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[CLICKING]

HAZHIR How was last week? I unfortunately, somehow this got disconnected, the recording, so I couldn't watch the
RAHMANDAD: session. But what did you guys discuss and how did it go?

AUDIENCE: We talked about-- oh. Oh, were you looking at [INAUDIBLE]?

HAZHIR It doesn't matter. Go for it.

RAHMANDAD:

AUDIENCE: We started by talking about when are system dynamics useful, this general idea when working towards models, which she said might be different from yours and [INAUDIBLE] but you wanted to get [INAUDIBLE] perspective on that.

HAZHIR That's great.

RAHMANDAD:

AUDIENCE: Then we started going model by model.

[INTERPOSING VOICES]

HAZHIR Yeah. Cool.

RAHMANDAD:

AUDIENCE: Yeah. We were talking about the debate, I guess, between whether to start with stocks and flows versus the feedback loops. And [INAUDIBLE] was commenting that there's no one answer. And for mine he said that I would start with stocks and flows and he that I should start with the feedback story and [INAUDIBLE] feedback on that, and then go towards [INAUDIBLE].

So there was an interesting discussion about where to begin from the Viking Age. And he said, sometimes the stock and flow stories are clear and other times the feedback [INAUDIBLE].

HAZHIR Yeah, that's actually generally an important architectural choice at the beginning about where to start. And it's
RAHMANDAD: absolutely the case that for some problems it is easier to go with the stocks and flows and sometimes with causal loops would add value too as a starting point. Cool.

I didn't see your model in the folder from last week.

AUDIENCE: Yeah.

HAZHIR It's all right, I just-- so you had something, put it for this week.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR Other observations? Anything else from last session to share?

RAHMANDAD:

AUDIENCE: Nelson, I thought it was a useful session. We spent more time on thinking about problem formulation and when is modeling useful, what types of problems. We talked about a few formulations. But I think the majority of the time was why model at all. So that was helpful for me.

HAZHIR Yeah, absolutely. And Nelson has a very good taste in focusing on really what is the value added of the model. So

RAHMANDAD: that's a great opportunity to get that. Cool.

Other thoughts, observations?

AUDIENCE: I also thought that the part of that discussion on not only just what problem are you trying to solve for who, but then also what makes it dynamic specifically or what is your hypothesis that makes you think that system dynamics is going to be specifically useful for it versus any other talk.

HAZHIR Yeah. And it's a conversation we haven't really focused on in this class because basically each week we gave a

RAHMANDAD: problem that you want to focus on. And then for your personal projects I gave the feedback not at the level of let's completely challenge the problem you're bringing in, but at the level of, OK, if that is the problem you want to tackle, let's try to mold it into something that you can build a model for.

And in many cases, you could argue that those problems are not the optimal dynamic problem. So I think that's an important consideration. In many ways you can build models in Vensim that are not dynamically that interesting or that complex. They are accounting models. They work, they are useful for some purposes, but you could also build a similar model in an Excel spreadsheet and it does the same job, give or take.

And that is not really where the heart of system dynamics is and where the real value of modeling is. But there is nothing wrong with building those models, and in some cases, they are actually very useful, just as Excel models are very useful for a lot of activities.

Now, whether it is more useful to build them in Vensim versus in some spreadsheet, then it becomes a more important question. That is, for some of these accounting type of models, like models that have basically stocks and flows without much feedback, sometimes it works easier to just build them in a spreadsheet, and sometimes it is actually useful still to have the explicit stock and flow structure in front of you. It makes thinking about them a little bit more clear.

Good. Other observations from last week?

AUDIENCE: He also mentioned that he's in favor of very simple models, in contrast to you and Jonathan. Oh. Yeah. So that was an interesting observation to me. And I've seen his papers, but two [INAUDIBLE] models, I think you're getting saturated in terms of attacking theoretical environment, maybe, I'm not really sure. When you're thinking of even comparing two theories, the interaction of the different mechanisms in two theories, the model suddenly gets big and how to tackle that.

HAZHIR Yeah, I would say there are really two different consideration sets that come into this, what's the right level of

RAHMANDAD: detail and complexity for a model. The most important one is what's the purpose of the model.

So if the purpose from a spectrum of theory-making, theory-building, to policy analysis, you think of that as spectrum, the more you are towards the theory-building, the simpler models add more value for that situation. And then the more you move towards the policy analysis, you would need more complex, more detailed models. So that's one spectrum, one dimension.

Empirical grounding in terms of numerical data is another dimension that becomes important. Again, when you want to have more empirically well-grounded models that are estimated based on real-world data, usually, not always, but usually very simple models don't do a great job. But that's at least a starting very simple model. Sometimes after doing a lot of modeling, you can come up with a very simplified version that can still do a good job of capturing the detailed data that you may have. So that's kind of a second dimension.

And then the third dimension is the audience. So if you are targeting organizational studies audiences, basically large models are not going to work for you. It's just they are not interested. They don't have the capacity to consume that. It's just not the type of thing that would work for that audience. You go into mathematical epidemiology, they are much more receptive to these more complex models. You go to sustainability, energy, economics, they are more receptive to complex models. So that's another dimension to think about.

So for a typical business school PhD student who is targeting business school audiences, I think Nelson's point about smaller models is a very good advice for the typical audience they are dealing with. So I think my experience has been you have to know your audience and your purpose, and based on that, decide on the complexity of the model.

There is a little bit of a process step as well that, when you start building a model, you usually don't know what are the best simplifications. So usually you end up building something more complex, and then you distill the main insights from that more complex model and try to get to something simpler.

So some of my PhD thesis work I built this very detailed model of software development projects, multiple releases, and working on cases studies in an IT firm. It was a fairly detailed large model. I built a management flight simulator on top of it, but none of that could go into a management journal.

And then I spent quite a bit of time reducing that model into a core theoretical insight type of a model that was two orders of magnitude simpler. We were going from really 2,000 equations to 20 equations. But I couldn't build that two-order-of-magnitude-simpler model as my first model.

