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Beyond Unprecedented: The Post-Pandemic Economy
Season 4, Episode 2:
"Transportation of the Future:
Market Drivers and Regulatory Roadblocks"

[00:00:03] **Sharon Di:** Self-driving cars. The technology is still not mature enough. I think the EV really can make our air cleaner. But the infrastructure is still not there yet. This is where the uncertainty comes in.

[00:00:21] **[Music and media clips of journalists]:** The coronavirus pandemic has tanked the global economy with unprecedented speed. The steepness of the decline here is unprecedented. This is a crisis that is unprecedented. It is unprecedented, and we just don't know.

[00:00:35] **Eric Talley:** This is *Beyond Unprecedented: The Post-Pandemic Economy*, a limited series podcast from Columbia Law School and the Ira M. Millstein Center for Global Markets and Corporate Ownership. I'm Eric Talley, Sulzbacher Professor at Columbia Law and co-director of the Millstein Center.

[00:00:53] **Dorothy Lund:** And I'm Dorothy Lund, Columbia 1982 Alumna Professor of Law at Columbia Law School and co-director of the Millstein Center.

[00:01:04] **Talley:** Today, we're going to be talking about the transportation of the future: electric vehicles and self-driving cars. We'll explore the current capabilities of these vehicles and their development. And we'll kick the tires on the market for EVs—or electric vehicles—and self-driving vehicles, as well as the roadblocks that have delayed and, in some cases, have prevented their widespread adoption. We'll road test the different types of regulatory frameworks developing around these different vehicle technologies. The last decade has seen exuberant, if sometimes halting, popularity of both electric vehicles and autonomous transport technology. Self-driving cars have had well-documented setbacks, including lingering safety concerns. But McKinsey predicts that we'll see widespread deployment of vehicles with some fully autonomous capabilities, such as self-parking, by 2026. McKinsey also estimates that by 2030, annual sales for electric passenger cars will reach about 40 million vehicles worldwide, up from a mere 6.5 million in 2021.

[00:02:10] **Lund:** You know what's unique about this episode, Eric, is that both you and I own electric vehicles that have some level of autonomous driving functions. So have you been using your self-driving function in your electric vehicle?

[00:02:24] **Talley:** I have a Rivian pickup truck, and it is equipped with some autonomous navigation technology. But I will say that as I've tried to use it, I believe it is being factory set to be extremely risk averse to prevent me from, say, doing emails while I am driving down the highway. And I guess while that's super inconvenient for me, it's more convenient for everyone else that's out on the highway, not to mention safer. What about you?

[00:02:51] **Lund:** I'm a risk-averse driver, and so even the most risk-averse autopilot-driving car makes me nervous. The only thing I routinely use is that self-parking, which in New York is amazing. You can get in spots you never thought you would be able to get into using the self-driving capability. So that's been pretty good for me.

[00:03:10] **Talley:** You know, I always have thought that, like, a badge of honor that I personally have as a driver is my parallel-parking skills. So it's the one thing that I'd, like, be giving up if I ceded all of it to an automated algorithm. The other thing, too, Dorothy, is that people have been talking about autonomous vehicles for a long time, and their imminent deployment out in the ecosystem of day-to-day commuter and city dwellers. But it seems to be getting pushed off again and again and again.

[00:03:41] **Lund:** I agree. I remember when we first got our Tesla in 2018, my husband predicted the car was going to be driving him to work in a matter of years. And then, you know, all we've seen is setbacks or now, you know, at one point, you didn't even have to have your hands on the wheel, but now, you know, it beeps loudly at you anytime you take your hands off. So it doesn't seem like we're any closer to that goal of being driven around by our cars.

[00:04:06] **Talley:** And, you know, that almost gets you thinking like, what—is this a technological constraint? Is that a legal and regulatory constraint? Is it a social sort of acceptance constraint, or is it some kind of a complex combination of all of them? Do you have any thoughts on that?

[00:04:23] **Lund:** I think we have the perfect person here to help us think through these issues. I won't waste any more time before introducing our wonderful guest for today, Professor Sharon Di. Sharon is an associate professor in the Department of Civil Engineering and Engineering Mechanics at Columbia University, and she serves on a committee for the Smart Cities center and the Data Science Institute. She also directs the DitecT Lab, focusing on transportation systems. Her research spans diverse areas, including autonomous vehicle control on shared roads with humans and the intersection of transportation with health considerations. Sharon, we're so happy to have you with us today, discussing these really interesting issues.

[00:05:00] **Di:** Thank you for the intro. Happy to be here.

