

ONLINE APPENDICES

Problem Formulation for Theorizing at the Frontier: An Oliver Williamson Inspired Approach

ONLINE APPENDIX A

Interview with Nicolas Argyres

One of Nicholas Argyres' primary research interests is understanding the origins, antecedents, and consequences of organizational capability differences. One of Nick's intellectual foci is exploiting *the difference between production and exchange* to generate theory. Moreover, Nick identifies this big idea, or what he refers to as "his orientation," as enabling him to find gaps in the strategic management literature. During the interview, Nick described sources of the genesis of his approach to discovering "white space."

He first described that following his Greek father's footsteps, Nick was a Marxist in college and studied with a Marxist historian. Yet, he also studied with neoclassical economists like Harold Demsetz. The philosophical traditions of Marx versus markets created inherent conflicts and tensions that Nick sought to resolve. That said, his early imprinting gave him more affinity toward Marx compared to markets at this early stage in his life.

Nick noted another insight derived from his father, an academic physicist, an insight that was a recurring theme throughout the interview. On the one hand, he recognized that his father believed physics delivered a single right answer, free from ideology. Yet, on the other hand, on the social science side, ideology mattered in how he saw the world. These differing perspectives were themselves an intellectual tension within his father.

The connection with his dad redounded to an interesting parallel with one of Nick's professors at Berkeley, George Akerlof. Winner of the 2001 Sveriges Riksbank Prize in Economics in Memory of Alfred Nobel, Akerlof was explicit with students about his motivation for becoming a researcher. He was passionate about understanding why his dad was unemployed for so long during the great depression, especially when classical economics predicted that markets adapt quickly to a market clearing price.

In commenting on Akerlof's passion, Nick observed that some bias is needed to develop a hypothesis. Emotion and caring are essential elements of theorizing because one must care about something to develop a hypothesis about it. Marx wanted to deny ideology as a prime mover, and economics is supposed to be devoid of ideology. However, ideology is lurking beneath the surface. Social science is inherently embedded in ideology, which is one source of this bias.

The importance of experiencing intellectual tension was further illuminated when Nick described the impact of his graduate school education at U.C. Berkeley's Department of Economics. His initial imprinting in Marxism was a source of tension and inquiry in graduate school. The labor theory of value and its view of capital maintains that not all exchanges are the same, whereas neoclassical theory views labor and capital as substitutable. Nick's Marxist imprinting drew his attention to the idea that something is different between production and exchange. This tension was a source of his dissatisfaction with Williamson's governance approach, which primarily focused on efficient exchange. Nick perceived Williamson missed how groups of people in firms create capabilities, especially concerning solving problems.

A pivotal moment occurred when Nick was required to present a paper by David Teece in Williamson's Econ 224 seminar. His presentation crystallized discomfort with the tension between capabilities and governance. Initially, he entered the Ph.D. program to focus on development economics in which markets were not functioning and property rights were not evolving toward efficiency. However, the lack of functioning markets seemed only partially responsible for the lack of economic growth. While Adam Smith and the spread of markets may explain how feudalism transitioned to capitalism, better-functioning markets will only partially explain the rise of industrialization. He claims that such growth depends on new ideas; it is more about cultural change as people accept new ideas than it is about formal institutions.

TCE did not explain where technological innovation came from. Similarly, Chandler (1977) sidesteps from where technological change came.¹ Teece was an early writer of capabilities, which appealed to Nick's desire to resolve the tension between production and transactions and between Marxism and markets.

What made countries grow and get rich was Nick's interest when entering graduate school. Yet, an easy and natural transition occurred to what makes firms grow and get rich. At the time, this question applied to firms seemed to be much less investigated and more *tabula rasa* than the question for countries, so Nick switched his interest. He formulated a research question: Why do some firms grow and become wealthy while others do not?

Ideological tension, or at least Nick's initial imprinting in Marxism and his exposure to TCE, including Teece's view of capabilities, led to him identifying a *tabula rasa* to develop and extend a theory to resolve the tension. Nick observed that improved understanding could be gained by viewing Alchian and Demsetz' (1972) team theory and Marx's teachings in seeking to "find a greater truth."

