited resources, which are changing within a time? So, for the prediction, this was again, one of the best choices that I made. And not only me, a lot of researchers around the world, they received very successful and very credible result using this mathematical expression. Of course, as any model, it has advantages and disadvantages, and one of the problems when, for instance, I would like to see how infrastructure of roads can be substituted by another infrastructure of transportation infrastructure.

And if I start to compare the roads infrastructure with aviation, I can say that number of kilometers in aviation is not two times higher, many times high. And if I try to put them onto the same floor, it is very difficult to catch how the system substitutes each other. So, but fortunately, from mathematical point of view, those problem was already resolved. And I am going to share with you Fisher-pry transform.

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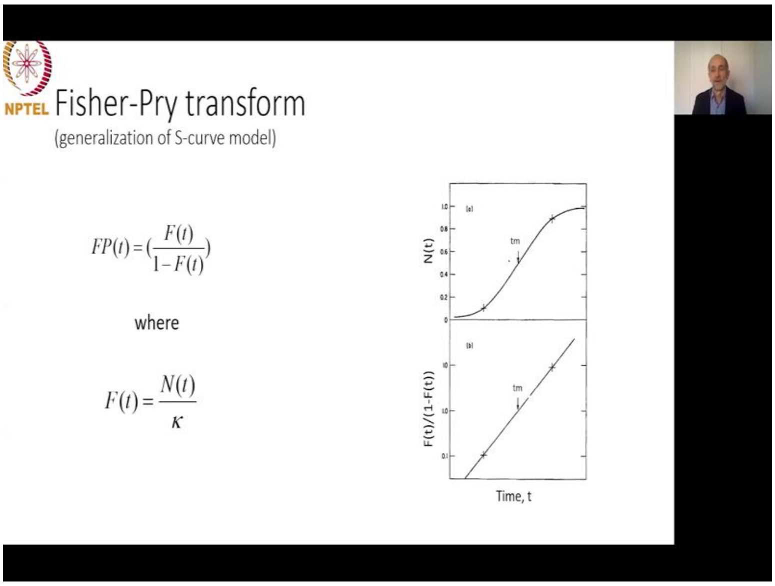

And let us understand, what does it mean and why it is so, interesting to learn the Fisher-pry transform, in fact, this is a kind of generalization of S-curve of model. If you look at S-curve model from very generic point of view, we have a upper limit of growth, which is on this diagram represent 1 and we have time of exponential growth and midterm of growth. But if we fix the upper limit of growth, if you take it as a not as a variable, but as a known, we can transform our nonlinear function into the linear one.

(F multiplied by P of t equals to F of t divided by 1 subtracted by F of t where F of t is equals to N of t divided by K)

For instance, in this case, the function can be the ratio of our population changes within a time divided by upper limit to growth. And this function of time in Fisher-pry transform, this is a ratio of this function of time divided by one minus function of time. What is interesting to see in this case, we arrive to the linear representation of the same growth process within the time, the time we do not change.

And here we arrive not on the number of kilometers for instance or not on the number of passengers but how the ratio of upper limit of growth of passengers to the present value of passenger per kilometer, for instance, if I take into account our example about mobility in India, how it changed.

One of the main advantages, why do we use this Fisher-pry transform, because with the help of Fisher-pry transform, we can see how technology substitute each other. Let me just give you an example in order to make clear, how it can be used these Fisher-pry transform. But before going the next, the present example I would like just to repeat and to be sure that you really catch the main idea.

In fact, we describe the same process of growth without any degradation of accuracy. The only difference we make transition from three parameters function to their linear function by assumption, that our upper limit of growth is fixed, when upper limit of growths is fixed, we plot on this diagram, how the ratio of population within a certain period of time ratio between populations a certain period of time to the upper limit of growth. And we use this ratio in order to depict.

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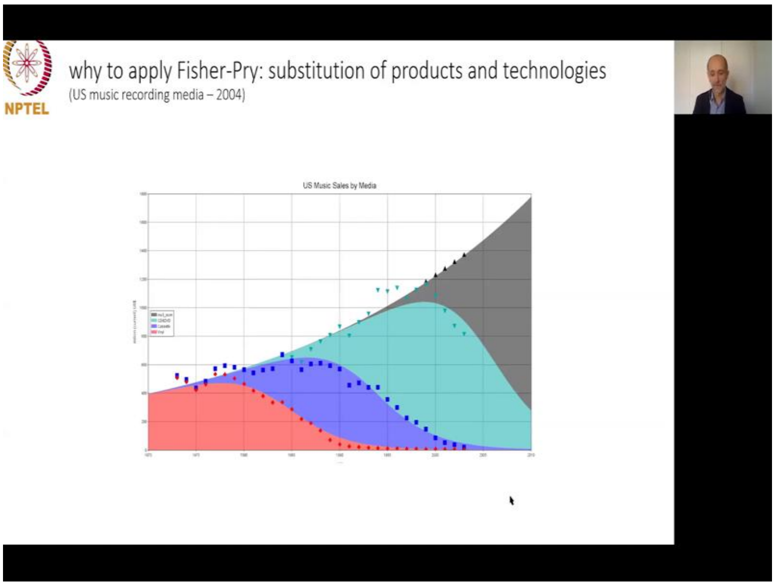