[00:05:03] **Lund:** Let's start with autonomous vehicles, or AVs, as they're sometimes called. The use and sales of AVs is predicted to grow exponentially by 2030, and according to some estimates, we can expect to see large-scale availability of robotaxis by 2030 and fully self-driving trucks by 2031. So, Sharon, is this realistic?

[00:05:23] **Di:** Maybe, first, let me clarify the definition of automation. So there are six levels, from level zero, one, two, three, [four], five. So level zero is no automation—just a regular human-driven car. Level five is full automation. And so when we talk about the timeline for autonomous vehicles—AV—probably we should also be clear about which level we are talking about. For example, Tesla's Autopilot is level two, but Waymo One service is level four. So level four means they—the cars—can run without any human intervention, but it's only working under certain conditions. So level five is better; they can run anywhere without human intervention, and they can handle all the situations. But level one, level two, or level three requires human intervention, which means if it's one or a couple functionalities are running, like a lane-departure warning or forward-collision warning, or just, maybe, the cruise control or ACC [adaptive cruise control], when these are running the driver sitting in the seat has to still monitor it. Maybe back six or seven years ago, car companies were trying to make a timeline for level four or five. But now that they become more conservative and say maybe it's more realistic to talk about the level two or even level three.

[00:06:59] **Lund:** I'm just curious: Will we ever get to level four or five?

[00:07:03] **Di:** So the Waymo One service, it's actually level four. And also recently, in China—in Wuhan—so a lot of robotaxi were also put onto the roads—so that's also similar to Waymo. It's level four. Per in the level four cars, even they are already very powerful in terms of sensing perception, computing, planning, etc. But they still probably need to improve in terms of the communication. So that's the challenge, when they put self-driving cars into a mixed-traffic scenario.

[00:07:40] **Talley:** Let me ask kind of a little bit more of an optimistic question, I guess. So if we were to get to widespread utilization at, say, level four or level five, where there is sort of minimal, if any, human interaction in the navigation process, you know, I'm guessing it would have significant impacts for customers, for companies, for communities. What would you say are some of the biggest sort of use cases of this technology on day-to-day life?

[00:08:10] **Di:** In many use cases, they mostly focus on, say, a very constrained environment, like an airport, like a public transit terminal, because everything's a control and there's no dedicated track, but the traffic background is easy to handle. So I think that's probably the first step. Also, people now instead of selling individual level four self-driving cars, they replace the robotaxi with a fleet. In Europe, probably in Germany, there's the self-driving trucks that are running on dedicated highways that can also

relieve drivers' burden, because when you drive on a highway, it's better for them to have hands off.

[00:08:57] **Lund:** I wonder if we may also see an impact on our auto insurance premiums as well, if we think AVs are safer in the aggregate, or maybe I no longer will face individual liability for an accident that happens while my car's in self-driving mode. So do we think going forward, consumers are going to benefit from this technology in the form of lower insurance premiums and liability for accidents?

[00:09:24] **Di:** Here's my thought, but I'm sure Eric can also jump in. There's this strict liability—negligence liability. And I think the current liability scheme—probably it is easier to adopt the strict one, because sometimes the way we lack the high-resolution data to determine who is actually liable. So normally if A crashes to B because A is driving behind B, we always assume A is liable. But sometimes it's because B had a sudden stop that A had no time to react. I think in the current torts law or framework, because the human-driven vehicle, we can only rely on the so-called EDR [event data recorder] box. So it records the last few seconds, the cars' information, but it is still very hard to judge whether it's actually B's liability. But I think with the self-driving car—with a lot more sensors and even cameras—probably by looking at the raw images, we can extract more information that can help us implement this negligence liability scheme more precisely.

[00:10:37] **Talley:** That's kind of an interesting point, Sharon, because one of the things that, in just about all states, when they depend on litigation and tort liability, if Dorothy runs into me and she's negligent, she might have to pay unless I was also negligent. And in some states, if I was negligent, then she wouldn't have to pay anything. Or maybe our liability would be apportioned by the degree to which we're negligent. Those are really hard, factual questions to reassemble when you get inside a courtroom, right, as to who was negligent, who is contributorily negligent. And one of the interesting things, regardless of whether liability systems change, this idea of these on-off switches of negligence and contributory negligence are going to be made possibly easier to test when you've got a data stream of activities that were going on because, you know, one or both cars have dozens of cameras that recorded the entire event.