The various tensions and attempts to reconcile these tensions reflect a process of inquiry that Nick had been thinking about for a long time, which he attributes to his psychological need to find "reconciliation" and avoid conflict. An important attribute of Williamson as a dissertation advisor was his open-mindedness and willingness to entertain these ideas that emerged from the conflict and tension.

Beyond his dissertation, Nick remarked that his co-authors often have intellectual imprinting that differs from their graduate degrees and himself. Interacting with co-authors brings new intellectual conflicts and tensions into focus. Janet Bercovitz, a co-author and the subject of the following interview, has an undergraduate imprinting in chemistry. Jackson Nickerson, a co-author and one of the others of this paper, was mentioned as having an engineering degree in systems theory and with whom interactions sparked Nick's increasing attention to more nuanced and precise problem formulation. Nick noted that personality and cognitive style might matter. Some people are brilliant at working with data, and others are great at developing theory and big ideas.

Another source of intellectual conflict and tensions can come from reading. Though reading broadly is essential to inform different questions and discover tensions, Nick maintains that he drew limits on which theories to combine. He noted that he "painfully" reached his cognitive limits as he moved to readings on social psychology, which are far afield from his home discipline. One must trade-off being broad versus narrow in knowledge because the former may lead to more significant insights but at the expense of career advancement as more time and risk are involved.

¹ See Crossan and Apaydin (2010) for a systematic review of the innovation literature.

Occasionally, the same question from different perspectives is answered. More often, Nick likes to force two perspectives to address the same question, try to extend them, and see if they work together. Therefore, he wrote a paper about capabilities and vertical integration and discovered new hypotheses. Combining provided perspective and gave new insight. He relies on an *evolutionary epistemology* of variation, selection, and retention (see Campbell, 1974; Weick, 1989).

As a member of the field of strategic management, Nick wanted to provide valuable ideas to managers. In all of Nick's projects, he asks if he has something interesting to tell a manager; otherwise, he might abandon it. His goal is to produce a paper that leads to a practical result. Prediction and the development of managerial implications are essential foci. Following in his dissertation advisor's footsteps, Nick likes working with theories in which prediction is the touchstone of science. Historians focus on explanation, not prediction. Some of Nick's research uses history yet also makes predictions.

Nick did not have much experience outside of academia before entering graduate school. He had to "manufacture" experience, so he engaged in many case studies and conversations with many businesspeople. These conversations gave him confidence in identifying what business problems are important to managers. He knew the challenges of moving from an economics department to a business school and deeply desired to fit in and belong. He also wanted to be a good teacher.

Like Williamson's idea of sequential adaptive decision-making, Nick believes in following his intuition as one thing leads to another. He does not think of himself as following a strategic plan concerning research.

ONLINE APPENDIX B

Interview with Janet Bercovitz

Janet Bercovitz seeks to understand how value is created through contracting. Janet is known for her research on franchise contracting, as well as university licensing and technology transfer. During the interview, Janet discussed how she came to discover and understand new ideas.

Before attending graduate school, Janet was a chemist. The marketing-driven company where she worked often did not fully comprehend what was going on in its scientific laboratory. She reports that conflicts between marketers and scientists in the lab were common. This conflict sparked her desire to go to graduate school to study and seek ways to resolve the conflict.

In addition to this earlier scientific imprinting from chemistry, graduate school gave Janet another and different imprinting, this time on transaction cost economics. A central aspect of this latter imprinting led her to constantly ask, "What is going on here?" Various phenomena caught her attention and interest, which she believes is not always in the mainstream. Janet likes to look at the micro-detail of phenomena, like contracts, and likes to look at the big picture, such as policy implications. Yet, looking at the micro and the macro is not enough to discover new ideas. This dialectic is only the beginning, as Janet strives to connect the two. Doing so illuminates a phenomenon up close and from afar, which helps identify the limits of extant theory and where other or new theory is needed to form these connections.