Now, maybe somebody who had done at the time a lot more modeling and had seen a lot more and knew the theory that they are trying to contribute to could build a version of that simpler model or model from scratch. And these days I do build very simple models from scratch, because I know the theory and I know what is missing in this space and what would be a contribution. As a starting junior researcher, I didn't have that big picture. So this journey through a complex model back into a simpler model was maybe the feasible path for me. So those are some of the considerations.

[INTERPOSING VOICES]

AUDIENCE: Very quickly. Nelson also mentioned that when you're adding another structure, your understanding of the model should go hand in hand with the extension of the model. And what you were saying is that since you have gone through that path and you have understood all the details, you were able to simplify.

HAZHIR Some of it is that but some of it is, as you build a model, because you're reflecting what you think is important in an empirical setting, that set of important mechanisms in an empirical setting do not necessarily overlap with the theoretically interesting mechanisms, because what is theoretically interesting in researcher space is what is new.

So basically you need to find a way of marrying what you see as important in the real world, if you're doing a case-based detailed modeling with what you have learned from the theory as, OK, everybody has already talked about project dynamics, so there is nothing new. Putting down the project dynamics structure is not a contribution and even multiple release type a-- so you have a platform and you're building different projects on top of that platform per se is not that new.

But then there are some dynamics that come from-- so I didn't have that big picture. I first needed to extract all of the mechanisms that empirically I was seeing as interesting, relevant, build them into my model and then decide that, OK, I throw out 90% of these because they are not, research-wise, giving me a novel angle to go and sell to the academic audiences and take that 10% that is new, that also is relatively important in my story, and it's not the whole story.

Empirically, if I wanted to estimate what was happening in the case, maybe those theoretical mechanisms that I picked up for my theory paper would have explained 10% of the variance. They weren't the only thing or even the primary thing, but they were important enough that I could bring qualitative data to support them. I could tell a internally consistent story in a simple model that why they would potentially be relevant even beyond this specific case. And that made the paper ultimately.

So I don't know. It's not an easy journey. It's the path that I took is not necessarily the right allocation of your limited time if you are trying to maximize your publications, going with a simple model from the start, if you're targeting management audiences, is better. But then how do you get to that simple model? You need to know the literature pretty well. You need to know what are the models that are around and then try to find an angle that has not been approached and used before.

Good. So we have a few models here and maybe more are coming. And my Dropbox is a little bit weird today, but now it says up to date, so hopefully it's all working. So I think we have Ross and Cathy's first submissions. So I'll start with those and then-- and also Serchin's. And we will then go to the ones that we had seen in the previous week as well.

This is Ross's model. So, Ross, would you like to give us a quick overview of what you're doing in this model? So the audience, all of us probably a little bit faster than--

AUDIENCE: So the one with inertia are the accessibility of the product as observed by customers and then the prestige associated with the brand. Accessibility is a function of how much of the demand was met with the sales and what portion of the sales was from-- for the price-sensitive customers.

And then the prestige comes from the relative price of your brand to the competitor, and then quality and then the accessibility. The demand is on the lower side.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: I wanted to make it-- when the prestige goes to zero, it acts like just a common goods.

HAZHIR So let me first, big picture, make sure I'm following what you're doing. So you're looking at a kind of demand and
RAHMANDAD: supply or maybe just the demand for a type of good that could be luxury and therefore prestige matters in terms of demand. You're dividing the population into two groups, those who are more sensitive about the price to quality ratio, and then the ones that for whom prestige also matters.

Then you are modeling demand coming from both of these groups based on the characteristics of the product, those characteristics that matter here are the prestige, the price, and the accessibility. Is there also quality, you said?

AUDIENCE: Yeah, quality is cost, but it's [INAUDIBLE] here. And then the-- I think quantity is also something-- quantity supplied is also something you can control at the company.

HAZHIR Yes. OK. And then the company has control over price and the quantity.

RAHMANDAD:

AUDIENCE: Price, quantity, quality, the quality is fixed.

HAZHIR OK, for now we are fixing the quality.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR That makes sense. So let's not-- good. And basically then there is the question of the trade-offs the company
RAHMANDAD: faces in terms of the overall demand they would expect, given these two policy levers at their disposal. You are not looking at competition or are you looking at competition?

AUDIENCE: I could, but it seems too complex.

HAZHIR Yeah, I think that's fine. I don't want to push you in that direction. Just asking. Great. So this is basically a single
RAHMANDAD: firm. And there is always a baseline external option, competition, in the sense that when you are calculating demand, people-- the reason they may go to not buy from you is that they have some alternative out there. In that sense, it's not completely competition-free, but the competition is not responding to you.

OK, good. So now I think I understand the scope. Let's now look at the structure of the model. So you have the prestige coming from the effect of accessibility, effect of price and quality. And for now we are just ignoring quality because that's fixed throughout. And you're using a multiplicative function for the price.

And then another multiplicative, I assume-- oh, this one is a power function. So you're saying prestige goes up based on-- oops. This is more complex. So effective quality. Let's put that out, effective RP. RP is the relative price. So it is some fixed number plus relative price effect divided by 1 plus that fixed number plus relative price effect multiplied by effective accessibility. So this overall indicated prestige scales with accessibility effect directly. And then effect of price divided by 1 plus effect of price with some additional component.

This is a little bit complex. Can you tell us how you were thinking about it, why you ended up with this formulation?

AUDIENCE: I guess I wanted to find a function that starts-- that is bounded by 0 to 1, and that has a domain of 0 to infinity.

HAZHIR So first, bounded by 0 and 1 because that's how you want to define prestige. That's good. I think I like that
RAHMANDAD: practice in general. OK.

AUDIENCE: Yeah. And then the I think the relative price [INAUDIBLE] with quality is just some positive quantity that can be bounded.

HAZHIR Yeah. OK. So I would say, perhaps a multiplicative effect that has the three effects multiplied by each other or
RAHMANDAD: two-- putting aside the quality-- would have worked just fine because if you keep each of them between 0 and 1, the total will remain 0 and 1.