[00:11:34] **Di:** Exactly. For example, now we have the data collected from my own car, but also there's data collected from the surrounding cars, even from infrastructure. So actually the best way is to use all the crowdsourced data. But I know there's a lot of challenges in terms of who owns what, what can be shared, what cannot. So I think with all these richer datasets and larger volumes of data, how can we create a framework to share? And that can help us better determine all these accidents. And also the auto insurance—it's also a challenge.

[00:12:21] **Lund:** This feels like there's an opportunity for regulators here, right, with all of this data that's being collected. And perhaps we might see AV regulation involve some data-sharing mandates that would improve both the safety and the efficacy of these AV programs. So how do you think we could get regulation that would incentivize

AV manufacturers to share data with each other? And what would be maybe some potential downsides that I may not be thinking of when we talk about encouraging manufacturers to share data with each other?

[00:12:59] **Di:** My feeling is there are several layers of challenges. For example, first is, nowadays—and Tesla actually has a lot of customers' information that customers may not be aware of. I read from one news that, some European researchers just took an abandoned Tesla car and then discover a lot of data, including not only the camera footage that recorded what the driver was doing while driving and the forward camera also recorded where he goes, what's the driving environment, but also his call information, email records, etc. And so a first step is if a customer who owns a Tesla is not aware of so much data that the car company has, should the car company first inform the customers about whatever they have? I think so far the answer is no. The second is, when something happens to—there's a car accident—the car company, whether they are willing to share that data, which probably will turn out to go against the car companies. And also, of course, they're afraid of the leakage of all those proprietary information or technology. Because California to allow, say, Waymo and Cruise to be, to run their robotaxi on roads, they have to have this approval from both DMV and a CPUC, basically the California Public Service Commission. And then they are discussing also what data they need to better deal with the cases or the accidents when something happened to Waymo or Cruise. So I think we can see both policymakers and also the public and the car manufacturer are in active conversation about this aspect.

[00:15:03] **Talley:** Autonomous vehicle technology has famously hit some speed bumps, if you will, in the last couple of years. And that involves not just overall safety concerns, but also consumer trust and perceptions of trust. You know, last fall, California halted operations of Cruise, which is GM's driverless car division, after multiple accidents that involved pedestrians, and the 2019–2023 Tesla's Autopilot software that Dorothy likes to use was involved in over 700 crashes that gave rise to 17 fatalities in the United States alone. I mean, these are tragic episodes. How do they stack up against just ordinary, level zero, pedestrian automobile interaction? This is technology people are still suspicious about, and they're going to obsess over every incidence that gets reported publicly. So how are, you know, carmakers, policymakers, trying to address either real or perceived safety concerns? I know that's a boatload of a question, but what do you think?

[00:16:08] **Lund:** A carload of a question, Eric.

[00:16:11] **Di:** Yeah. The series of accidents you mentioned from Tesla and Cruise probably were caused by different reasons. For Tesla, the driver was totally drifting away so he couldn't take over. So this is more about how much human drivers rely on the technology. And for Cruise, because they are level four, there's actually no operator sitting in there. And then this kind of emergency situation, they couldn't recognize the objects on roads, especially pedestrians are many times unpredictable. So this is because of the failure in the technology side. So I think these different reasons can—because we don't really have a clear regulatory framework up there, we talk

about, OK, what's the approach to let this technology test on roads? So, seems the U.S. tried to have the approach that is more—try to encourage it. Once they think that it's OK, then they just let them run and use the public as the test bed. But there's another way: It's like a drug test. We have to have done tests, different phases, make sure they reach certain percentage of safety threshold before it can be put to the public road. And I think, given all these cases, apparently the technology is still not mature enough. Because I'm an engineer, so my understanding is people spend a lot more time investing in, say, computer vision, object detection, using camera lidar, but also after they recognize these objects, how they make decisions, strategically, given all the other players around the car also are game players. I think that's also an important missing piece that the industry has to more focus on.

[00:18:17] **Lund:** Sharon, can we—I would love to talk about regulation, which has come up a few times. Right now we don't have federal, congressional regulation of AVs. Instead, things are happening really in a state-by-state basis. Some states have upfront regulations. Others say, well, let's just handle this with tort liability. If somebody gets into an accident, they'll be expected to pay. There's a sort of regulation in hindsight, and this is very different from the approach that the U.K. has taken, which has come up with a comprehensive regulatory framework that addresses safety, legal liability for accidents. The Chinese government is also working on nationwide rules and has also addressed some safety guidelines recently. Do you have any sense of what's the right way to regulate AVs?

