RICHARD SCHMALENSEE: Today, we're doing electric power systems, sort of as they are, and as they have been. In 2010, electric power systems were about 40%-- I'm going to have to stand here and use the keyboard-- about 40% of primary energy, and 40% of CO2 emissions, roughly. Most electricity goes to residential and commercial sectors and supplies about 46% of the energy they use.

What I want to do today is to talk about the essential features of these systems. I'm guessing most of you haven't had a course in power systems since MIT doesn't teach a course in power systems, really, and talk a little bit about the regulatory regime. Monday we'll look forward, what are some of the challenges, what are some of the opportunities, what are some of the policy issues? So let's talk about the power system.

The one thing you really do have to keep in mind is despite all of the interest in storage, and everybody talks about storage of electricity. As a practical matter, you simply can't store electricity in bulk at a reasonable cost. You can pump water uphill and use pumped hydro, and that's pretty good, that's pretty efficient, it's very hard to build new pump hydro sites.

There's one in New England. There are no plans for any others. And as we'll see next time, the value of storage goes up over time. You can also pump air underground. And there are like two of those in the world. And there's a lot of research into batteries, but so far nothing looks cheap.

So at the moment, the system operates effectively without storage. And this matters because demand varies over time in ways that are perfectly predictable. Here's some seasonal variation. This is a forecast for New England. And you'll see that as it says, their week 8 is late July. Week 8 was forecast to be the peak. And week 32, which is that sort of secondary peak is early January.

Most American systems now look like that. They peak in the summertime, that's air conditioning. There's also a good deal of variation. So you have to follow that load. You have to follow that variation in demand.

But hour-by-hour, there's a lot of variation. Does the laser work? No. OK, how long are my arms? That sort of an interesting-- that's what? Last week for New England. And you'll see first of all that the load in this relatively uneventful April week varied within a day between 9,000 and just about 16,000 megawatts. That's fairly substantial.

You see April 2nd was a Monday. So you can see demand is higher during the week than the last two which are the weekends. You'll also see the distinctive feature. There's sort of a morning peak and an evening peak most days. The evening peak, again focus on the actual load, the blue. The evening peak is the higher. And the minimum occurs in the middle of the night, not too surprisingly. But the system has to track that. The system has to track that.

The other thing you will see in terms of predictability, forecast load, I'm not sure how far ahead that forecast is. But DA is Day Ahead. So the New England system operates with a market. And there's a real time clearing, which there has to be because you have to follow it second-to-second.

But there's also a day ahead market. So the DA gives you in effect the day ahead forecast. And you will see the difference between the green and the blue is usually small but not trivial, not 0. What else to say? Any comments or questions so far on this. Yeah, Jacob.

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: Well, it's got to be made up. The question is, that's a day ahead. Some of this is going to be-- the actual load tended to be above the day ahead which suggests-- well, if this were the summertime, I'd say this suggests warmer than expected, which is sort of what it was that week.

You get better at forecasting the weather as you get closer. So an hour or two ahead. It's not like, oh, my God, right now we've got to make a change. But you may have a few hours warning that it's warmer than we thought. So we really have to ramp stuff up.

But yeah, something has to follow that load. It could be hydro. It could be gas turbines. It's not going to be big coal plants because as I'll come to in a minute, following load with big coal plants is very expensive. There's a lot of stuff you get hot. There's a lot of stuff spinning. And to let that cool off and/or slow down and then bring it back wastes a lot of energy.

So you want things that are quick that don't have a lot of rotating mass. And that don't have a lot of stuff that you have to heat and cool, I have to heat and then reheat. Anything else? [INAUDIBLE].

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: Why is there 10,000 what?

AUDIENCE: Megawatts [INAUDIBLE]

RICHARD SCHMALENSEE: Well, it could. What are these people doing? I don't know. This is you guys working late, I guess. You've got me. Some of that traditionally would be industrial load, like if you're running a factory three shifts. There's not that much of that in New England.

Some of it may be HVAC in some buildings consuming electricity, fans running, various kinds of machinery. There are also these vampire load devices, when you have almost anything plugged in, even if it's turned off, it sucks power. So those loads have gone up.

I have never really seen an analysis of 3:00 AM load. But you're right. Your consumption probably goes a lot lower. You're within day variation is probably greater than that. And I'm trying to think about the apartment building where I live and what goes on at 3:00 in the morning.

And about all that's going on is in a warm period like this there may be some AC usage, although ours wasn't on. So I don't know. And you know, you've got appliances running all night long, refrigerators and such. But I don't know. Anything else? Yeah, Jacqueline.

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: The forecast is presumably-- and I should have checked before I put this up. The forecast is presumably farther back in time than day ahead. The forecast is a forecast. This would be the regional authority. And I'll talk about them a bit later. The regional authorities guess maybe a week ahead or two weeks ahead.

Day ahead clear demand, that's a market. People bid to supply. There's demand. Well, it clears at a price. We'll come to price later. But that is a market. That's a market outcome. That's a forecast outcome. And I just don't know how far in advance. But it's clearly by the regional authority that runs the system. An actual load is what actually happened when you turned on your computer, so OK.