Much research frustrates her because it does not connect micro and macro. Therefore, when exposed to a phenomenon, Janet has two streams of thinking running parallel in her head: one is about understanding a phenomenon, and the other is about what theory tells her about the phenomenon. Her goals are to understand the phenomenon from multiple perspectives and find a way to bring them all together to get to an outcome that will create value for academics and practitioners alike.

Working with co-authors offers another way to develop this understanding and achieve a valuable outcome. The fun of working with co-authors, Janet explains, is that typically, they come with disciplines and perspectives that differ from hers. As a result, she and her co-authors spend much time describing and explaining the phenomena from different perspectives, facilitating dialogue about why each perspective is valuable. Throwing a paper back and forth over the proverbial wall is not her style. She claims that these conversations opened her eyes to many things. Conversation with co-authors makes her question her assumptions, clarifies her thinking, and shifts her beliefs.

Typically, a collaboration ends up on a middle road that melds aspects of each co-author's differing perspectives to create a new one. This new perspective can also lead to new questions. Yet the emergence of new questions is not like a discrete function; what often happens is that the questions evolve.

Understanding or making progress on a research topic to discover a new question or empirically address one does not always happen quickly. Janet's second-year Ph.D. paper is a case in point. Written on the idea of governance inseparability, only recently—more than 25 years later—does she now have access to data from franchising that may enable her to evaluate her question empirically.

In essence, ideas are not dropped. Janet keeps questions on the proverbial shelf in the back of her mind and ruminates on them because not figuring them out bothers her. She ruminates on many such opportunities because she feels that research cannot tell people what they already know. Instead, the research needs to provide something new, what Janet calls “bringing it up to the next notch.”

She offers the metaphor that research is like Brownian motion to find that notch. You go in a direction until you hit something that changes your direction. Her father once told her that everybody knows something you do not know. Thus, she keeps moving forward, exposing her thinking to other perspectives to discover insight and reassess ideas on the shelf in light of learning others' perspectives.

Exploring university technology transfer is an illustration of this Brownian motion. Shortly after graduating with a Ph.D., David Mowery, on her dissertation committee, invited her to a conference he was hosting with Nate Rosenberg. Maryann Feldman also attended. During the conference, a conversation arose about research on lead universities involved in technology transfer. No research was available on universities that were later starters. David suggested that Janet and Maryann should talk because their two universities had great medical schools yet were late to technology transfer. Several conversations led to a Mellon Foundation application and the receipt of a substantial grant. The conference invitation was happenstance, as was the conversation on late-start universities and the recommendation for Janet and Maryann to get together. Janet concludes that if you do not go out, engage in the academy, and put yourself in places where interactions occur, you will reduce potential idea flow.

Upon reflection, Janet would advise her younger self to engage, listen, and take better notes to help the conversation when sparks arise, sometimes occurring a year later. By “engage more,” Janet refers not just to academics but also to stakeholders more broadly. For example, understanding what

the data mean requires understanding the situation. Talking to practitioners and other stakeholders in the investigated domain is vital to understanding the situation and the meaning of the data. Consequently, her approach leads to relevance being woven into her inquiry.

Another aspect of looking from multiple perspectives is that Janet is always anxious about not understanding a phenomenon correctly. She is especially nervous when entering a new domain because a vast body of work always exists, and she wants to ensure she offers something new. Collaborating with co-authors already in that area is vital to building the requisite understanding. That said, she states that she never gets to the point where she feels like she fully understands.

Notice that Janet focuses on her understanding and on bringing something new to the conversation. She does not expect to be the one to discover an overlooked puzzle. Instead, she seeks to understand a phenomenon through a learning orientation. She must have a reason other than to get the publication to engage in inquiry. This perspective comes from her background in science. In science, she believes that one can seek truth, but in social science, which deals with human nature, she does not expect to discover laws of human nature. Therefore, through her inquiry, she is seeking understanding, which is a quest for wisdom.

She does not think of herself as a theorist, although she believes she is a good logician. She constantly reflects and seeks ways to strengthen her logic, especially by asking what else could explain the phenomenon.