Let us see how it works through the example. Let us see the history of United States music recording media. But I am not going to show you the history up to now, I am going to show you the history up to 2004 with data which is available, just before two songs, if you look, for instance, how the market has been changed.

And when we measure it in millions of United States dollars in absolute values, we can see that this is a market of vinyl, which was after that, we had a cassette after that CD and mp3. And before 2010, we have a kind of forecast on the basis of the data available up to 2004. When we looked at these absolute values, it is kind of tricky to forecast when the technology are substituting each other, it seems that they are coexisting.

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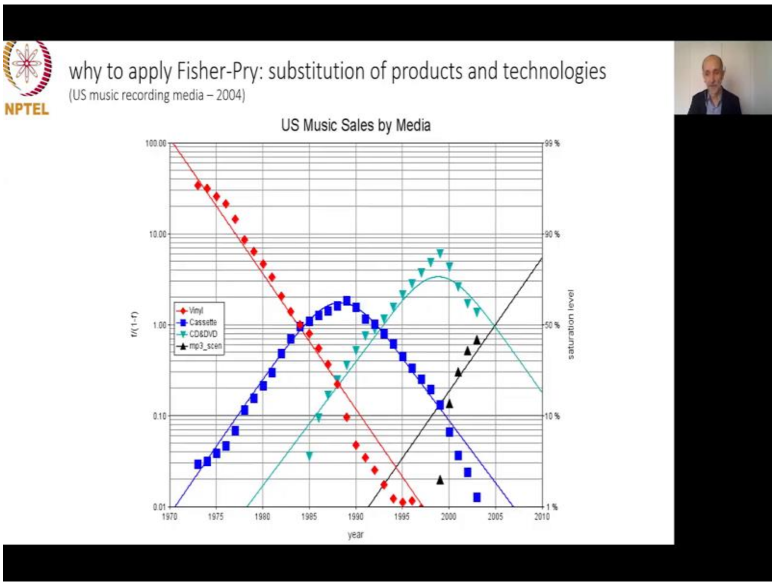

But if you take the same data through the Fisher-Pry transform and fit it logistically, we arrive to this model of the vertical x we have a ratio, it is not anymore millions of dollars, we have a ratio according to the upper limit of goods, when on the horizontal line we have a timing, what is interesting on this diagram with the line is straight it represents logistic S-curve. Well, it is not straight, it is non logistic S-curve, this is another part of the world.

The points, the different kinds of represent data when the lines with the same colors they represent the model. Here we can see for instance, within a time the market share of vinyl decreased and before 1985, precisely in 1984 in US market, it was a 50 50 percent with a cassette. When our CD and DVD they started to grow somehow, in 1985, please pay attention that in the vertical axis, we have a logarithmic scale.

For instance, these line represent 10 percent of market growth, we remember our infant mortality threshold, when the one represents 50 percent of market and 100 represent the whole process of growth. What is interesting to see that Fisher-Pry transform allow us to point clearly how the technology compete on the market.

For instance, if I take the point in a time 1987 I can see that, in this very time the CD and DVD and vinyl, they occupied almost the same part of the market when the dominating technology was the cassette, and those technology took much more than 50 percent of the market. And within a time, we can see the substitution of different technology on this diagram. In fact, we have four technologies and how did they substitute each other is not a time with a prediction.

Which of those times were the data available up to 2004? This was a prediction but in fact, this was a reality how on the market of United State, the downloadable digital music and share the market with the CD and DVD in 2005, and later on, it start to grow. Yes, please. What is the question?

Professor Bala Ramadurai: The question is I understood the Fisher-Pry and how it comes about. You showed the linear model. So, what is the nonlinear model became a linear model by the formula. But these two ones, the cassette and CD seems to sort of bend about how do we include that in the model.

Because if you were, if I were I do not have much experience, let us say with modeling this, I would just draw a straight line I would have drawn two parallel lines like that the blue line and the cyan line and gone about it, I would never have done this curved part. So, how do we do that?