So this non-linear transformation that you have under this equation, because it then gets combined with another nonlinear transformation in the previous step, becomes very hard to imagine. So when I look at this, I don't know how to mentally calculate what will happen and think about what will happen. So that transparency is really helpful for yourself when you get into diagnosing why the model behaves the way it does.

So I would probably go for each of the effects being between 0 and 1, and then multiplying the three of them to get your indicated prestige, or even doing a weighted average, if you think multiplication is too strict because, the way multiplication works, it says, basically it reduces the probability of getting something close to 1.

So if you have two numbers that are 0.5, you get 0.25. And if you have three numbers that are 0.5, now you get less than 12%. So it just brings down the mass of the distribution, each factor that comes in. So that may indicate something that is more average of the ones or weighted average of the ones based on each of them having an effect, maybe a better choice. And that's OK. That still keeps it between 0 and 1, as long as each of them are between 0 and 1.

But putting that aside. Now, accessibility, assuming that it is between 0 and 1, then the effect of accessibility will remain between 0 and 1 in this equation. And you have 1 minus it because the more accessible something is, the less prestigious it is. So that's the idea that you are trying to highlight here. And you have this power function. That's all fine, I think. But because accessibility, assuming that accessibility is between 0 and 1, then raised to a power, it will remain between 0 and 1. It does what you want to do.

The effect of price the way you currently have, it wouldn't remain between 0 and 1. So that's the place that an alternative formulation between 0 and 1 would do a little bit better if you went with that indicated prestige. I think the reason you went with the current formulation is that your current effect of relative price was not bounded between 0 and 1, so you needed to bring it into the 0 and 1 range.

So what you have done all makes sense. It's just that it's not the easiest to consume for yourself and for anybody who looks at them all. And then you have an asymmetric adjustment time, I assume. But otherwise this is a first order smooth. Good.

So prestige is determined this way. Let's now look at accessibility. So you're tracking demand to sales. And you're saying, if sales was close to demand then accessibility was close to 1 and therefore this is not very prestigious. If sales was much lower than demand, then that's creating prestige. I think that's good.

And you don't need any non-linearity in this part because you will have a non-linearity later on the right-hand side. So it is good to keep it clean and well defined so that when you see a value of 0.5 you know it means half of the demand was served on average in the recent times.

Now, it is important to use the same time constant here for this averaging. I mean, it's not critical, but it is a good idea because you're basically saying, sales to demand is getting averaged. Now, you didn't need necessarily to create these two stocks to track the indicated accessibility. You could just calculate current sales divided by current demand and then take a smooth of that function.

So it is the current accessibility, and then you're taking an average over the season duration. So that will have saved you a stock and a little bit of a structure that may look unfamiliar to people. I don't think you're using any of these two stocks in any other place. If you are, then you'd need them, but you're not using anywhere else. So that would have been an easier, cleaner formulation.

So sales for action price sensitivity, OK. So now sales recorded has this thing that is sales multiplied by fraction price-sensitive demand. So this is-- what's the story here?

AUDIENCE: I wanted to see, of the demand, how much went to the price-sensitive customers.

HAZHIR OK. So then the sales that you're tracking here is only the fraction of sales that is going to price-sensitive
RAHMANDAD: customers.

AUDIENCE: Yeah.

HAZHIR Well, because you're dividing it by total demand, not by demand from price-sensitive customers. Correct?
RAHMANDAD:

AUDIENCE: Yeah. What's

HAZHIR So what's the story? Why are you doing it that way?
RAHMANDAD:

AUDIENCE: It's actually a model. I think it is a multiplication of two [INAUDIBLE] First was the quantity sold to the sensitive segment over the quantity sold times quantity sold over demand. So how much of excess demand there were and other demand, how much went to the price-sensitive customers.

HAZHIR Yes. But why do you want that concept? Why is that driving accessibility?
RAHMANDAD:

AUDIENCE: I want it to be always in excess demand, so that you have more prestige than of the things that are sold, that they don't go to the price-sensitive customers.

HAZHIR I see, so you're saying a prestigious product could have full sales to-- I mean, supply and demand can match,
RAHMANDAD: that is, sales could be the same as demand if it is all of it going to folks who are kind of snobs. So that wouldn't reduce the prestige factor for the product. What does reduce the prestige factor is how much of the price-sensitive customers are going to get the product.

OK, so if that's the argument. Then I'm following what you're doing here. So it's the fraction of total demand that is sold to price-sensitive customers. That's good. OK, that makes sense.

Let's now come down to the demand side. So you have effect of these different factors on demand. So there is a baseline demand. There is effect of-- what is trend?

AUDIENCE: I just wanted to make it some exogenous trend, like--

HAZHIR Oh, OK. So this demand is exogenous?

RAHMANDAD:

AUDIENCE: No, just the trend part is [INAUDIBLE], but it's 6 to 1 right now.

HAZHIR OK. Yeah. Got it. OK. So then effective prestige and relative price are the two primary drivers. And are you

RAHMANDAD: creating-- yeah, this is soft-scripted. Is it soft-scripted? Yeah, it is on different types of demands. And these people have different--

AUDIENCE: They have different elasticities.

HAZHIR --elasticities for the price. So the E sensitivity to price for first group is more sensitive to price than the second

RAHMANDAD: group. And then the prestige effect is first group-- sorry, first group is who, are the normal people or is it snobs?

AUDIENCE: I think the snobs are more sensitive to the prestige.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: Very sensitive parts.

HAZHIR Yes. So this 0 point--

RAHMANDAD:

AUDIENCE: There is sensitivity to prestige.

HAZHIR So this is sensitivity to prestige or no, this is price sensitivity.

RAHMANDAD:

AUDIENCE: I made the elasticity to change with the prestige [INAUDIBLE].

HAZHIR I'm not following. Can you explain?

RAHMANDAD:

AUDIENCE: So prestige, I accounted for it twice.

HAZHIR I see, I see, I see. So here you have baseline price multiplied by 1 minus sensitivity to prestige multiplied by

RAHMANDAD: prestige itself. So tell us, what was your thinking to create this equation?