Teaching has been an integral component of her discovery of new questions. While her research career started with franchising, her teaching began in entrepreneurship. Going back and forth between teaching and research in entrepreneurship, she discovered an interest in how start-ups scale up over time. Indeed, this topic is what she is currently exploring and is related to one of her long-term interests, which is the role of dynamics in creating value.

ONLINE APPENDIX C

Protocol Application Conversation

AB: In 2013, an unattended freight train that was improperly secured and carrying millions of liters of crude oil “ran away” and derailed in the town of Lac-Mégantic, Quebec, Canada, resulting in the death of 47 people, fires that decimated the town center, and a mass evacuation involving 2,000 residents. Despite exhaustive investigations, even 5 years after the accident occurred, no one seemed to be able to pinpoint the root cause. And so, the interesting question for me was: what can explain this accident?

JN: Okay, so give me the nub of your theory.

AB: First, hazards arise from a misalignment between decisions rights, and expertise. Second, there was an issue with smallness of size that meant that resources were often unavailable. Third, the system seemed to drift into failure. An added issue was that nothing that the regulatory bodies had done would seem to do anything to prevent accidents of this sort in the future. Considerations of bounded rationality are also important. These are my key takeaways.

JN: I see the situation entirely differently. Your description of the accident recalls an investigation I conducted when I worked at NASA years ago, and the insights from it can be applied here. Consider the innovation of reducing from two to one engineer on the train and leaving the train parked on the main line, which are decentralized decisions that regulators okayed. At NASA, a similar dynamic occurred – maintenance practices were incrementally dropped until, eventually, a failure occurred. Without the original system designer or their equivalent evaluating these adaptations, the system can lose its safety redundancies.

AB: That's certainly a possibility. I would like to share a couple of ideas. First, rules can be captured in routines, but there is an organizational memory loss in that no one understands why it was justified. When those routines are adapted over a long period of time, and nothing happens, folks mistakenly assume it is safe to do so – this leads to drift. Second, time is compressed in an emergency situation, and people make incorrect inferences. For example, the engine fire at Mégantic was mistaken for something else altogether.

JN: But those inferences are associated with this decomposed structure. People dealing with each element are specialists who don't have the overall system knowledge. This time dimension is really important. The mechanisms are less about having to make quick decisions, and it's more about ... you use the word “drift,” and I use the word “innovation;” we also can use the word “adaptation.” I use innovation instead of adaptation (and we can use either one) because of an incentive component to it. With innovation, I save time and money. An incentive reason is needed to change what you're calling a routine.

AB: What you're suggesting does make sense. The other thing I've always found interesting is James Reason's Defense-in-depth model, which says that artifacts have layers of defense. These redundancies, layers of defense in his language, are being removed, ultimately creating a path for an accident. Over time, changes in the environment occur. In response, you add or remove layers of defense locally without realizing its broader implications.

JN: I see this situation as one where there isn't a mechanism for the governance to evolve at a system level; instead, what was put in place was a governance system that was decomposed at the subsystem level. So, I see this accident more as a governance issue about long-term governance. I don't see the accident so much as an incentive issue, although incentives played a role. I don't see it so much as a technical issue, although technical stuff plays a role. I don't think it is so much of a routine issue, although they played a role as routines did change. What's unique about this accident, as you mentioned, is the long-term nature of it. We haven't heard from Joe, and I want him to participate. So, let's shift to him.

JM: Alright! I have many questions and comments about each part of the story. Let's go back to the beginning. When you park the train and leave, how do you know that you have sufficient handbrakes to ensure that it secures the train? Just the fact that it doesn't get done is a real puzzle. And how does the engineer apply handbrakes?

AB: To use handbrakes, you must first secure the train using air brakes, walk to the back of every car, and apply the handbrake. The handbrake is a big wheel.

JM: And to set the handbrake, you turn the wheel.

JN: To secure the train, the rule of thumb was to count the number of cars and apply the hand brake to 10% of the cars plus 2. Yet, I suspect this heuristic is incorrect for heavy-set cars parked on

a hill. But it may have been fine if the system was working the way it should have been on a side rail because side rails are unlikely to be on hills.

AB: You're right. I've never seen a sidetrack on a hill.