Professor Dmitry Kucharavy: Yes, in fact, this bending part, this bending part represents exactly the situation after our model arrived the situation point when our technology arrived to this maturity point, and stop its exponential growth and stay on the plateau, it does not grow, but it does not decline it start to decline when the straight line appear within this bending point, our technology stay on the plateau.

But, why it is bending? In fact, because there are other technologies which participate in competitions in the same time. Let us revise a bit more in detail the basic assumption about Fisher pry transform in order to understand how it goes.

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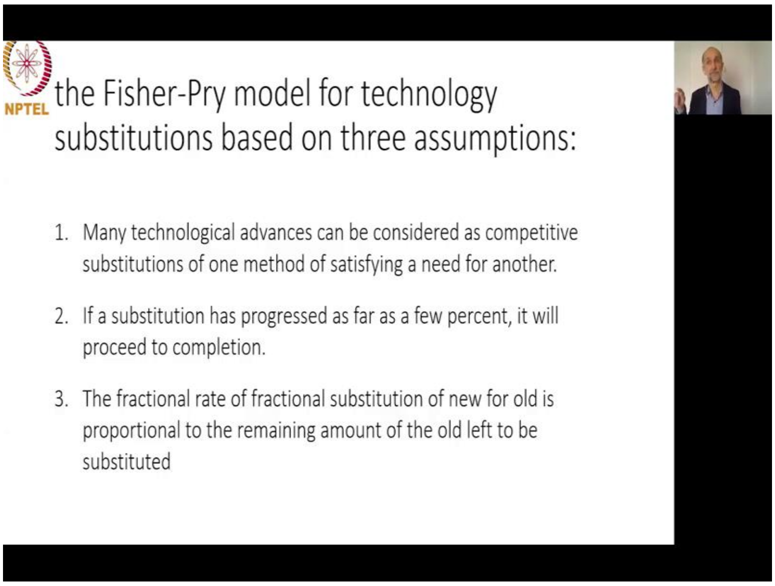

In fact, the basic assumption about Fisher-Pry transform, they are the following, there are three basic assumptions, the first one that the many technological advances can be considered as a competitive substitution of one method of satisfying the need by another, we can see the technologies for technologies but they satisfy the same need, the same function they provided access to the music, they recorded music, record and make it accessible.

We satisfy the need and this is a part of the answer, how can we predict emerging technology because whatever technology we have, those technology they will satisfy existing need. For instance, if we substitute transportation on the road by transportation by airplanes, the need is the same to move from one point to another one.

So, the one of the assumption Fisher-Pry and a model for technology substitution that we whatever method, we use, we satisfy a certain need. The second assumption is, if a substitution has progressed as far as a few percent, it will proceed to completion. It means if our technology pass through the infant mortality threshold, it becomes competitive, if it does not pass it does not participate in substitution process.

It has to arrive to the certain level of the market. And the third assumption that the fractional rate of fractional substitution of new for old is proportional to the remaining amount of the old left to be substituted. And this is exactly the explanation about this curved path. Because if you look carefully on the example, that they suggested for your attention before.

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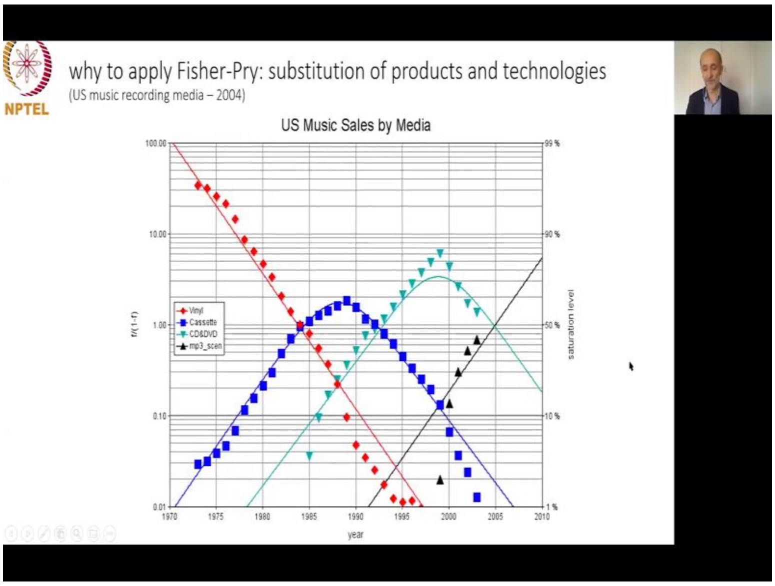

On the vertical x, this is a 100 percent of the market and even market is growing we keep is as a ratio. So, this is why, this is a 100 percent of the market, it is not absolute value of people who are listening music, this is a 100 percent of overall market. So, that is why the fractional rate of fractional substitution of new method for old is always, the ratio the proportional to the remaining amount of the old, less substituted.