Short term variation, minute to minute, the frequency, right? Everything assumes, all your equipment assumes, your appliances assume that you'll be getting electricity that vary 60 cycles a second. That frequency has to be maintained. And it's mainly maintained by sort of automatic control at designated units.

But when you get big changes like that, governors aren't going to do it. And you will need to bring units on and off. So let me talk about technology mix.

So we mentioned a little earlier that you have fast responding generating units, turbines say, or diesels to respond to short term variations in load. But even if you could forecast the load, you would want units like that.

And as I mentioned, it's expensive to vary the output from what are called base load units, nuclear power plants, big coal plants. But not only that, when you run them flat out, they have very low running cost, nuclear virtually 0, coal pretty low.

You can buy turbines or diesels. But they're very expensive to build these big units. The little units, peaking units or intermediate units, but let me just assume two kinds, think coal plants and gas turbines, they're cheap to build, but they're expensive to run, relatively on today's prices.

So you would want since load varies, you're not going to run your whole fleet all the time, right? If we didn't have those variations, if demand were constant, you just build, well, but for environmental issues you just build cheap coal plants, cheap nuclear plants if you could find one, combined cycle plants and run them all the time. But since the load varies, you know that you're not going to run your plants all the time. So what do you do?

If you look, Imagine two plants of the same capacity. One is, I call it a peaker, but let it be a gas turbine. And the other is a baseload, let it be a coal plant. They don't tend to have the same capacities, but for the sake of argument, suppose they do.

You ask, what's the total cost of this plant? The more hours you run it, the larger will be the fuel cost as a component of total cost, right? So the total cost consists of the cost of building the thing, basically taken down to say a per day cost or a per year cost. And then the slope is the marginal cost of running it. So the height gives you the total cost.

If you're going to run all year long, then the base load plant is the plant to build. Because way out here, the fact that the fuel is cheap makes up for the capital cost. But if you're only going to run it a little bit but you have to have it, then you want to build a peaker, right? Is that notion clear?

The fact that there's output variation means you want to have plants of multiple types. If you can get a base load plant to run almost all the time, or all the time, then you're in great shape. But if you have to have plants that run only a little bit, only a few hours per year, then you've got to have some of these. And you've always got that mix.

We're going to talk about wind and solar next time. They don't quite fit either of these categories, if you think about it for a minute. But if that's clear, then let's look at this.

The red curve is what's called a low duration curve. And it's the actual curve, because I happen to find it. It's the actual curve for-- it's probably England and Wales. It says Great Britain, for 2007.

What a low duration curve is, you look at how much electricity was consumed hour-by-hour. And you basically convert those to a graph putting the hour with the highest consumption here, then the second highest there. You basically stack it up.

So out here at 100%, you have the consumption, the demand, and it's expressed as a percentage of peak to keep life simple, the percentage of peak demand at the lowest hour of the year, presumably at 3 o'clock in the morning on some day that was neither hot nor cold so nobody needed to run anything, any HVAC. And it was a holiday, so there was no industrial work going on, or whatever.

So if you go back to this picture, this picture says, if you're going to run a plant fewer than H star hours a year, you're going to want to peak. It's going to have to be a peak. It should be a peaker rather than a baseload.

Come to this picture, and you say, OK, let's suppose-- just because it fits the picture-- that if there are 8,760 hours in a year, this is like 42 gallons in a barrel, another one of those numbers you have to have. 8,760 hours in a year, let's see if I can do this.

If you build baseload capacity up to this line, you know that it will be running at least that fraction of hours. You'll have to cut it down somewhat in the really low hours. But if you build that much baseload capacity, it will run for at least this many hours. Because demand exceeds that capacity for that fraction of the year, right?

So we're asking, you decide what you want to build in terms of baseload capacity as a fraction of the peak. Read across to the curve and come down and you get the fraction of hours of the year when demand is at least that high, right?

So we've normalized the low duration curve so the peak is 100. We also normalized time, which is kind of awkward so that 8,760 hours equals 100. So we can do percentages.

So again, this is just stylized. But if H star over 8,760 is here, then that says you build half baseload capacity and half peaker capacity, right? The peakers are only going to come into play when demand is above-- and this is where I need the laser-- is above that 50% point. That's an artifact. This is stylized 50%. It has no particular significance in life. It just works out in this picture.

So you'd build 1/2 peaker capacity and 1/2 base load. The peak units would be on for less than H star hours a year, or less than this fraction of hours per year. So it makes some sense.

You see why you need the mix. And this is just mechanical to say, if I know where the breakpoint is, then I've got to say, what fraction of the year. I've got to use the low duration curve to go from the break point where I decide between the different technologies, the base load and the peaker in this case, and to get a capacity mix out of that, for what fraction of the year, blah, blah, blah.

OK, I know I want to build baseload plants that will run at least this fraction. We'll run at least this fraction of the year. I want peakers that will run less. The load duration curve translates that into capacity, OK. Detail is not critical, concept pretty critical. Questions? Yeah.

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: I'd have to use them both, right? I'd have to go back and say, OK, what are the characteristics of these technologies? Where's the breakpoint? Where is the breakpoint?

And then what I would do in fact, if I'm doing this, if I'm centrally planning and I'm not a market, if I'm centrally planning I would A, allow for reserve margin. So I wouldn't build just capacity. And I would allow for the fact that I don't know the load duration curve exactly. So I'd do a little stochastic work here. I'd say, if the curve varies up and down by 20%, what do I need to be sure? And I'd work out a somewhat more complicated problem.