JN: That's precisely my point. The system likely was designed so that side rails are in safe locations. No one ever contemplated in the original design for trains to be parked on the main track, but it just so happened that this insight may have never been documented because the governance structure was rule-based, and the rule didn't anticipate decentralized decision-making for adaptations or innovations.

JM: My next comment is about the misalignment of decision rights and expertise, just in terms of the earlier question about long-run governance. An element of decentralization is connected to the misallocation of decision rights. You can decompose or not in a way that puts the people in the know with the people making the decisions.

JN: You bring up a great point, Joe. This decentralization of decision rights occurred in a regulatory environment, which is special here. The regulatory environment allowed the misalignment of decision rights to happen. Why did the regulatory environment support decentralizing decision rights that allowed these adaptations or innovations? That's curious.

JM: Yes! As you said earlier, this system designer is gone. So, there's no ownership of the system. Let me get back to a few other comments. One: If people don't understand how an incremental change, combined with other people's incremental change, will affect the system, they will find out painfully. The second one is the idea of memory loss. My comment is that over time, the know-how remains with the routine--the know-why degrades, and resources are scarce in systems knowledge. So, that's part of the story.

JN: Hold on a second; I'd like to probe deeper to understand our collective thinking on why does the system knowledge dissipate? If you don't have major failures, do people lose sight of the value of maintaining that knowledge?

JM: Oh, here's my initial comment. It may not be the sophisticated correct answer, but when you ask the question, it makes me think of a scene from Forrest Gump. In the scene where the sergeant asks, "What is your sole purpose in this Army?" Forrest says, "To do whatever you tell me to, sergeant." And the sergeant tells him, "That has to be the most brilliant answer I've ever heard. You must have an IQ of 160." Then Gump says, "Being in the Army is not really hard. Every time the sergeant speaks, you say, 'Yes, drill sergeant.'" So, if you're the engineering systems guy, and I'm a young person just starting, and you have all the experience, and you tell me that this is the way it's done, I go, "Yes, drill sergeant," and I do it, and I get rewarded for it. You take it forward ten years, and maybe you've moved on and promoted somewhere else, and I'm now in charge. I will follow all the rules because that's my job, and I've been successful for ten years following the rules.

JN: So, the designer conveys rules instead of thinking. Is that true in academia with faculty and PhD students?

JM: I don't think so. Maybe it is true for some. I try to transfer everything I can.

AB: There is also this notion of being unable to transfer knowledge.

JM: Systems designers know more than they can codify easily and tell others.

JN: I don't know if I buy that so much.

AB: Okay, know-why is linked with justification for the second one. In the beginning, when the engineer came up with a rule on contaminants in the engine oil, they probably understood why you didn't want that level of contaminants because it would damage the engine. He tells the maintenance guy to make sure it's never exceeded. Then, the maintenance guy economizes on bounded rationality and never actually tries to understand the justification, and the older person leaves.

JN: Okay, maybe you've convinced me. It could be the loss of tacit knowledge.

JM: We are stunningly unaware of the knowledge lost over time, especially when paradigms change, as Kuhn points out.

JN: It may not be a loss of tacit knowledge but a loss of knowledge that comes from one paradigm replacing another, which resonates more with me. Since the origin of the railway in Canada, which could be a paradigm, could a new regulatory regime or some other paradigmatic shocks have triggered a loss of knowledge?

AB: Canada used to have nationalized railroads. The railroads used to be bigger, and now you have smaller local players, which has happened at the industry level.

JN: The paradigm shift is that the regulated national railway system fractured into many companies with size dispersion. That could be the reason why knowledge was lost. I'm trying to make a connection between what Joe said in terms of the loss of knowledge and a paradigm shift for which the governance structure isn't designed to compensate and retain the knowledge.

JM: Part of formulating the problem might be to think about the interplay. To us, like Williamson's picture of the interplay between the institutional changes and governance that the governance may be well adapted under one institutional regime, but then, as the regulatory, institutional regime changes, the governance may not adapt in a way that achieves the same functionality, as the original combination of institutional governance arrangements allowed.