And those idea was first presented years ago by Fisher-Pry in their publication and simple substitution model for technological change, which is a foundation of many many interesting findings, which were done later on. But it is interesting to see that those models since those time, was tested for many different domains, for many different industries and very useful result for strategic decision making when we are talking about substitution.

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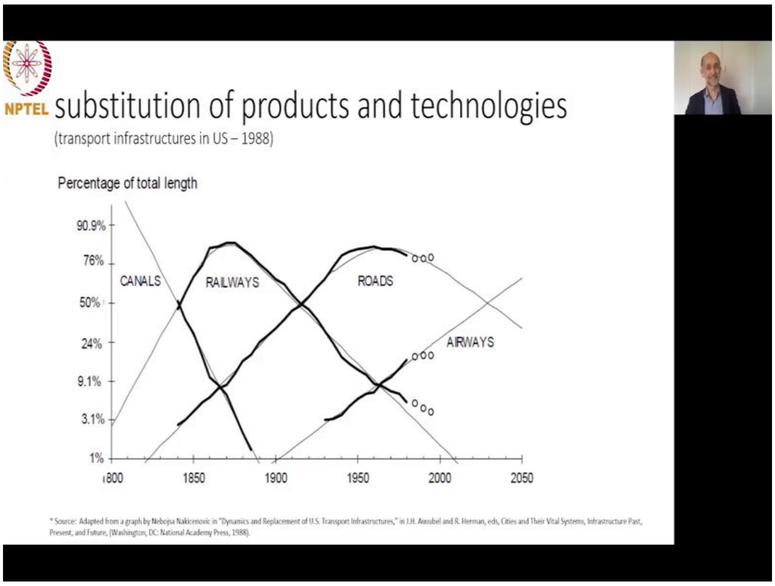

Let us see how transportation infrastructure can be. We will see after answering the question. Please, the question.

Professor Bala Ramadurai: Now, this is a philosophical question. Fisher-Pry model sounds dangerously close to Charles Darwin's theory of evolution itself, where it said, how competition among many species, actually, and one of them sort of prevails, and rest of them are still sort of there. But eventually the one species wins. That is, as far as I understand about theory of evolution. So, what is your opinion on that? So, this is the philosophical question.

Professor Dmitry Kucharavy: Yeah, of course, he has a lot of in common with evolutionary theory of Charles Darwin. But what is interesting also to see that it was proved through the observation of hundreds of examples and hundreds of substitution process within a time.

Professor Bala Ramadurai: And, yeah.

Professor Dmitry Kucharavy: This is how we can perceive the results, the results of competition and the results of substitution. And yes, of course, if you just otherwise, our basic assumption about S-curve, or remember niche capacity species. And if we just review the basic assumption for Fisher-Pry model, it has a lot in a common with biological system.

And this is how do we learn about reality by observation of biological system, and after that we use the generalized model, if they are relevant, to analyze diffusion, diffusion of our technologies and to support our strategic decision about technologies in order to answer to the question. To which technology we have to invest or to from which technology we have to step out.

Because for instance, if you look to the slide that I am sharing right now with you, this is a story of transport infrastructure in United States, with the data just up to 1988 and what is interesting to see that using logistic substitution model, which is based on the Fisher-Pry transform, they are both wavy curve, this is a data point where the thin lines those are the model. And for different countries, the situation will be different. Here we can see for United States.

And when we have our small circles, those are the data points after we use the available data up to 1998, to make a projection and if we, for instance, a need to take strategic decision. In 2010, for instance, in which infrastructure we are going to invest, or for which infrastructure, transportation infrastructure in the United States, we have to step out, we can clearly see that the market share of the roads is going to decline.

When the market share of the airways is going to increase, it does not mean when it declined, it does not mean that the absolute value is going to decline. No, it can be it can continue to grow, but much slower than for instance, something for airways and what is more interesting, even more interesting with those kinds of models, we can predict when the next infrastructure is going to start to grow and how it is going to grow.

And this is something that we can practice in order of advanced course. And we are supposed to suggest after this introductory course, that we propose for your attention. Yes, please.

Professor Bala Ramadurai: A quick observation, more than a question looks like the influx the changeover point seems to be around 80 percent is that safe to assume that after 2050 when airways also sort of would taper and turn around 80 percent is this naive or is this science based logically?