What I gave you was, well, if I've only got two technologies and the slate is clean, then I know how to choose based on how long the plant is going to run. And using this curve, I can go from how long the plant is going to run to how much of it I need, based on how many hours demand will be above and below certain levels, right?

So yeah, that's exactly what this exercise in the very simple case would do. It would optimize the fleet. And you need both. Even if you don't have to worry about quick response, which is not present in this picture, you'd need both, OK.

In fact, in real systems you have multiple technologies. And this is a very strange graph, but it makes that point. This shows in 2008 supposedly ranked vertically by marginal cost and horizontally by capacity, all the plants in the lower 48 states. And so it gives you sort of a supply curve.

The lower 48 states are not a single market. So it's a funny kind of supply curve. But it gives you the sense. It shows hydro there in the far left, which essentially, it has only an opportunity cost of running, right?

If you let the water out now, you don't have it tomorrow. So there's a little bit of an opportunity cost. But out of pocket is 0. And then you've got nukes, which have a very low running cost. And then you've got this mixture of coal and gas and others. And then finally, up here that vertical portion, that's the oh, my God, start the diesels portion. That's the very hot summer day when very inefficient, very dirty diesels that are kept around to run for only a few hours a year get fired up.

So there are really expensive units that you keep on hand, even though they're expensive to run because you've got them. And on a hot summer day, you may need them. So in fact, that two technology picture that I gave you is too simple because you'd want to build a more complicated mixture. But you need a mixture, OK. Comments, yeah, Scott.

AUDIENCE: So by capacity, does it mean what capacity you turn it on?

RICHARD SCHMALENSEE: No, it means, this tells you the total hydro capacity. This is the total nuclear capacity, this distance. So it's giving you a sense of how much you can get at different marginal costs. So it is a supply curve in that sense if they were all in the same market dot, dot, dot, dot, yeah, OK.

OK, what's the grid look like? You can have multiple generating plants in any particular region. But you really can't economically have multiple transmission systems and multiple distribution systems. They are typically considered natural monopolies. What a natural monopoly means is generally defined as having more than one of them would raise costs.

So if you think of the X's in that subadditivity bullet as basically electricity supplied to houses, so each component is a house or a building, rather than total kilowatt hours, but a vector of locations, then subadditivity by that definition means it's cheaper to supply. You can't split the system without raising costs.

The normal picture you get for this is, if the X's are scalars, then it's just economies of scale. So natural monopoly is present in electricity. It's present in other areas as well.

Let's do a minute on why there's a problem when you have a natural monopoly. What's the policy problem? Why do we bother to talk about it? Alex, are you raising your hand? Or no, you were not raising your hand. You were thinking about raising your hand? No, not even that. OK, OK, we're back in 1401 or 001. Kierstan and then David.

AUDIENCE: [INAUDIBLE] otherwise a natural monopoly would release them to just take as much as they could.

RICHARD SCHMALENSEE: So what enables it to take as much as it could?

AUDIENCE: No competition.

RICHARD SCHMALENSEE: So you think there would be no competition and they'd make a lot of money. But we like making a lot of money, don't we? Consumers don't. So there'd be a welfare loss. David?

AUDIENCE: I mean, yeah, they could just charge as much up to the point where it would be profitable for another firm to enter.

RICHARD SCHMALENSEE: I mean, it's actually interesting. We always assume in these discussions that competition isn't viable. And cable television is a standard example of a natural monopoly, local cable television distribution. But there are a number of places where there are competing cable systems. And that's wasteful, but it may be less wasteful than having really high prices-- welfare loss because of high prices.

AUDIENCE: They can also under supply.

RICHARD SCHMALENSEE: Well, that's the same story, right? You raise the price. You supply less. I can't draw it. You might like to end up at some point like A, and in fact, what a monopoly in this situation might do is produce 1/2 that where the production would B, but the price would be notably higher than at A.

AUDIENCE: That's good for the environment.

RICHARD SCHMALENSEE: What?

AUDIENCE: It's good for the environment [INAUDIBLE],

RICHARD SCHMALENSEE: Good for the environment. Good for the environment. So we should just deregulate electricity throughout because we'd spent a lot of money. Interesting point. Anybody else, anything else that could go wrong in this situation?

OK, what about cost? Let's think about human beings running an organization. And you have no competition. And you're providing a necessity. And your brother-in-law asks for a job.

You hire your brother-in-law, right? There's a cost problem. We always draw these curves like these come out of the sky. And we march down cost curves. In fact, these are determined by organizational decisions.

And when you have a monopoly, the pressure to actually do unpleasant things like firing people or not hiring your brother-in-law, those pressures are gone. Not gone, they're diminished. They're diminished. So you expect high costs.

There's another reason, and it's not true for all natural monopolies. But it's true for the ones that we're mostly concerned about, most of these things are called public utilities. Now, it's not true for cable television yet. Electricity used to be a luxury good. Telephones used to be a luxury good. They're not anymore. They're mostly considered necessities.