[00:19:12] **Di:** We talked about two or three more ones. Some, if we just have a top-down regulatory framework, make sure they meet a certain safety level and then we allow them. The other way is maybe we just go the bottom up, trying to come up with a liability auto insurance scheme. And then people will gradually, or car companies will gradually adjust the safety level based on the loss if there's any accident involved. My personal take is that we should combine both. Probably at the beginning, we should be a little more strict in terms of the regulation, when and under what the safety specification a car is allowed to be put on a public road. In the U.S., there's no clear federal framework. So each state has their own. California is more flexible than others. But San Francisco sued the DMV because they let the Waymo to take the residents there as the guinea pig. Eventually that didn't work out, but at least we can see people are trying to have their voice heard and try to tax or even ban self-driving cars. There's another, like, a National Highway Transportation Safety [Administration]. Instead, they are trying to collect more data and make a framework to decide in what testing scenarios a car has to go through before they can put them onto the road. But my understanding, there is also this data-sharing issue involved.

[00:20:57] **Lund:** Well, let's shift over to electric vehicles. So it's not necessarily the case that AVs have to be EVs. There's a strong tie between them. EVs are basically battery-operated computers on wheels. And at the end of 2023, EVs were the fastest-growing slice of the auto industry, and they're becoming more and more affordable. There's predictions that there'll be more than 100 fully electric models of EVs available in the U.S. next year, which is double what we had last year. And again, we're

seeing this cost come down. The average price of an electric car in the U.S. has dropped about 10% to $55,000, per Kelley Blue Book estimates. At the same time, the pace of electric car sales has slowed over the last year, and some carmakers are now pausing their planned expansion of EV productions. What's going on with this market?

[00:21:55] **Di:** Actually, I always have a concern about EV because the infrastructure is still not there yet. So that's why even we see the rising numbers in the U.S. probably is more concentrated in California or the East Coast because we have more charging facilities and people still have this range of anxiety. And I think the EV—I agree on one hand, it really can make our air cleaner, reduce pollution. But if we trace the whole life cycle of how the battery—because that's the key of EV—how it's produced, it highly relies on the metal, the U.S. highly relies on other countries like South Korea or Japan, or even China. So if we really want to decouple U.S. reliance on all those other countries. So I'm not sure how this can be sustainable in the future because the lithium metal that's the key for the current battery-powered electrical vehicles. So I'm actually more optimistic about, like, hydrogen cars or battery-swapping technology. But they all, they both die out. At least in California, hydrogen cars, they can barely even find a charging station.

[00:23:26] **Talley:** Well, you know, this is a thing where that, you know, even if you end up choosing a technological platform that isn't the best, once there are network effects in place, then it becomes easier just to double down on that network. And for whatever reason, electric vehicles within the United States seem to take dominance over hydrogen. Sharon, you've been doing some interesting work on how to deploy batteries within electric vehicles in ways that don't have as many implications for range anxiety. How could you maybe reimagine battery swapping or other sorts of technological approaches?

[00:24:09] **Di:** Even the faster charging takes 45 minutes. In China and in Europe, we see a lot more charging stations in those countries compared to the U.S. That's why the battery swapping is another alternative, because it only takes probably about five minutes to swap the battery. But then it requires a totally different business model because you have to decouple the chassis of the cars with the battery. And the battery itself actually is also a complex system. And when they reach 80%, then the charging rate will become very slow. And also, a battery has life cycle: If you discharge too many times, it may also take a much longer time. For example, in China, Nio—it's one electrical car company—they tried to also build up a wider network of battery-swapping stations. But that's only restricted their own cars. If you have to decouple the car from the battery—which, battery is a key asset for the car company right now. So first of all, nobody likes that idea. Second, if Tesla can swap a battery that originally belong to Nio, probably the car owner also is not happy. And also whether we should charge those batteries in a decentralized way or transport them to a central station that has probably has got more power, connected to power grids. So there are a lot more issues involved in that.

[00:25:50] **Lund:** I think this battery-swapping idea is really smart. You know, you completely bypass the problem of having to sit and charge your vehicle or having to install charging stations all across dense areas. Is this a realistic possibility? You know, right now it doesn't seem like any manufacturer is developing a battery that can be taken out and swapped. What are the roadblocks here in order to make this battery-swapping concept realistic?