Professor Dmitry Kucharavy: No, this is more or less relevant observation. Yeah, when we have a normally two or three not more competitive technology on the market, usually we have one which are dominating one, and the 2nd one which are on the decline. And when we are talking about three, we have a one technology wishes on the client, one technology wishes on the on the growing.

For instance, if I look to the situation 1960 for the transport infrastructure in US, the roads, they were on the top when airways started to grow, and they start to buy past infant mortality when the railways infrastructure decline, yeah, the observation more or less, but I do not want to generalize, is it 80 percent, or is it 70 percent. It has to be treated. Let us take data, let us take time series and let us see each time in a particular case.

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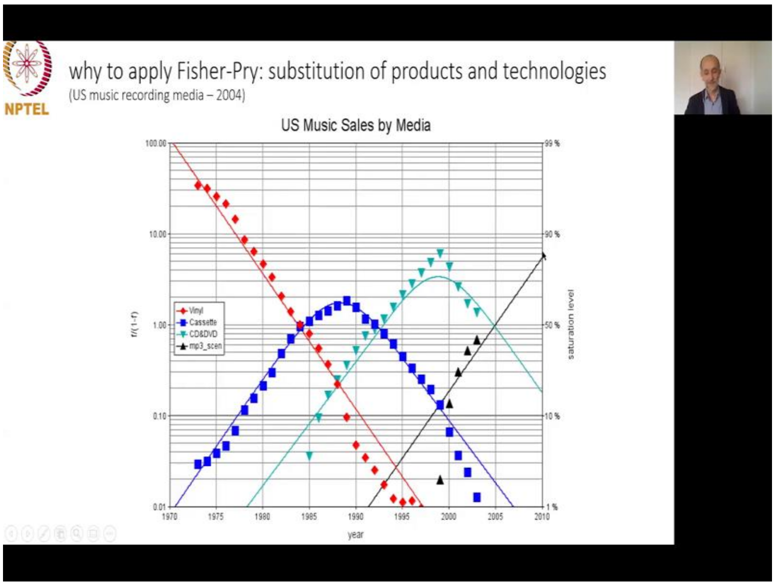

Because if I for instance, try to check this generalization according to our music, music sales in US, I can see that for instance, the CD they were on the curve when they took. Yeah, almost 85 percent we have to always check it through the data. Because the idea the main idea we are interested to catch at the bottom of revolution was in a time.

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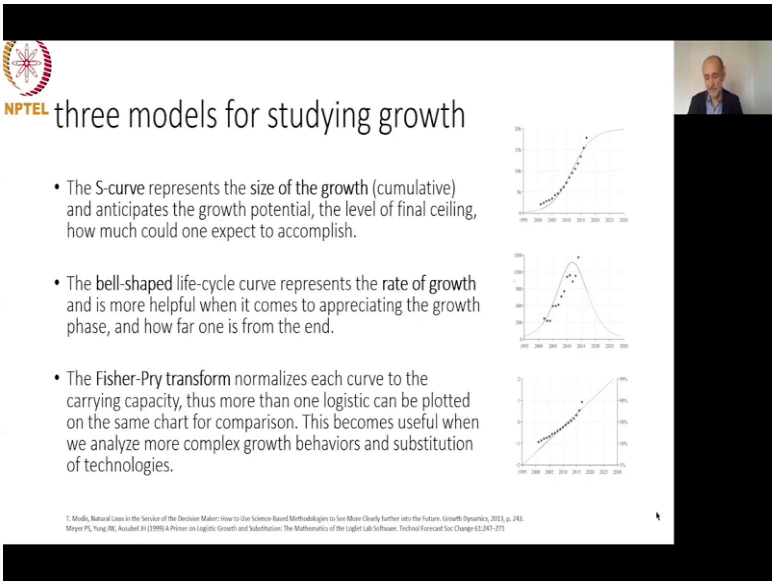

Well, in fact, if I tried to sum up, we use three main model in order to understand the evolution in order to predict evolution with the help of quantitative model, we use S-curve, which represents the size of the growth, cumulative size of the growth and anticipate the growth potential and the level of final upper limit of growth and how much would one expect to accomplish we use the bell-shaped curve.

Which represent the rate of the growth how fast with the bell-shape; we can always predict what will be the next year will it increase or will it decrease the next year. And, what is interesting that if you have a feet using logistic S-curve, you can always make derivation of bell-shaped curve because those are representation of the same process.

And the bell-shape allow us to know the growth phases and how far one is from the end, because the bell-shaped curve represents clearly what will be the end of the story for the certain system and the Fisher-Pry transform normalize each curve to the carrying capacity, it means what according to the upper limit of growths what will be the evolution and this is very useful because more than one logistic can be plotted in the same chart.