And when you raise the price, as Kierstan wanted them to do, to raise the price to pay for necessities, you're basically taking money out of poor people's pockets and giving them to rich shareholders. So these are the problems that people mostly worry about. And that business about triangles and rectangles, let me just remind you.

For some reason let this be marginal cost equals average cost. And this is the demand curve. And this is, of course, what you'd like, right? You'd like production at the point where price equals marginal cost. And this is the price axis, and this is the quantity axis.

The classic thing that a monopoly might do is to produce say, QM, and charge PM. And then the deadweight loss, this triangle over here. I'm hoping, I'm reminding you, it's the difference between what people were willing to pay and what it would have cost to produce this output that's not produced.

So that's a loss, right? If you reduce output from say Q star to QM, you lose that triangle. But suppose what in fact, happens is the monopolist is really lazy and costs go up to PM.

Well, in that case, you lose the rectangle too. And in most reasonable cases, the rectangles are bigger than the triangles. So that if I can't resist hiring my brother-in-law, neither can anybody else. That could be much worse aside from the rich/poor issue, than the fact that I'm pricing high, OK. So these are things you worry about.

What do you do about it? Water supply is like this. You could argue bus service is like this. Telephone distribution is like this. Electricity distribution is like this. Electricity transmission is like this. Now, we're mostly about energy. But it is a general problem.

What are some of the solutions, right. This difficulty, a natural monopoly arises across time and space and industries. And a variety of mechanisms have been adopted. What might you do? So we could have a private firm, and we could regulate it, OK? Anything else, Brendan?

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: Well, that's not good. What am I going to do? If I can't have competition as an economic matter. I can split it. You're saying forced competition.

Well, what if I split it and in fact, one of them goes out of business? See, the problem with this, if you go back to this picture, if I've got two firms and they're both on this cost curve, the larger one always has a cost advantage.

So you can imagine competition working. But you could also imagine the larger firm drives the smaller firm out just competing. And nobody comes in because they have a big cost disadvantage if they come in. So that's a tough one.

Most industries, that's what you want to do. And that's what's done. But that's tough here. Anything else? Yeah, Max.

AUDIENCE: A government run enterprise.

RICHARD SCHMALENSEE: You could have a government run enterprise. Let me drill down a little bit on regulation. How might you regulate? Max.

AUDIENCE: Price floor.

RICHARD SCHMALENSEE: Well, no, you actually probably don't want to price floor. Price ceiling maybe. Oh, you want them to raise prices to bring in entry? Yeah, ooh, ooh, that could be really expensive, right? Remember, if you split, you've raised costs. And now you're going to raise the price to make sure that you can survive with higher costs.

You get more companies in. There actually have been examples of competing telephone systems historically. I don't know of any competing, I don't know offhand of any competing electric distribution systems. There are competing cable systems. It's expensive, right? I mean, you're duplicating. You're duplicating.

So most people say, that's triangles versus rectangles. You're saying, I'll tolerate, I'll tolerate a higher cost as long as they're not making any money. Well, I don't want to pay a higher price, Max, I'm sorry.

I'm happy that they're not making profits. But what you're managing to do is to raise the cost. And that's the natural monopoly problem. That's the core of it. If you get competition, then you will have it at a higher cost.

And sometimes, if you think about ways that curve could look, sometimes in fact, if that curve is shallow enough, you'd be right. Let's have a little competition, the costs will go up, but the incentives will be stronger. They will not hire their brothers-in-law. And yeah, the costs will be up. But the pressure on prices will overwhelm it.

Mostly that's not true. I mean, telephone it might be. Wireless, it surely is. That's why we can have competing wireless companies. We have maybe three in Europe. They tend to have more. That's easy. But wireline, that's tough. Yeah, David.

AUDIENCE: So the shareholders are the people who are using the services, do You know?

RICHARD SCHMALENSEE: Well, that would be a cooperative model.

AUDIENCE: [INAUDIBLE]

RICHARD SCHMALENSEE: That's exactly the cooperative model. And you do see it. You do see it. Let me just mention, there are a number of different ways. Those are the three main alternatives. There are a number of different ways to skin this one, to regulate. And I'll just say a little bit, not go into too much detail.

Regulation, so I've got government ownership at the top and cooperatives at the bottom. I didn't talk about franchise bidding. I think that will take us a little too far afield. But that's the bid for the right to provide electricity.

Different kinds of regulation, you could do-- the early streetcars and buses and electric power systems and cable systems were regulated by cities. And the city had jurisdiction because they needed to use the streets. So yes, you can put up your phone lines, yes, you can run the streetcars. But you need to comply with certain restrictions.

I will talk about rate of return regulation. That's been the dominant way electricity has been regulated since the early 20th century. It's focused on profits. And incentive regulation is to try to hold prices constant for a while to give incentives to cut cost. I will cycle back to this. I will cycle back.

But just to know that there are a whole set of approaches that have been used. They all become political. They involve decisions made by people. They involve decisions made by people who are subject to voters, typically, one way or another, either government enterprise or they are regulated or the co-op members vote. So one of the things you want to do is as little of this as possible.

So transmission and distribution, natural monopolies pose a policy problem. In terms of the architecture, I don't know why this is a blackboard talk. But when I say that low voltage distribution systems are a tree, there will be a substation and feeders go out to serve neighborhoods and houses and so forth.