AB: The existing governance structure was operating under a different set of rules of the game, and you have a shift in the rules of the game. But I want to continue to play the game, and there's no reason to believe that continuing to play the game in the same way when your rules have changed will lead you to good outcomes. And, as the evidence seems to show, it doesn't.

JM: What is needed for a solution is to deal with the governance issues and then with institutional changes, the need to solve problems with maladaptation that can occur in adapting the governance system, but also, it seems to me like much atrophying of capabilities are independent of the incentive system.

AB: Yeah, that's the other important thing to realize. Trying to explain this accident entirely with incentives is too narrow.

JM: Another way of expressing this is through Williamson's work, which suggests two problems. There's the opportunism problem and the bounded rationality problem. So, his ideas are that organizations economize on bounded rationality and attenuate opportunism. I think both problems are at play here. It's also related to the deep composition of the problems coping with the system's complexity. But then, as Jackson notes, over time, there's a price to pay for that decentralization in the form of lost knowledge, lack of know-why, and lack of systems knowledge. Then, a failure occurs if you incrementally change too many things in the system.

Now, the one concept that needs to be unpacked more is this idea of safety drift so that I would phrase it a little differently than Jackson. The safety drift has to do with the time pressure. It has to do with saving money.

JN: That's the same thing as the normalization of risk. Are those two things the same thing? [Head shaking] Okay, I want to make sure that I understand. In that case, I agree with you, Joe, although the coupling is much broader and tighter between the capabilities, the cognitive aspect of it, and governance.

JM: I've written about it consistently over the years; I'm much more on the side, as Williamson would describe it, rather than the Kogut and Zander way of describing it.

JN: I want to throw out a couple of things to see if they matter. We haven't talked at all about double-loop learning. In what we're talking about, we lose the outer loop from these paradigm shifts to which our governance system hasn't adapted. Does that comment give us any insight into the phenomenon or explain it in some way?

JM: One comment I would make on the thesis of double-loop learning is that one of the major impediments to it is "don't tell me what I don't want to hear." When you have an organization where there's not a culture of trust, and there's fear, there is no learning. You know academia can get like that, too, by the way.

JN: I heard you say that double-loop learning may be a topic for the discussion section, but it doesn't provide a mechanism.

JM: When we talk about the impact, I mean, if we conclude that we need to be in a continuous learning organization, then we do want to talk about double-loop learning, which is needed. But most of the Argyris and Schön book in 1978 on organizational learning is about the impediments to that happening.

AB: There's a book called "pre-accident investigations." I think it's written by a guy called Conklin. And this whole idea was to learn using counterfactual reasoning. One of the things he identified that impedes it from happening is people getting defensive, not wanting to be told what to do because they're not interested in changing the way they do things.

JN: Isn't it a failure of imagination that leads to underinvestment in safety?

JM: This systemic underinvestment occurs at the university too. People involved in coordinating and making the system work hardly ever get more than an intrinsic reward for preventing glitches from happening. So, all the benefits from non-events don't yield credit or rewards.

JN: Unless these non-events are baked into the governance structure over the long run, which is likely not to be, or it's easy to decay, you don't have an incentive to engage in prevention.

AB: One last point: the thing that also strikes me for this case is that when the engine was failing, it was abnormal. You know, something is wrong when oil droplets are falling 25 feet away and on the taxi's windscreen. It's a screaming anomaly. Yet, no one paid real attention to the anomaly, so there's failure of foresight or imagination. I haven't seen anyone focus on how organizations can better identify these moments.

JN: Two things are needed for an organization to deliver this capability. The first is attention to something that is amiss. The second is imagination, which simulates what might happen under various scenarios. This simulation is an individual matter and cannot be readily routinized.

JM: Let me ask one question about how to position the paper. At the most basic level of the story about this disaster, is it a management problem or a technical problem? And are our current business school curriculums and management teaching the management skills that are needed to avoid such problems?

JN: The issue is about governance.

JM: So, we're on the same page. One of the central aspects of management is governance. From a publishing standpoint, we can use the rich case study to generate theory. Yet, we will need to have a few other illustrations to show that the theory can explain other catastrophes. We first have to (re-)conceptualize what the problem is. It'd be great if we could reformulate and agree on the formulation of the problem. Then, we can think about how to write it up.