And they can be compared because this is a ratio about carrying capacity about upper limit of growth. The bottom line of each slide you have always the source the reference that you can penetrate bit more in order to go in deep about what we are talking with in our presentation. But let me discuss a bit about the pitfalls and difficulties. And for that this is something that I am going to share with you.

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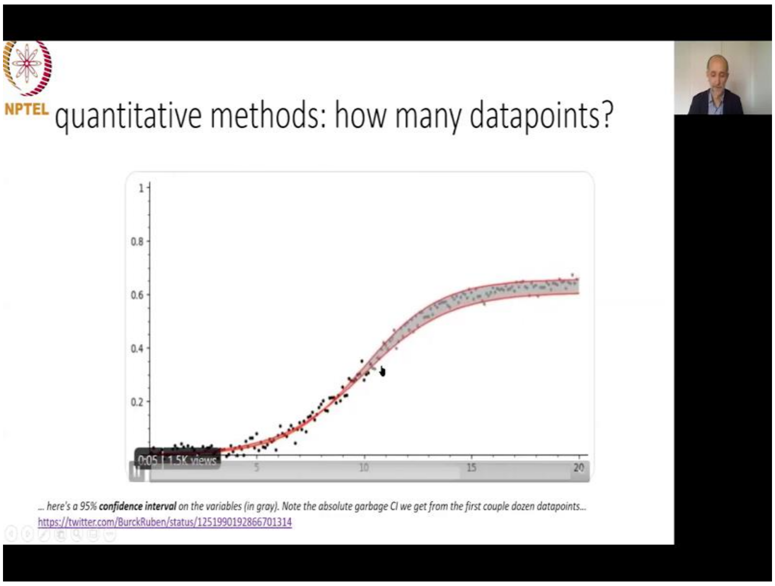

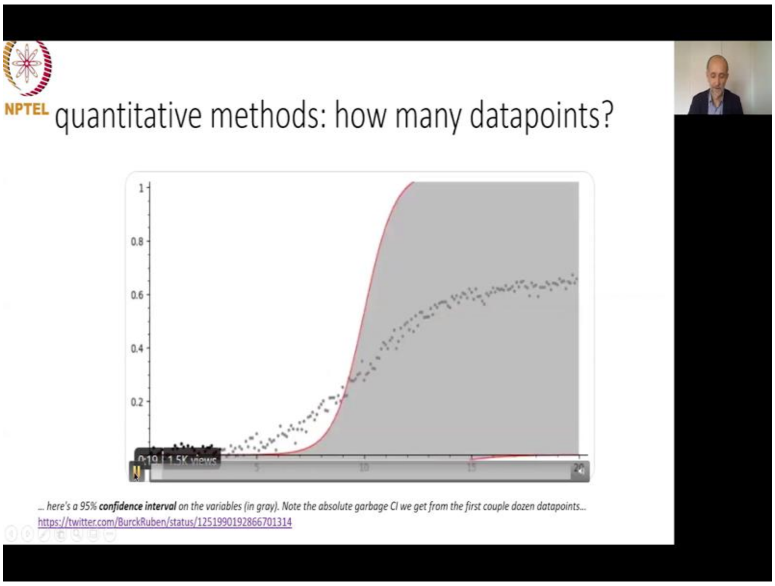

This is a problem which is common for any kind of quantitative models, which use extrapolation of data points. And in fact, the more data point we have, the more accurate prediction we can obtain, let us see through this video which is build it for 95 percent confidence interval. And we have a variable in gray. It means the result of our feed. When we change the number of data points and when the number of data point is small we have a very big area gray.

But the more we increase the number of data points, the more accurate prediction we can obtain. And the black one this is a data points available when the green one this is what is predicted, as I see it once again at the very beginning when we have a not enough data point our prediction is not so accurate and valuable, but as we increase the number of data points, the accuracy of prediction increase, out of this we can draw kind of generic conclusion that if you use logistic S-curve for forecasting the minimum number of data points has to be 12.

Why 12? Because we are talking about three parameters equation and if you have just 6 data point, the accuracy of your prediction will be really questionable, because for the 6 data point three parameters mathematical function can produce very good feed, but this feed will not be how to say this reasonable and interesting it all from point of view of reliable for the customer.

The more data point you have the more accurate result with quantitative method and in particularly with logistic S-curve we can achieve So, the one of the drawbacks we have to find data point, but what is a good idea we can connect data point about previous generation of technology. So, that is why we always start with definition of what is the main function of our technology what kind of need our technology satisfy.