The transmission system, if you look, I'll show you a map in a little bit. But you might have a generator here. You might have city or load here and load there and another generator here.

The transmission system will be a mesh. It's a different architecture. It means there are multiple paths. In the tree structure, you'd have a substation. And this would be a house. There's only one path. There are multiple paths, well, in this case three from this generator to this load.

The reason for multiple paths of course, is reliability. The reason for a tree structure is cost. In some dense urban areas, the distribution system is a mesh because the lines are short. And you might as well. But if you think of any rural or suburban area, it's a tree.

The transmission system, I have to say for most of us it takes a little getting used to. You don't switch current, right? If you do the analysis, power from this generator to this load goes on all three paths, depending on the characteristics of the path. You can change those characteristics with expensive technology. But mostly it's passive.

That means-- well, it means two things. That means if I demand more here, Demand goes up here, and I increase generation here, I could in fact cause a problem on this line because some power will flow through it. And if that line can't handle it, I could run into, it could overheat. It could sag. This is called loop flow.

When electricity over multiple paths causes problems, particularly let's say, that's a national border. So I can cause congestion over here. I can cause a problem over here when I increase demand and generation here.

Now, you might say, well, can't we fix that? The answer is a little bit. We can fix that now with power electronics. We can change some of the characteristics of these lines. But it's expensive, and it's not much done. OK, so it's a strange system. It's not intuitive, not intuitive.

Question about the architecture or about the problem? OK, here's the picture. Yeah, there are about 170,000 miles in the US of high voltage. I think it's 200k, 200,000 volts, 230,000 volts is the threshold for transmission. You will note that the country is divided into three things that are labeled interconnect.

Technical description, the interconnects are connected with relatively low capacity, direct current lines in a couple of places. Each interconnect is basically one big machine. Everything is turning together, everything is synchronized, all the generators, all the frequency-- little variations, but not much.

It's easy to see why there's an Eastern and a Western, right? Because you've got the Rocky Mountains, relatively low population density. It didn't make a lot of sense to try to connect New York and Los Angeles in the same synchronized system. It certainly didn't 50 years ago. Probably doesn't now.

Why is Texas independent? Why is Texas a separate interconnect? Why isn't Texas synchronized? Oh, take a jump. Take a shot.

AUDIENCE: Didn't want to.

RICHARD SCHMALENSEE: There was a political deal made in the '30s. It was a political deal made in the '30s that has the fiction but near truth that electrons don't cross the boundaries of this area. Therefore what goes on in here is not subject to federal regulation because it's wholly within one state.

Does that make electrical sense? No, Should it be obvious that Texas and Louisiana should be separate electrically? No, but in the '30s, it was part of getting a deal done.

Whenever you see something like this, do not assume it's a technical reason. Because it usually isn't. I'll give you one other example and then I'll take your question. Within the country there are about 107 so-called balancing areas. Each balancing area is a control center that's responsible for electrical flows across its boundary, right?

It will have certain obligations like not sending a lot out or not bringing a lot in. So there's one control, there's one balancing area in New England. There's one balancing area in New York. There are eight balancing areas in Arkansas. That is not the answer to any technical question, OK, Brendan.

AUDIENCE: Because of this system, do people in Texas pay a higher, lower cost for electricity?

RICHARD SCHMALENSEE: Oh, I would say trying to figure out whether this system has had any effect on Texas costs is probably impossible. Texas rates are reasonably low. Texas burns a lot of coal.

Texas is big enough that the reliability implications aren't that great, right? If you decided to make Belmont, Massachusetts separate from the rest of the country with say one generating plant if Belmont has one, you would expect reliability problems just because if that plant goes down, which it has to occasionally, the system goes down.

Texas is big enough that hasn't been an issue. Texas has a lot of renewables, which is kind of a surprise. But Texas has a lot of wind power. That's an issue, it is also is a cost issue. But I don't think this has much to do with the price of electricity in Texas.

It's just a really interesting oddity, and is I hope always a cautionary flag. When you see something that looks like it's weird, it's either a political deal or a consequence of the tax system is my rule of thumb. And this is a deal. Yeah.

AUDIENCE: So why isn't all of Texas?

RICHARD SCHMALENSEE: Yeah, it's a good question. And I don't know. I don't know. You wonder why I say, I think that's Amarillo up there, that top dot. And I do not know why whoever made the deal wrote off North Texas.

AUDIENCE: [INAUDIBLE]?

RICHARD SCHMALENSEE: Same boundary, boundaries haven't changed. No, no, you don't want to say that too close to Texas. I mean, Texas is-- when I asked this question the first year I taught the course, the answer from a Texan was, so we can secede.

I don't know why they wouldn't take Amarillo with them. And whoever that second dot is, I don't know who that is either. I don't have an answer. My guess is that actually was an electrical response. That part of Texas may have had closer electrical connections outside the state than inside. And somebody said, look, that would be really stupid to kind of reconfigure the transmission system. I'm guessing. I don't know. Anything else?

OK, all right, let me spend most of the rest of the time on sort of how we got here and walk through the regulatory history. First, central generating station, Thomas Edison, New York, 59 customers, lighting. And by the way, you think you have a load variation problem now with those New England things, think about when your only product is lighting.