[00:26:21] **Di:** Yeah. So for example, actually Elon Musk was very excited about this idea a few years ago. So they built a few, but then now all the stations were deserted. So he decided to come back to the charging station. Because the battery is one important asset that can also be profitable, I think that's what the car companies don't want to give up. Also, there's, in the future, the whole business model of how car companies run has to be transformed, because if we have a lot more millions of batteries we have to manage, and that is a complex system, it would require a third party—a new entity called the battery-management unit. And then, but given the marginal profit of a car, industry won't let a third party to jump in, to, like, share the one piece of the pie. So I think that's all the roadblocks right now. In China with Nio, they are trying to do, say, subscription, monthly subscription. If a customer buys a car like that, then in one month, they can have fuel, say, four or five times of battery swapping in any stations. So it's more like a cell phone plan, that it's not like you'll pay for every time you swap, but it's more like a package.

[00:27:51] **Talley:** That's interesting. I certainly, you know, remember this debate when it came to cell phones, right? That if you had certain types of cell phones, you could just pop the battery out and go buy a new one at the drugstore and pop it in, and you were good to go. But with some, including Apple, you know, you got to take it in and pay a fair amount of money to have to have the battery swapped out. Let me ask you about politics. Like, we've kind of steered clear of that. And I understand it's maybe a little unfair because you're an engineer to be asking you about politics, but it plays a real role here, right? Federal legislation under the current presidential administration is aimed at developing EV infrastructure, right? The Inflation Reduction Act offers various types of tax credits to locations that install charging stations, both owners and residences, as well as businesses. Then Vice President Kamala Harris, who is now presidential candidate Kamala Harris, has supported the Biden administration's climate measures that include these tax credits for installation and for electric vehicles. Has been a big supporter of various types of measures to combat climate change. Now, in contrast, former President Trump, the other major candidate, has consistently blasted electric vehicle tax credits and other key parts of President Biden's Inflation Reduction Act. He said he even wants to kill the electric vehicle market. Yet at the same time, he seems to have struck up a little bit of a bromance with Elon Musk, who, you know, runs a major electric vehicle company and is supporting Mr. Trump's candidacy. You know, do you have any thoughts, even as an engineer, about how the expectations of the upcoming U.S. elections are going to affect this development?

[00:29:44] **Di:** Yeah, I think this is where the uncertainty comes in. So it will affect definitely consumers' choice because—let's look at the Chinese market. So China has

provided a lot of incentives and, like, a discount or credits or subsidies to electrical car—that's why the ownership is rising right now. However, once the subsidy gradually goes down, now people's charging cost is back up. And also sometimes they still face this range of anxiety, especially in some places because of the climate change, they found out they are, the battery of their car, actually dies out much faster than before. Even in winter while driving all of a sudden they cannot turn on the heating; summer, they try not to turn on the AC. So that caused a lot of inconvenience to the consumers. And I'm thinking after reading those news, probably if they decide to buy their next car, they will still go back to the conventional-fuel-powered cars. And certainly here because of the politics, really, as I'm sure it will play a big role in people who plan to buy an electrical car. They may want to watch and see, well, what's the next step? If the administration decides not to support it or give a subsidy? So what's the benefit of getting it at this moment? And also because of this and all the back-and-forth battle, I'm wondering for those charging stations that the U.S., under that Inflation Act now to initially would try to expand, but whether people will also wait and see because if not only just to expand the capacity, building those charging stations and then the policy changes, then nobody will use it. And this happened actually in China: They built a lot more charging stations than they needed: So many charging stations become ghost stations. Nobody used it. So then it's a loss to the company and, you know, filter [down] will impact the consumers.

[00:32:03] **Lund:** Well, Sharon, this has been a wonderful, wide-ranging conversation. What key issues or developments have we not discussed? What should we be keeping an eye on as we talk about AVs and EVs in the coming years?

[00:32:17] **Di:** These are the new emerging technologies, and we will get a lot more data. And I think we need the real people who understand how to download, extract, and analyze the data to not only help when there's a car accident, but also try to improve the future road safety. For example, for a self-driving car, even they provide some data. But the question is, what data exactly a policymaker needs to improve road safety or to understand their safety level. And I think this is the unprecedented question. And nobody has addressed it before because everything is new, and we really need those analysts or engineers who have the knowledge or who understand both car and also data as well as AI to move forward.

[00:33:19] **Talley:** Well, I think that, at least for now, is going to have to do it. You've given us a lot of food for thought, Sharon. So thanks so much for joining us.

[00:33:29] **Di:** Yeah, thank you for having me. It's a great conversation.

[00:33:33] **Talley:** Our guest today was Sharon Di. Join us next time for another episode of *Beyond Unprecedented*. And make sure to follow us on Apple, Spotify, or wherever you get your podcasts. Thanks so much for listening.

[00:33:46] **Lund:** *Beyond Unprecedented* is brought to you by Columbia Law School and the Ira M. Millstein Center for Global Markets and Corporate Ownership. This

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