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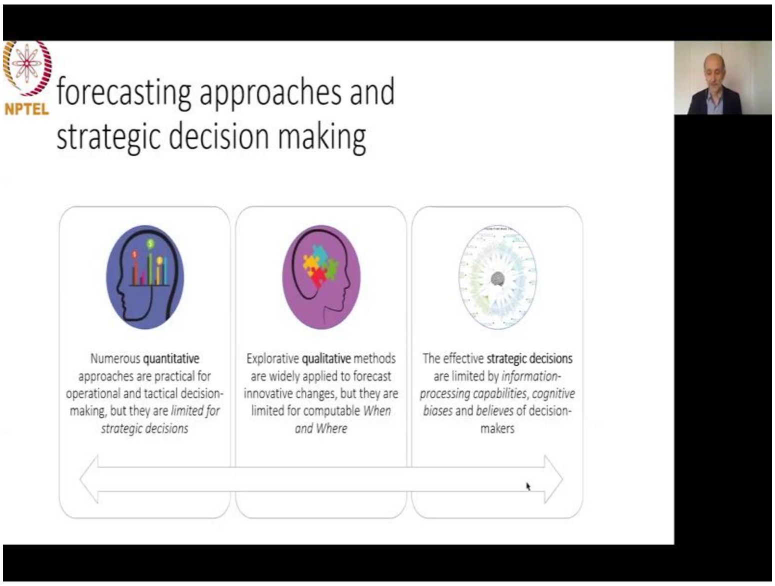

If, I just try to see another limitation, which arrived on the discussion with the forecasting approaches and strategic decision making, they can be grouped by quantitative and qualitative methods separately. In fact, we have a lot of quantitative approaches they are well representative they are well described well started and widely applied, but they are widely applied for operational and short term decision making for tactical decision making.

And but they are they have very limited application for strategic decision why, because quantitative methods usually can show us when our system arrived to the plateau of development, but they cannot answer what will be the next one, what are the features of the next system. We can compute when aviation when airplanes will arrive at the plateau, but what will be the next transportation means which will be used.

What will be the next transportation infrastructure? For that we use normally qualitative methods and the qualitative methods like Delphi's array and other judgment methods, they are also widely applied for forecast, to forecast innovative changes, but they have limited ability to answer for the question when and where. For instance a lot of people are talking about 3d printing, but in order to answer the question, well 3d printing will be the dominant technology for manufacturing in India, with a quantitative method we cannot answer.

The general idea lets us combine two methods quantitative and qualitative in order to arrive to the clear concept for supporting strategic decision making about technology management. Yeah, and there are a lot of approaches which suggest those combination, but those approaches are facing with the following problem. In fact, those approaches are limited by a human being capacity, like information processing capability, how much information which time is possible to treat and which is much more difficult to bypass this is a cognitive biases and beliefs.

Cognitive biases and beliefs, this is something that really hide from us the future and we need to have some methods, and some resources to bypass our cognitive biases and to bypass our beliefs, because our beliefs plays with us very, very tricky game, in fact, our beliefs they limit what we can see, even we see, but we do not believe in this in this situation we do not see what is well presented to us.

So, those are the difficulties that we need to find a way methodological systematic way, how to bypass when we try to forecast technological evolution from strategic point of view for strategic decision making, which is from one point of view has to be long term from another point of view has to be very precise, to answering question, what will happen when and where with a qualitative method we can answer what but we are always interested from business perspective from strategic decision when and where. So, those are limitation.

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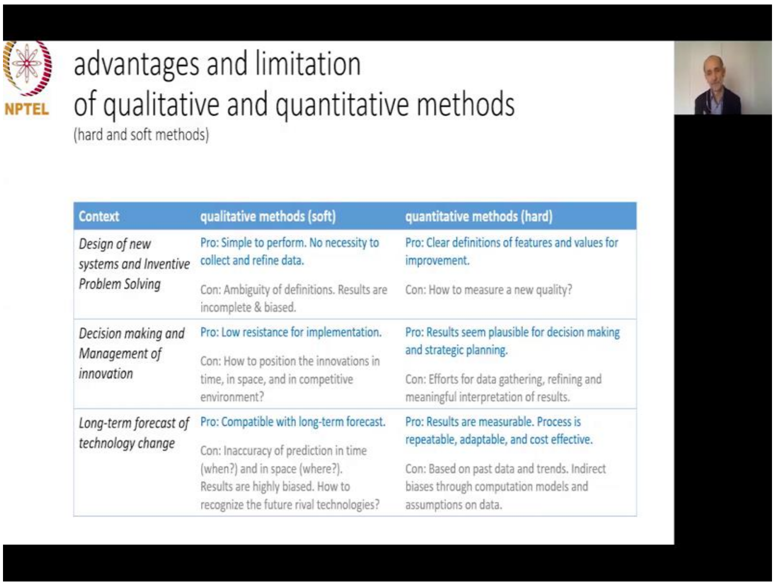

Another limitation can be regarded from different kinds of activities, if you look to the advantages and limitation of qualitative and quantitative method, but from my point of view of different kinds of activities, we can see that they have different pro and con, because if you are looking for the forecasting from point of view of design of new system, and inventive problem solving, the qualitative methods they are simple to perform not necessary to take data but they are very ambiguous of definition and the results are highly biased.