You shut the whole system down in the daytime. This is not a good way to use your assets. So one of the first things they did was push for electric streetcars.

These early systems, direct current systems were regulated mostly by cities. They were local. They were direct current. Direct current at low voltage doesn't travel very far efficiently. And you don't want to put high voltage into people's homes. So we had a bunch city-regulated systems and then we had a bunch of city-run systems. So in 1900, as far as I can tell, the peak of municipal systems, Belmont has one, Los Angeles has one, they peaked at 8% of generation in 1900.

As alternating current came in, and the big thing with alternating current is you can change it's voltage relatively easily. So you can have high voltage to send it long distances. And then you can take it down for use in homes. So the transformer really makes alternating current the winner. Now, You can take DC up and down. But it's more expensive. And you couldn't do it for a long time.

So alternating current wins. And as you begin to make it technically possible to go beyond a city-- if you're doing direct current, you're building a generating station, you're serving a neighborhood. We talked about the London system and how it stayed that way for a long time. That's how they grow up. You build a generator to serve a neighborhood. And then maybe you go to alternating current.

But technically, once you can do higher voltages, you can expand. You can link up separate cities. And that began to happen after the turn of the century and states took over-regulation from cities.

The idea was we'd set up these impartial commissions. And these impartial non-political public utility commissions, not elected in most states, not subject to removal by the government, independent commissions was an invention that started, I'm now forgetting, I think Wisconsin in 1907. And by 1920, everybody, almost everybody had them.

Is anybody here from Nebraska? OK, Nebraska doesn't have a public utility commission because no private firm is selling electricity in Nebraska. It's all government and co-ops. But everybody else has one.

The Europeans didn't do this. What happened, the European system started out like this. It started out local, began to grow and became government enterprises. Why? OK, you figure that's the answer to an engineering question. That is not the answer to an engineering question. The same electrons, same technology, similar densities in many areas. Jacob, save me here.

AUDIENCE: Although they may have provinces, they're not as independent government institutions as they are in the United States.

RICHARD SCHMALENSEE: Well, that's true to some extent. Although, take Germany. Germany is and has been to the extent that it was-- well, it wasn't democratic for a long time. But it began as a set of independent countries that became the [INAUDIBLE]. It became a federal system. So when the government took over the Berlin system, it was the Berlin government. It wasn't the national government.

So not all of these government enterprises were national. But it's a good point. The political structures differed. And the US was if not unique, then it stood out as having this whole state structure. It's just an ideological difference. An ideological difference. The US had a strong preference for private enterprise. Europe had a less strong preference.

It was a big debate in the US through the '30s. Should this stuff be government or should it be private? Private mostly won in the US. Government mostly won in Europe. You can make arguments both ways. I talked about various solutions to natural monopolies.

The government solution is, look, there are no shareholders trying to rape and pillage here. We're just all trying to serve the customers. The private response is, yes, and you're all hiring your brother-in-laws.

The costs are high. You have no stockholder pressure to be efficient. Costs will be too high. That debate ran for 30, 40 years. It still goes on in some quarters.

One side won in Europe. One side won in the US. OK, so far the states, now the feds. The federal government got into electricity first in 1906 selling cheap surplus power from irrigation projects. It gave preference to municipalities rather than private buyers. Why was it cheap, do you think? Why was the power cheap from irrigation projects?

OK, today is quirky political explanations day. In calculating the cost of building something, the government tends to use its borrowing rate. The cost of capital to the government, which has the power to tax is lower than the cost of capital to private firms that don't.

So all else equal, the government can produce power cheaper. And if the main cost is capital, which it is for a hydro facility, it could be a lot cheaper. So the government says, we're not making any money, we will sell it cheaply. But then you've got to figure out who gets it. And the decision was municipal utilities.

During the run up to the '20s-- and that's an amazing period if you think about growth industries. I just ran the numbers. The growth in electric power between 1900 and 1929 averaged 14% a year. That's a boom. That's a long boom. That was fun.

It was fun except that these guys were being regulated. So their response was, we're being regulated by states. Let's have holding companies that operate in multiple states so we can kind of hide the ball from regulators.

And it was used to fuel stock speculation. So they had a lot of fun. They built these big holding companies. I'll come back to that. The federal power commission, now the FERC, was formed in 1920 because all navigable waterways are federal. It began to do some regulation from 1935. In 1935 in response to these holding companies, which really were weird creatures.

And they were blamed for the stock market crash of 1929. You always need to find a scapegoat. So the scapegoat was these utility companies. They were broken. They were broken up. You had to operate in one contiguous area. You couldn't have a company here and a company there under the same umbrella.

Well, that really enforced what was the vertically integrated monopoly structure. The same company would generate the power, transmit the power, and sell you the power. In the '30s, one of Roosevelt's initiatives was to get power to rural areas, one of his priorities.

The existing utilities weren't interested in doing it because it's expensive. And their current customers didn't want to pay higher prices so the farmer in the next county can get power. What the federal remedy was, we'll enable a set of co-ops. And we'll sell them cheap power from federal facilities. That's what was done.

TVA is the most visible sort of we'll generate from federal facilities and sell cheap. But we did a bunch of it. And in 1950 when it peaked, the federal government generated 12% of us electricity, OK. So far so good? That's the history.