AUDIENCE: On the demand side, some people have higher elasticity, lower elasticity. And given that demand we're going to have different elasticity depending on the characteristic of [INAUDIBLE]. If it is a luxury brand, you're going to have more elastic demand-- inelastic demand. And then, yeah, there's that two dimension.

HAZHIR I see. So basically, you're saying the snobs are only snobs for products that are prestigious. If this product loses

RAHMANDAD: its prestigeness then they wouldn't be snobs. They would be price-sensitive about it. Got it. That's pretty thoughtful, interesting idea. And yeah, I think the way you have captured it does make sense.

Now, given that prestige changes between 0 and 1, a prestige of 1 in this case-- now it is 1 minus this factor. So the 0.8 in the other one now turns into 0.2. So the parameter names could be better specified because this sensitivity is actually not the sensitivity, it is 1 minus maximum sensitivity or something like that.

OK. All of that makes sense. And then you have the price effect and the prestige effect separately. And the prestige has lower impact for the normal people. And these effects are-- oh. So here you're using a linear effect for the effective prestige on demand.

So I think in system dynamics, community people wouldn't really have a strong opinion on this formulation. But if you talk with more econ-oriented folks, this linear effect is perhaps not as attractive as a power function because power functions directly translate into elasticities. So people have an intuition for them. Now linear is also simple. So you can build an intuition for what it does. Just a little bit of a consideration for alternatives.

For price you do have the elasticity as defined. Interesting. And then, because you're using effective PR on E but with the negative sign here, so the larger it is the more-- the faster they reduce their demand. That makes sense.

All of that is sensible, I think. So then what's the analysis you're doing here? You're looking at different policy choices of the firm to see how they maximize--

AUDIENCE: Yeah.

HAZHIR
RAHMANDAD: Yeah. So this is their price, how it changes the demand and--

AUDIENCE: I feel like for now you can't really-- there's no feedback to price and quantity.

HAZHIR
RAHMANDAD: Uh-huh.

AUDIENCE: I was thinking, shouldn't strategy be a function of the state [INAUDIBLE]?

HAZHIR
RAHMANDAD: Very good question. So this is kind of-- OK. So for now, let's say this is your model that is for the core engine of generation of profits. We settle with this. We could talk about gaming and having a competition and so on. But I think that's too much. I think, given that you have one more week that you can work on this, if you want, you can go in a direction that is aligned with your interest in what is the optimal solution.

So this is, in a dynamic system, you have, let's say, two policy levers. There is the price and there is the supply, how much you sell and what price you sell. So these two you could think of as fixed numbers for the whole simulation and you get a response in terms of profitability. That's the easiest way to start thinking about optimal solutions.

And that is OK. That's a good starting point. You can do a quick analysis. You can create a 3D graph that has, for each value of price and each value of supply, what is your net profits in this market. And you can see a surface plot or a contour plot that summarizes that. And that becomes the output of the analysis. So that's a first order take on the optimal question.

Now you can bring a rebuttal to that, or a kind of a complication to that. And that is what Ross was saying, that, oh, these things are dynamic. I could change the price over time. And I could change the supply over time to get myself into the right range for what is a better long term. So if I have 100 months total in this market, I can actually do much better than just having a fixed number. And that's absolutely correct. That's the more sophisticated version of the optimization.

So that more sophisticated version, solving it becomes a harder problem. So it now becomes a dynamic programming problem, or a reinforcement learning problem, or some stochastic optimization problem, depending on what kind of a tool you want to solve that. Now, system dynamics doesn't have that toolbox as its center of gravity or attention. But basically any dynamic model can be optimally controlled. So you can think of it as an optimal control problem.

So which of these tools you want to use to solve that problem partly depends on what you are comfortable with, what you're familiar with, partly on how complex the problem is. In the general space that we are talking about, these problems can be simplified into a mapping from the status space-- and we should define this status space-- into the action space.

So the action space in Ross's problem is a two-dimensional set of, OK, what is the price and what is the supply production. Those two, at any point in time, the firm can change. And the status space is basically what are the stock values, the values of different stocks in the system that you can look at or the important stock values. Not everything is important.

So creating that mapping optimally becomes an optimal control dynamic program problem that you can try to solve. Even for a simple model like this, it probably is not feasible to solve anything analytically. And then the numerical solutions are also non-trivial.

That is, if you have a continuous state space and continuous action space, this is a computationally intractable problem, dynamic programming typically creates grids on this status space and says, for example, if you're at the low levels of current prestige and low levels of current-- and early time, because time is one of those state variables that is changing over time-- then maybe you should price it very high and then later bring it down or something like that. So that's one way of solving it, a dynamic program.

Then there is this whole neural network-based methods for approximating that functional form. So basically we are looking for a function from a status space, let's say, a two-dimensional status space into a two-dimensional action space. So all the functions that can create from a two-dimensional space to a two-dimensional space are candidates. And now you're optimizing over that functional space. And doing that using neural networks is now the standard method.

Basically, if you go, you want a scalable, high-quality methods, people will say, go reinforcement learning using neural nets as your approximators for the value function, in the lingo of dynamic programming or reinforcement learning, and that value function-- but all of it is pretty involved. That is, in the SD community, there are very few people who actually have done this and have built models to connect your Vensim model to the machinery for doing this.

And even on the reinforcement learning side, this is not a fully solved problem. For every problem you need to actually create the machinery from scratch. It's not a black box, I throw it in and get the results.

Then there are simpler hacks in between that would say, OK, I understand this is a complex problem, but based on my intuition for this system, maybe a linear function that says, the output, these actions is a linear function of my state variables, and I'll estimate those parameters of that linear function using an optimization. That can do well. And maybe I use that.

So that you can do inside Vensim, basically come up with a flexible, functional form that says your price is a function of your couple of variables that are important here. In this case, I think the most important is the prestige and perhaps the-- and time. I think those two are the critical ones.

So you can create a linear or a quadratic function with a few handful of free parameters, then use Vensim's optimization engine to maximize your profits by changing those parameters. It gives you a decent first-order approximation. So that's another way to do it.