JN: Joe's offering very good advice on this point. But first, I'd like to see if we can agree on the canonical problem.

AB: How do you prevent system decay...how do you prevent governance decay over time? In a way, we are looking at a sort of governance entropy.

JM: Another way to rephrase the question is, what are the skills needed to have a good architecture of design of an organization? I'm with you on the idea of maintaining an effective system. But an antecedent question is, what exactly are we maintaining?

JN: The system is designed for redundancy. But a shock occurs, and somehow, the shock leads to decaying redundancies. How can the governance structure renew the system's resiliency after some shock?

JN: As we've explored many different ways to formulate and are zeroing in on a new formulation, let's take a break and digest our conversation. We concurrently and empathetically seriously engaged in four to six dialectics open-mindedly. We focused near and far and talked about what was happening with those frontline workers, but we also thought at a high level of conceptualization. We relied on pre-PhD and post-PhD imprinting. We all did, although I don't know if Joe talked about his pre-PhD imprinting. We had not only a dialectic between two theories but among perhaps six theories. We've talked about the practical and the academic, and the three of us have come to the context from different perspectives. We're focused on getting it right, yet we also put a time limit around ourselves to get this out and have some practical output. We also recognized different languages, tried defining terms, and created a concordance. The protocol also allowed us to reveal our conflicting assumptions about knowledge and the difference between management and governance. We discovered the potential antecedent of paradigmatic shocks that are not just technological, which informs the operating environment connected to the second step of the protocol is all about.

The third step is to identify these conflicts and tensions among perspectives. We went through various aspects of governance versus incentives and technology versus organizational and managerial factors. Near decomposability and the notion of administrators versus designers' dimension in which we found tensions and conflicts. Finally, the fourth protocol step sought to formulate and reformulate until a truly novel question emerges that promises to create new value. We haven't finished this last step. We've been talking for two hours and may be cognitively overloaded. We have a bunch of clay and have to squish it around to figure out which questions make sense. We also devised a few title possibilities that should inform the specific language we use to reformulate. That's the final step.

Our conversation is consistent with the values of humility, motivation, courage, and curiosity with a learning mindset. We worked through the framework in a thorough way. We can write up the conversation to say here's what we started with, here's how we did it, and here's what we ended up with, which is why we must eventually reformulate the problem precisely.

Here's your opportunity to make me feel good [Akhil]. Was this a transformational conversation for you?

AB: It certainly was. I might even grow some hair on my bald head tomorrow! [laughter].

Epilogue: After a few additional email exchanges and video calls, Akhil, Jackson, and Joe unanimously agreed to a revised canonical problem formulation. The initial formulation was:

Using the theories of accidents (e.g., defense-in-depth), how could the Lac-Mégantic accident have occurred, and what could have been done to mitigate such events?

This formulation led to a technical perspective that offered a midrange theory of faultless accidents. The theory was motivated and applied to the specific Lac-Mégantic accident.

The new formulation is:

Are catastrophes the inevitable outcome of day-to-day operations of complex socio-technical systems, and why are regulators unable to mitigate their likelihood of occurring?

This new formulation led us to recognize a general phenomenon that we call “fragility drift,” in which the safety redundancies found in the operations of complex socio-technical systems are incrementally removed or made less robust.

The reformulation also led to a novel theory focusing on post-arrival (demand or innovation) changes to a complex socio-technical system and political influence over decisions by a regulatory administrator. These decisions enable localized innovations or the acceptance of new routines that, while locally beneficial and do not immediately precipitate accidents, increase system fragility at precisely the time when system safety may need to be enhanced or redesigned because of the shock. Assuming that politicians cannot credibly keep from attempting to influence regulatory administrators and that administrators consider technical and political recommendations, the probability of fragility drift is expected for all complex socio-technical systems in the aftermath of demand and innovation shocks. While a catastrophe is not specifically predicted under such conditions, our theory predicts that the likelihood of one increases.