State regulation-- so the bulk of the regulatory effort from 1907, particularly after 1935, that's PUHCA, always pronounced puka. State regulators required just and reasonable rates. This was rate of return regulation. They would set prices in principle so that the utility would just earn a fair rate of return. You've got to have some profits. What's a fair profit?

Well, we know what your cost of capital is. We'll figure out what that is. And we'll set the rates so you just earn that. So what might go wrong? Alex, Shirley you're about to raise your hand now. I keep watching this hand going--

What do you think? What could go wrong? Anything? We're going to set prices so that you just earn a reasonable rate of return.

AUDIENCE: [INAUDIBLE] what that is.

RICHARD SCHMALENSEE: You can get it wrong. We'll set a price. And we'll let it. Well, we'll set a price and let's suppose we adjust it when we get surprises. Or let's say, we are worried about, and this is what they did do after a while.

We know that you can't control your cost of fuel. That's on the open market. So we'll pass that through automatically. Anything else? Anything else that could go wrong if I make sure you just earn a reasonable rate of return? OK, let me not torture you, think about it. Yes.

AUDIENCE: [INAUDIBLE] the variable cost. They have no incentive to try to be efficient.

RICHARD SCHMALENSEE: So you would expect the big problem would be that the cost would be too high. Suppose-- and we can even sharpen that a little bit. And that is the main defect in that form of regulation. Suppose we recognize the following.

If I say that a reasonable rate of return is below your cost of capital, then you can't function, right? If you can't raise money to invest because you can't earn enough on it, if I've set the rate of return too low, you can't go forward. So I don't want that to happen. So I make sure you earn more than your cost of capital on the investments.

I have to make sure that every dollar you invest earns more than what it costs you to raise that dollar? What might that lead to, just intuitively? David.

AUDIENCE: Over-investment.

RICHARD SCHMALENSEE: Over-investment, which they referred to in the literature as gold plating, right? If I have a choice of doing it with three people or a $5 million investment, I'll do a $5 million investment because I'll earn money on that. And I won't earn any money on the three people. So you have a tendency you would expect to have capital investment too high.

There are a couple other problems, we've hit two of them. I'll just mention the others. When people talk about this system, they talk about capture. Well, I actually gave a talk at the Massachusetts Commission a couple of weeks ago. And it turns out there's a little office complex inside South Station. You don't see it, but you kind of go around the corner and you go up and they have some offices.

Who do you think goes into those offices? The companies they regulate. Who do you think says nice things to them, talks to them, has any relationship with them at all? The people they regulate.

Who has lots of lawyers and lots of PR people to make a lot of noise if they're unhappy? The people they regulate. So a strong model not an entirely accurate model, but not an entirely crazy model is, after a while, the regulators serve the folks they regulate. Because you want to make them happy. You see them every day, they come in your office.

You can imagine a different kind of relationship and sometimes you see it. But one argument is, all the consumers are not organized. The utility is. The electric companies are organized. They have the lawyers. They have their lobbyists. They're in every day. They write the stuff.

Those of us who only pay bills aren't in there every day. So that's one problem. The other problem, it's a more subtle problem is, who determines who pays what price? And the simplest example is, prices to industry versus prices to consumers.

Industry takes power at higher voltages. So they ought to pay a lower price. What's the price difference? Well, I submit to you that price difference is a political decision as much as it is anything. And under a regulated regime, it's hard to see how it could be anything else.

OK, so this system actually worked. And I'm going to answer this question just in the interest of our leaving today. This system generated almost no complaints until the 1970s, in electric power, despite all of these well known, well-documented problems.

And the reason for that is in electricity, technical change was very rapid. Energy costs were pretty stable. And so the price of electricity was dropping. Very often the utility would come in and ask for a rate decrease, all right.

If you fixed my price, and my costs keep dropping, there comes a point at which the price is embarrassingly high above the monopoly price. I'm going to make me too much money to survive political scrutiny. I'll ask for a lower price. So an awful lot of that happened.

That's a great system. The regulators don't have to do much. The utility comes in and says, may we please lower our price. We do a big fuss. We have lawyers. We write briefs, after a while we say, yeah, lower your price. We all go out to lunch.

This is a good system. It didn't work in the '70s very well when fuel costs began to rise. And the utilities came in and said, now let us raise our prices. And then people began to say, wait a minute, your costs are too high. You are gold plated blah, blah, blah. And it began to be nasty.

OK, so let me take this up to date. In the 1970s, we deregulated a lot of things in this economy. We deregulated airlines. We deregulated trucking. We deregulated railroads. We deregulated the wellhead price of natural gas. And most of those worked.

Price of natural gas went up. But we stopped having shortages. Airline prices came down. Trucking prices came down. Railroad prices came down. And costs came down. And electricity prices were going up. Fuel costs were going up. There was excess capacity. People had to pay for that capacity. There became a move to deregulate electricity.

But I just told you it was a natural monopoly. So the first step was this law that said, you have to buy from renewables. And you have to buy from combined heat and power co-generation, hexion type units at avoided cost. What's avoided cost?