So that, I went through this because we have never had the opportunity to talk about optimal control type of things. But this is a simple enough problem. You can imagine doing it in this case.

Now for you, Ross. It really depends on what you want to get out of it for the next week. I would say doing one of these spectrum of things from just a two-dimensional space where you're running different combinations of price and supply and you calculate the profit. So it is a fixed policy, you create that contour plot, that's a one level, all the way to more complex dynamic programming ones. But I think that's too much unless you are planning to do something more with that space in general. So this is an opportunity to learn that.

The intermediate one would be running something inside Vensim that is a simple function connecting your inputs to your outputs, your status space to your action space, and optimizing those parameters using Vensim's optimization engine. I would say that is probably as far as you should push yourself if you're not building a capability longer-term from this exercise.

OK, good. I think this is a nice model for what you're trying to do. We discussed a few things that you can improve, but I think it's in the right space.

Let's next look at Cathy's model.

AUDIENCE: And I'll say, it's not 100% formulated. This is structure.

HAZHIR Sure. So maybe tell us a little bit about what you're trying to capture, how you're trying to capture it. And what
RAHMANDAD: are the questions that we can focus on, the places where it adds more value for you.

AUDIENCE: Yeah, so I am trying to model the trade-off between social and human capital and also the heterogeneity among readers, and to see if I can incorporate both of those and explain the divergence between buying and reading books rates.

And so I started with this social influence feedback loop on the right here, where books become more attractive, people are buying more, and then because they're buying more, they're kind of showing them off, social pressure for book-buying should increase. And then the indicated social capital-- or the social capital that you get from buying a book should increase. And then that changes the calculus in terms of it's important for me to buy books versus it's important for me to buy and read them. And so it influences buying books and the fraction of books that are read.

Then that goes to the attractiveness piece, but then it also influences the fraction of books that are read. So out of the books that are bought, how many of them are read? And that depends on both this relative importance, so how important is it for me to read the book that I bought?

And then this two groups, low-frequency and high-frequency readers, I just divided-- I had three before, but it was suggested, two is best. So yeah, there are people who read-- I think over half the people read zero. And so I was switching it from-- I was dividing it into zero, low and high. But I think just low and high is [INAUDIBLE] around here.

And then-- OK. So let me pause here. So yeah.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: The low- and high-frequency readers [INAUDIBLE] just kind of this-- it's coming from this indicated fraction that is determined by the reading rate. And then that I actually want to formulate, because it's kind of-- I don't know how discreet to make it. There are definitions in the literature, but no high frequency readers are reading at least one or at least two books a month.

HAZHIR Yeah, but then you don't need to-- I mean the definition can be whatever you choose and it can be discreet, but

RAHMANDAD: the movement between these stocks wouldn't be discreet. So you don't need to worry too much about the discreet definitions.

AUDIENCE: Yeah.

HAZHIR OK. Sounds good. So let's now go through some of these. So basically you have the high- and low-frequency

RAHMANDAD: readers. They each are reading a number per month. Is that how things are determined? So the reading rate, so right now--

AUDIENCE: So that big spot for Kristen should be subdivided or [INAUDIBLE]. But right now, it's in the-- it's not.

HAZHIR So books bought per person should be subscripted by high versus low frequency.

RAHMANDAD:

AUDIENCE: Yeah, but then it's kind of double counting.

HAZHIR So yeah, I'm not quite sure if-- so you could have that-- so there's book buying rate and then you have book

RAHMANDAD: reading rate. So this comes from fraction of bought books that are read.

So the worry I have is that you're calculating this fraction of bought books read somewhere, and then you're capturing book-buying rates somewhere else. And the two need to be fairly closely integrated. So if I increase the number of books that are bought to a very large number, the fraction of books that are read should go down in a very consistent manner.

So if today I double the number of books that are bought by me, my reading rate should go close to half as a fraction.

AUDIENCE: So there should be some kind of reading capacity?

HAZHIR Something. That's-- Right now it is not tightly connected. So you may get very weird behaviors that just don't make sense physically. So you want that tighter connection.

Now how do you impose that tighter connection is non-trivial. So maybe capacity is a useful thing. So that is each of these two groups, you think of them as people who have this much time at a maximum for reading. And as you buy more books, you get closer to saturating that amount of time that you may allocate to reading. You can never exceed that amount. And that amount of time that you spend reading determines how many books you are going to read.

Now, if you're not buying any books, you're not reading any books. So the lower bound is also should be there, but the upper bound saturates. And now if you're buying 100 books, you're not reading most of them per month, and that's fine.

So making that connection tight and clean is really important. That might be the most important part of getting this model to behave meaningfully.

AUDIENCE: That makes a lot of sense. I think I was so focused on those things being decoupled that I didn't think about that.

HAZHIR Yes, but decoupling comes from really physics of reading. So if the physics are not captured well, everything else will break down and do weird things.

Then you have this attractiveness factor that you're saying, OK, buying books because of the social media creates a signal of attractiveness, prestige, whatever, that adds to the reasons for buying books. So basically, people have some desired level of reading that might be driving the buying of books before this attractiveness came in through the social media channel.

And now you're saying, OK, now they are buying more books beyond what they normally read to show off to say that-- so to capture that you would anchor the demand, probably, to what they are reading right now or what they want to read. They have a desired level of actual reading. That's your initial anchor. And then you can adjust from that anchor towards a larger or smaller value of purchasing based on their social media prestige factor you're highlighting.

AUDIENCE: Is that captured by the reference books bought per person and I can flesh it out, or is that-- are you referring to something different?

HAZHIR So these reference, SC reference, HC, these are what?

RAHMANDAD:

AUDIENCE: Well, sorry, below those there's reference books about the person.

HAZHIR Oh.

RAHMANDAD:

[INTERPOSING VOICES]

AUDIENCE: Reference SC is reference Social Capital, HC is Human Capital.

HAZHIR I see. So the equation here is one of these complex ones. I feel intimidated by this.

RAHMANDAD:

AUDIENCE: This is the attractiveness section.