But if you are talking about designing new system quality quantitative methods like logistic S-curve they, the main advantage, they have clear definition of features and they use for the improvement, but how to measure the new quality, how to measure what is not still exist. From decision making and management of innovation point of view, the qualitative methods which are so soft, I mean which are based mostly on the judgment.

They have low resistance for implementation, easy to implement, but how to position the innovation in time in space or in time or in the market and in the competitive environment, because they have to be measured. When the quantitative method is in such a situation for decision making, the main advantage they provide results which seemed plausible for decision making. But the efforts for data gathering refining and meaningful interpretation of results are really enormous.

And if you are talking from perspective of long-term forecasting of technology change the soft method they are compatible with long term forecast it means they can be used in order to predict new quantities to describe what kind of transportation will be after the aviation but they are not accurate for predicting time and market and the results they depend on the panel of experts they are highly biased.

When quantitative methods in such situation, the results are measurable process is repeatable adaptable, we can arrive to the reproducible results, but the problem is they are based on the past data and trends and in this case, we have indirect biases and computational models and the assumption of the data and if you look for instance 50 years prediction of energy technologies, which was perfectly done with logistic substitution model, we can see that some derivation recently appeared last 10 years just because we have new players on the market, which those time did not play so much so, so the quantitative quality.

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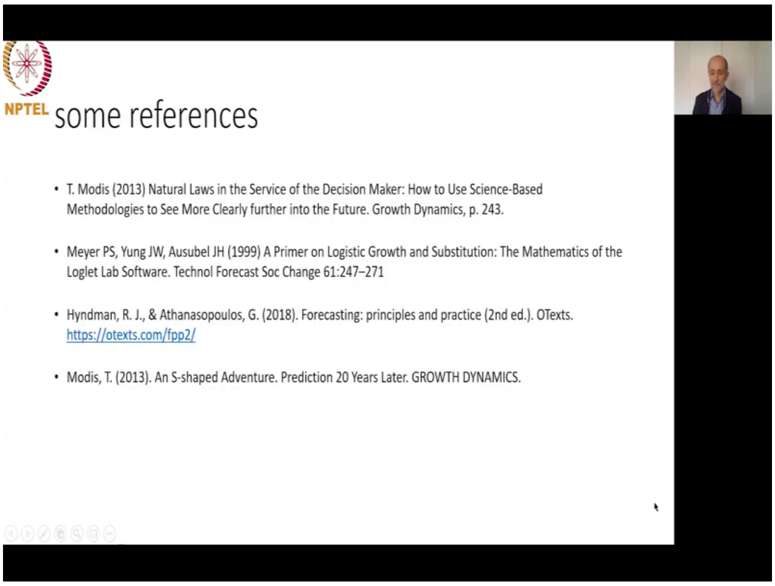

If you are interested about the topic that we discussed today, a logistic S-curve and quantitative methods of forecasting, we suggest for your attention the following references, which is nice that for instance the book which is a 3rd line in our list is freely available in the internet, you can use this link to go and to read this book where you can find a lot of different quantitative models and you can really go in deep on the subject how to forecast using quantitative methods of forecasting.

Professor Bala Ramadurai: Okay, quick comment from my side is, for learners is when they look at qualitative and quantitative, we feel, which one do I choose. The answer is rarely use the combination which is what we have prescribed in our entire course, is we do the quantitative as well as the qualitative and both go hand in hand.

So, to me that is the exciting part of trying to combine the two effectively and make sense of it and be sure of it. So, that is for me my personal favorite in trying to combine these two and making sense of the data itself. Thank you so much.

Professor Dmitry Kucharavy: Yeah, exactly Bala for strategic decision making, there is no other choice we have to combine this which is qualitative forecast puzzle. Assemble the puzzle with a measurable, when these puzzle will take place.

Professor Bala Ramadurai: Absolutely, yeah. Welcome, my dear. Thank you.

Professor Dmitry Kucharavy: Thank you very much. And thank you for your attention. See you for the next part of our course.

Professor Bala Ramadurai: See you next module.