Well, each state got to determine that. Big mess, there were no markets. But an interesting step, early '80s, and I will cite myself here because I do tend to get cited for this. In the early '80s, Paul Joskow and I were working in this area. And we began to hear from people in the Reagan administration, all this other stuff worked. We deregulated gas and trucking and airlines, why don't we just deregulate electricity. Why don't we just let the market determine electricity prices?

I have to say, the words natural monopoly came to mind. You're not going to have competition in transmission. You're not going to have competition in distribution. But you know you could have competition in generation. It's not like there's only one generating plant per city or per state. There are a bunch of them.

So maybe you could. So we actually wrote a book called*Markets for Power* that people tell me was influential more outside the US than in. But we said well, you could do it if you were careful. If you were careful, and you worried about market power, and you worried about the proper rules, and you worried about a half a dozen other things, you could actually deregulate generation.

Well, it happened. And I don't claim credit for this. It was mostly because the Thatcher administration in England needed money. So they sold the electric power system. This was a shock.

It had happened in Chile a few years earlier, nobody noticed Chile, besides they did it in Spanish. But in England and Wales, they did it. They kept the grid, the transmission system together. They regulated the distribution companies, but they sold the generators. They sold the generators.

This was pretty exciting stuff. And it actually worked, not perfectly. They had monopoly power problems in generation in some areas. They had to make changes. But it sort of worked. Other countries started to follow. We started to follow.

Suddenly transmission lines had to be willing to carry anybody's power from anybody to anybody just like trucks do. The FERC set up, independent system operators, they set up a regime where you could have one entity run the system, not own it, but run it. And you could have wholesale markets for electricity. Some people did it, and I'll show you what happened.

Then we had California. Who's from California? Was that fun? That was not fun. Prices went crazy in California, around 2000, 2001. There were blackouts. There was screaming. There was political crisis. There was Enron doing various interesting things.

There's litigation, which may now have finished. I'm not sure about who did what to whom, reform stopped. We'll say a little bit about it. But let me just say sort of where we are. So basically nothing's happened since California to a first approximation. But a lot happened before California.

So there is competition in generation. Generators sell into a market. In England and Wales, it's the core European Union policy. All these state owned monopolies are moving toward markets, dramatically, dramatically.

And about 2/3 of US consumers are served by markets. This is the picture. The colored areas are roughly-- they change slightly over time-- roughly the boundaries of organized wholesale markets. So in New England, I showed you these day ahead clearing demands. And I'll show you some prices in a little bit.

This part of Texas runs a very nice market. California after a while restarted. This part of the country is traditional, vertically integrated. We generate. We transmit. We distribute. What's a market utilities.

In the West, the federal government has a huge presence, operates a lot of the transmission system. There are sort of elements of market, but not really. And there's an awful lot of preference power. Because there's a lot of government-owned hydro. If you go up the Columbia River, you pass a dam after dam after dam which you all own.

So New England, one of the earlier ones, very nice little market. These are average wholesale prices in New England for the last year. The prices are hourly I think. Maybe they've gone down to 15 minutes now. But at least hourly. They also are differentiated by region.

If there's a problem transmitting power from A to B, the prices in A and B can differ. If there is no problem, they differ trivially. So again, this is the day ahead price, and this is the real time price.

I don't know what happened last August, or late July, whether that was a particularly hot day. It was clearly anticipated. You see the blue shot up as well as the green. Sometimes the day ahead is too high. Sometimes the day ahead is too low.

There is a day ahead market. And then there is what actually has to happen to follow the load. So sometimes the day ahead market overestimates demand and thus costs. Sometimes it underestimates. But those are daily prices.

I'll show you some hourly prices on Monday. And here's what the US looks like. No other country has a system that is this fragmented and diverse, with the possible exception of Japan depending on how you count fragmentation and diversity, since half of Japan runs on 50 cycles a second and half of Japan runs on 60 cycles. We at least beat that.

So about 2/3 are served by organized markets. ISO is Independent System Operator, RTO is Regional Transmission Operator. Differences are immaterial. We have a transmission system owned by about 450 different entities, some federal, some local, some state, some private. About 2/3 of the system is owned by private firms.

We have on the order of 3,200 entities selling electricity, 3,200 entities selling electricity. Cooperatives aren't regulated by anybody. Investor owned utilities, which are about 2/3 regulated by states and by feds.

The munis and the federal systems are not regulated by anybody. And that retail competitors at the bottom is a development that was under way before California. It has gotten stalled because of California. But in Texas is where it's most prevalent.

You can buy electricity from any one of a number of competing firms. It will be delivered by the monopoly distribution company. But you will pay for it to some other firm that's responsible for making sure there's enough electricity to serve its customers. That's the model in Europe.

It exists in Massachusetts, but isn't very effective. Just last week I got my first solicitation-- this has been 10 years-- to switch suppliers. And because I believe in computation, I did. So there's enough retail competition that people who don't own wires-- plus I thought I'd see what would happen-- plus people who don't own wires sold 8% of the electricity in the country. I think these are 2010 numbers. That's a big change. That was 0.

The bigger change is on the generation side. So you have government systems-- and this is a big number, 16%. Not all federal, some state, some municipal, Los Angeles for instance, 16%. Investor owned utilities with retail sales, 42%, independent producers, folks who have entered the wholesale market who do not sell directly to retail customers 42% of generation. So we have moved a fairly long way toward a market based system. But we're not quite there.