HAZHIR So each of them, you have a sensitivity. You have a human capital gain via buying and reading divided by that
RAHMANDAD: reference.

AUDIENCE: And then it's just a multiplicative.

HAZHIR OK, got it. So HC and SC are the high and low frequency readers? No.

RAHMANDAD:

AUDIENCE: No, human capital and social capital.

HAZHIR OK. So you have the human capital and social capital factors.

RAHMANDAD:

I don't know, this attractiveness of books. First of all, you need to separate it for these two groups. Right now it is a single value. Now, you may say the effect of prestige or social capital on that attractiveness could be the same for both groups. That's OK assumption.

So you would calculate that effect of social capital on attractiveness and multiply it by the baseline book demand from each group. But the baseline book demand should be distinct for the two groups. Otherwise, it just doesn't make sense internally.

So let's say you have these separate demands or baseline demands that is coming from, you're calling it human capital. But I wouldn't-- basically it is, yes, how many books they want to read left on their own devices.

AUDIENCE: Yeah.

HAZHIR So you can do that. And then you get this social pressure effect that expands that number that are purchased.

RAHMANDAD: And then you can decide whether reading of books go up because I have bought more books. So maybe I read a little bit more or maybe I don't. You can make an assumption on that.

You should have a parameter that says, what is the effect of buying more books or having access to more books on your reading rate for these two groups that would saturate to how much maximum time you are willing to allocate to it. So maybe if your baseline demand is for two books per month for the high readers and 0.2 books per month for the low readers, you're not going to more than double that amount of reading just because you have bought more books or something like that. And so you create that saturation point.

So that's, I think, the key pieces you need to incorporate. Then there is the question of movement of people between low-frequency and high-frequency readers, and whether that is endogenous or exogenous. So if I'm seeing people in the low-frequency reader group who are reading more books than the baseline, my expectation is that a few of them will move to the high-frequency reader category.

Alternatively, if I'm seeing them read less, I would expect some high-frequency ones to come to the other one. There is a source of endogeneity here, but your story is a little bit more exogenous, that there is a trend in general, that people are reading less books and moving from the high-frequency to low-frequency category just because they are busy doing other things, and maybe they're too much on the social media looking at other people's books. But that story then has an exogenous flow.

And basically then your solution to the puzzle is this exogenous flow of people from high frequency to low frequency, combined with this social pressure dynamic that might be increasing the attractiveness of buying books.

AUDIENCE: So try it with an exogenous transition?

HAZHIR Yeah, for now I think that's a good starting point.

RAHMANDAD:

AUDIENCE: OK.

HAZHIR Again, there is-- so that is the effect coming from all the other factors. And then there is the effect of, oh, I have

RAHMANDAD: more books, so I'm reading more books. So maybe a few of these people become interested in books and actually go to the right-hand side. That effect is worse incorporating in your model as a second step once you have the first exogenous part working. Jason.

AUDIENCE: You could make it-- you could tell another story where older generations are the high-frequency readers. They die and go away.

AUDIENCE: Actually, older people, for the first time, are reading less books than the middle-aged groups.

AUDIENCE: I was just trying to get more people in your low-frequency stuff.

HAZHIR Well, so you could tell those other stories. But I think at this stage you don't want to go into the demographic

RAHMANDAD: part. That's a whole different story structure. First get the very simple without demographic one.

AUDIENCE: Yeah.

AUDIENCE: I think the exogenous explanation for why these are diverging but we still have all the high-frequency people who are reading 150 books a year, is-- there's some reinforcing dynamic just among high-frequency readers where they're going from 20 or 40 to 100 or 150. And I think that's, in article that I've read, that's driven by-- or that's emphasized to be driven by e-books and audiobooks being so much more available and popular.

So I think I could just have an exogenous model that would do this with that dynamic and the social capital then is driven by this small segment of the market.

HAZHIR So the story you are telling might suggest that people, how sensitive they are to this social capital mechanism

RAHMANDAD: may actually be differentiable between the low-frequency readers and high-frequency readers. That is, the high-frequency readers are more sensitive to the social capital story, and the low-frequency readers are not sensitive to it. And that could create a situation where the high-frequency readers buy more books and read more books. So they don't saturate as fast, even though they are spending a lot more time on reading books.

So your model, I think, should allow you to generate that hypothesis as well. That is, it should have enough degrees of freedom in parameters to do that as well.

AUDIENCE: OK, that's helpful.

HAZHIR Good. Other questions you may have on this

RAHMANDAD:

AUDIENCE: I think it's OK that I was just finding the [INAUDIBLE]?

HAZHIR So I think the part that we haven't talked about is how this social capital gets constructed.

RAHMANDAD:

AUDIENCE: Yeah, I have not formulated that.

HAZHIR Yeah, and that is not necessarily very easy as well because that's the more softer side of the model. So what are

RAHMANDAD: the thoughts? Anybody has suggestions for how Cathy can formulate the social capital in a simple way and well-grounded way?

AUDIENCE: Is it going to be separate for high-frequency versus low-frequency?

HAZHIR Could be. I mean, that's a decision on the modeling side.

RAHMANDAD:

AUDIENCE: Are you aware of any papers that have done on this [INAUDIBLE] model? I was wanting to--

HAZHIR So it's actually a good question that is, what is a standard formulation that captures this idea of social pressure,

RAHMANDAD: role-setting, norm-setting.

AUDIENCE: You could use social learning models.

AUDIENCE: Yeah.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: It's a little different.

HAZHIR It's a little bit different. But you have to adopt something. So, Oriana, did you have some ideas?

RAHMANDAD:

AUDIENCE: I was thinking maybe you could do something like does social capital gain because the fraction of the books that you have over the average number of books per person if you have-- well, it wouldn't be linear, but if you have 10% more books than the average person, then you're 5% [INAUDIBLE]. But I actually don't know how that would go. You need to do a singular agent thinking about their own social capital and however [INAUDIBLE] a bigger model.