ONLINE APPENDIX D
Applying the framework

	Principles	Dialectic	Protocol
Examples*			
	<i>Curiosity:</i> the question of <i>what's going on here</i> acted as a driver for AB, JM, and JN as they sought to develop a plausible explanation for catastrophe.	<i>Ideological:</i> this dialectic is evident in AB's pre-PhD engineering training, industry experience, and post-PhD governance imprinting.	<i>Empathetically seek out multiple perspectives:</i> In seeking out differing theories across paradigms (safety science, economics), AB, JM, and JN examined the problem from various perspectives. They also sought to employ different perspectives, such as technical and organizational.
	<i>Humility:</i> AB, JM, and JN approached the case through multiple perspectives, such as theories of accidents, governance, and learning. They recognized that a perspective that integrates insights might be useful.	<i>Collegial:</i> the dialectic between AB and JN led to a shift in the approach. JN offered a more "systems" perspective, with an explanation centered on innovations stripping the system of critical safety features. JM drew attention to the importance of knowledge and the decomposability of systems.	<i>Engage in multiple dialectics:</i> AB initially employed the dialect of theories of accidents and safety science, while JM and JN employed the dialect of theories of governance. AB also employed the dialect of the railroad industry. They also borrowed from popular literature (e.g., Anti-fragile) to clarify their arguments as needed.
	<i>Motivation:</i> In an email to AB and JM after the conversation, JN conjectured several necessary conditions that may result in similar catastrophes while admitting that	<i>Paradigmatic:</i> the dialectic between AB, JN, and JM spanned disciplinary paradigms in that AB drew on theories of accidents (safety science) while JN and JM drew on theories of governance (economics). Mutual understanding was	<i>Create a new dialect as needed:</i> In formulating the term "fragility drift," AB, JM, and JN created the basis for a new dialect. The dialect of system fragility links to failures of governance, and system fragility seems to be an outcome of failures of

	he may be “missing” something or that the conjectures may need revision.	enabled by having some shared language (governance) and an effort to explain terms (e.g., artifact) better.	governance. The link needs to be explored further, and the logic needs to be fleshed out.
	<i>Courage:</i> The dominant paradigm to explain accidents is Normal Accident Theory, and theories of safety drift are also frequently applied. JN challenged the latter, while AB, JM, and JN later (not in the transcript) decided to challenge normal accident theory.	<i>Theoretical Practical:</i> AB’s previous work experience in the industry aided in keeping the theorizing relevant. JN’s work experience as an engineer in NASA also played a critical role in promoting practical relevance. JM was able to draw on his organizational experience to highlight the practical challenges of coordination.	<i>Create (essential) tensions:</i> during their conversation, it became evident that the explanation developed by AB, JM, and JN would challenge the work on system drift by safety scientists (e.g., Dekker, 2016). In their correspondence following this conversation, AB, JM, and JN have zeroed in on challenging Normal Accident Theory with a perspective and theorizing based on the literature on governance (with insights from theories of accidents).
	<i>Reflection:</i> In an e-mail following this conversation, AB e-mailed JM and JN, informing them that his stance of no evidence of opportunism was misplaced. During the conversation, JN quickly reflected and changed his perspective about the possible role of knowledge.	<i>Micro-macro Bridging:</i> The dialectic between AB, JM, and JN exhibited the concern of establishing the micro-macro bridge by considering the link between operational decisions taken during day-to-day working (play of the game) and industry-wide regulation (rules of the game).	<i>Repeatedly reformulate in search of a Canonical question:</i> AB’s reformulated question centering on preventing system/governance decay was reformulated by JM and then by JN. The most recent version of the reformulated question is: <i>Are catastrophes the inevitable outcome of day-to-day operations of complex socio-technical systems, and, if so, why are regulators unable to mitigate their likelihood of occurring?</i>
		<i>Getting it right and getting it out:</i> AB, JM, and JN discussed a path forward in terms of where the study may fit and	

		how to move toward publication.	
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** see key to abbreviations below*

AB: Akhil Bhardwaj

JM: Joseph Mahoney

JN: Jackson Nickerson