HAZHIR That's an interesting idea. So basically, you're saying, look at what's the norm in terms of the number of books

RAHMANDAD: per person that is being bought up, and then you try to anchor to that and go a little bit higher or potentially more than a little bit, depending on how aggressive you are. But average of those folks, they are trying to anchor to that and go a little bit above that. That's how they adjust their buying rate to gain social capital. So that's a decent way of tackling it.

Now that creates a very simple, quick reinforcing loop. So basically people buy more books per person. That increases the goal for everybody. And everybody is going to do more. So you leave that on its own, people will buy infinite number of books very quickly. So that creates a weird dynamic that is not realistic. So in practice, what stops you from that?

AUDIENCE: Income.

HAZHIR Exam?

RAHMANDAD:

AUDIENCE: Income.

HAZHIR So you need to think about the bounding factors that slows down that reinforcing loop if you are going to use that

RAHMANDAD: reinforcing loop formulation that Oriana suggested. I think the reinforcing loop mechanism is OK. I think that's a decent perspective because people are doing peer comparisons and try to outperform their peers. You need the balancing mechanisms, either coming from your income or from your ability to read these books. So yeah.

AUDIENCE: I think maybe another way you can stop it from getting too crazy is how much social capital you gain is dependent on how many people care or can compete on that scale. So at five books, you have the entire population of readers is competing. And so you'll see it go up pretty quick.

But look, when you're buying 100 books, you're saying, the income, there's a very small number of people. And so then the number of people who really care about that book or that competition gets really small. So that should make it plateau and then eventually fall off.

HAZHIR Yeah, that's an interesting way of thinking about it as well. So but to do that, basically you now have to break

RAHMANDAD: down the population of readers into different buckets. So this is now you would have movement of people across these buckets of 10 books a month, 20 books a month, or whatever.

AUDIENCE: [INAUDIBLE] at some point, you look at somebody who has-- they're buying just a number of books that's unreasonable and you think, oh, they're not actually reading those. It becomes kind of a cloud story where they actually get discounted. So maybe there's a way to, if you're buying too many that it's ridiculous.

HAZHIR Yeah. So basically you need a feedback there. It could be because of the money. It could be because you think it is ridiculous, because you think for yourself, I'm not going to read all of this book. Why am I going to buy them? Any of those are fine. So basically you would have a decreasing return and, at some point, negative return on your utility from buying more books because you're losing money and not reading anything.

AUDIENCE: There is a 2014 [INAUDIBLE] paper on the curse of publicity. It kind of related to this looking at prize-winning books. And they're saying that these prize-winners, because they're getting a lot of attraction, they actually reach to certain markets, people are not very interested in those books, but they've heard that quote, this is a famous book. So that's why. And they use Goodreads data showing that actually those types of book tends to get lower ratings compared to finally [INAUDIBLE] the price.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: So if you want, I think that's social--

HAZHIR That's very interesting.

RAHMANDAD:

AUDIENCE: [INAUDIBLE] because I feel like, part of it isn't just necessarily the book-buying by itself. I mean, that's complicated too much, but I feel like the reason that now book-buying-- or now there's so much more social capital from buying books, does directly have to do with social media and does directly have to do with, oh, do you have 100% of the books that people are talking about. Whereas if you were to model this pre-2014, I don't know that the social pressure for book-buying would be directly determined by the book-buying rate.

[INTERPOSING VOICES]

AUDIENCE: Same.

HAZHIR Yeah. And I think Cathy's hypothesis is also very much aligned that with social media and creating a different set
RAHMANDAD: of pressures that didn't exist, and now it creates this kind of separation between reading and buying.

AUDIENCE: I just saw this student thesis that says that Goodreads is--

AUDIENCE: Performing [INAUDIBLE].

AUDIENCE: --some tracking from Lipton and Foucault's governmentality, Goodreads is a disciplinary technology.

[LAUGHTER]

[INAUDIBLE]

HAZHIR Cool. So let's now switch to Serchin's model. So Serchin. Please tell us what you're trying to do. This is-- let me
RAHMANDAD: first get a feel for-- OK. This is a little bit of a big model. So hopefully there are not too many views.

[LAUGHTER]

OK, so this might be well above what we can cover in the class because I think this is a model of the whole economy or something. But tell us where we should focus on so that it is useful for you and we can also have a good chat in the class.

AUDIENCE: So first of all, good morning, Professor. Good morning, everyone. Maybe I should start with the problem definition. Maybe I can explain a little bit.

HAZHIR Sure.

RAHMANDAD:

AUDIENCE: Because I couldn't attend the session that my problem definition is discussed. And I would like to thank everyone who took the time to comment on my problem definition. It was really useful while writing my final problem definition.

So my main central question is that can the behavior of the firms, in order that are meant to tackle with uncertainty, can be a source of instability and create endogenous oscillations in the economy.

Back in the day, Frank Knight and John Maynard Keynes made a distinction between risk and uncertainty. And in risk situations, we can list all possible outcomes and assign probabilities to them. On the other hand, in the case of uncertainty, we cannot even define the exhaustive list of outcomes. That can always be some black swan events. And we cannot assign a probability distribution.

And in order to tackle with these situations, Keynes argues that economic agents act on animal spirits. And these are akin to what we might call as gut feelings or sentiments.

In fact, sentiments are very important data that are closely followed by financial markets being real. For example, University of Michigan Sentiment Index or/and Consumer Confidence Index are two important sentiment indicators in the USA. And these intersect-- capture how optimistic or pessimistic economic agents feel about the present and future of the economy, which influence their spending and investment decisions.

Apart from that, in mainstream economics, there are no buffer stocks. It is all about flows, as you probably know, which are assumed to be equal to each other all the time. So the demand is equal to supply and the economy is in equilibrium all the time.

But in order to tackle with uncertainty, we know that economic agents use buffer stocks. For example, in order to avoid stock-outs in the case of unexpected demand, firms hold buffer inventories, or in order to be able to make payments in case of shortages in cash flow, they hold liquid assets, and so on and so forth.

My hypothesis is that there are important feedback loops running through sentiments and buffer stocks. And these will generate macroeconomic fluctuations at a business cycle frequency. And one of them runs through these sentiments and decisions of the real sector.

My goal is to show that stability is destabilizing, as argued by Minsky, and namely, even if the economy starts from its equilibrium, psychological factors would give rise to macroeconomic fluctuations in the presence of uncertainty, and the cycles would be amplified or dampened by the psychological parameters.

So I tried to build this model in order to depict how the behavior of the real sector affects these cycles, or create these cycles. So the focus on the real sector, and therefore I simplified the behavior of the household and the [? banks ?] in the sector. And I assume the way the price mechanism. So all the adjustments is through the quantity adjustment.

I don't know if--

[INTERPOSING VOICES]

HAZHIR That's very helpful. So if I understand correctly, basically you're saying, depending on the sentiment, you are
RAHMANDAD: changing your buffer stocks, your inventories, think about it, but also your cash in your bank account that you desire.

AUDIENCE: Right.

HAZHIR And those changes have real impacts in the supply, and in the demand side primarily, which then creates more
RAHMANDAD: instability, volatility downstream, which leads to potential need for even more buffer stock. But at some point that becomes too much buffer stock or it becomes too much demand, because now you have built your buffer stock and then the demand goes down. So that becomes the trigger for the endogenous oscillations in the real economy.

AUDIENCE: Exactly.

HAZHIR OK.

RAHMANDAD:

AUDIENCE: So yes. And the finished good inventories is just one side of it. And apart from that, in the stabilized balance sheet of the firm, we had capital stock, inventories, liquidity assets on the asset side and loans and equity at the liability side.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: I assume that if there were no uncertainty, the levels of these stocks would be equal to their inflows and outflows, and the firms would not hold any excess inventory as it is assumed in mainstream economics. But in order to tackle with uncertainty, firms do hold excess inventory.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: And the excess, the normal level of these excess inventories, changes with the sentiment. So I also endogenize the sentiments which has a range between 0 and 2, with a normal level of 1. The normal level of excess inventories is equal to their level when sentiment is equal to 1.

HAZHIR Yeah. Makes sense. So big picture, I think that's an interesting problem. Now, outside of the relevant literature, a
RAHMANDAD: lot of people have built models of instability in an economy, I think kind of old work in system dynamics in the '70s and early '80s has been focused on some of this.

I don't remember having heard about the kind of sentiment based on the instability, based on the deviances of the demand growth rates, so I think that this is a new channel for that literature, but I don't know enough in the econ literature and how these are modeled and treated to have a meaningful advice on what is the right level of aggregation or what to include and what to exclude, so that your contribution is clear and novel.

For an uneducated person in this space, like myself, I would say, focusing on the simplest structures that gets you the core idea-- allows you to show the core idea would be the right choice. So I'm not sure if you need to include all of those buffer stocks going over the capital, stock of the companies, and their balance sheets and earnings and so on.

I would say, just pick, for example, the inventory and see how you can just capture the core effect within that inventory sector. But that might not be good enough or the state of the art for an econ audience who may say, oh, the inventory kind of adjustment pathway should be complemented with these other pathways. Otherwise, what you see for the inventory does not make much sense. So I don't know that, what is the right choice there.

So with that caveat in mind I can see two different ways. One is let's stick to what you have here, because you have been looking at this problem and thinking about it, and you tell us where we can provide more meaningful feedback, because I don't think we have the time and also the expertise really to provide feedback on everything you have here. So that's one way we can move ahead.

The alternative is to think together to more what would be a minimalistic model that can capture this instability without a lot of the additional structures you have. So that would be a little bit more conceptual conversation. So what is your choice? We can go with either of those.

AUDIENCE: I would appreciate feedback about how I can formulate the endogenous sentiment. So here in this model I thought that it is a function of the growth rate, the average percent growth rate of the aggregate demand.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: And it's supposed to be function of that. And it is a negative function of the volatility of the growth rate of the economy.

HAZHIR Yes. Got it. So one question. The sentiment index, do you have a more clear definition for it? This is kind of the

RAHMANDAD: Michigan Survey of Households and what's their sentiment about the economy? Is that what is kind of the idea?

AUDIENCE: Yes, exactly. Or the Confidence index sector confidence.

HAZHIR OK.

RAHMANDAD:

AUDIENCE: How optimistic or pessimistic--

[INTERPOSING VOICES]

HAZHIR Pessimistic that, yeah, the business climate.

RAHMANDAD:

AUDIENCE: --picture of the economy.

HAZHIR OK. So I assume empirically these two factors that you have, that is the recent growth rate and the volatility in

RAHMANDAD: the recent months are the primary candidates for driving this effect. Is that a correct understanding?

AUDIENCE: Yes.

HAZHIR OK. So then, big picture, you're doing the right thing. Now what would be the right formulations here, I would

RAHMANDAD: certainly go into the econ literature that looks at these and see what functional forms they use for estimating sentiment index based on growth rates and volatility.

So volatility, typically, they use something like a standard deviation variance in whatever the underlying factor is. So if this is the growth rate they are looking at, they might be looking at the variance in the growth rate. So that is pretty common. And then I suspect they would be doing regressions on the empirical side for estimating sentiment as a function of these factors.

So regressions are typically a linear function. So whether linear function is the best thing you can do here or something more bounded might be useful because you are trying to keep the sentiment index between 0 and 2. That's a little bit open to me. You could go either way. And then some weighted average of the effect of volatility and effect of growth is perhaps a good mix, a good way of doing it.

So right now you have a lot of things going into this equation for the flow of sentiment index. So that's makes me a little bit worried in understanding it. I'm not saying it is wrong, I just, yeah. You see?

AUDIENCE: So basically I'm formulating it as a logistic function with ranges between 0 and 2.

HAZHIR Got it.

RAHMANDAD:

AUDIENCE: And average growth rate affects positively, and the volatility or the variance of the aggregate demand has a negative effect on that.

HAZHIR Got it.

RAHMANDAD:

AUDIENCE: And in order to give that negative effect, I assume that there is a minimum variance, normal variance, that people or [INAUDIBLE] as normal.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: So if it is below that normal level, sentiment index increases. And if it is above that level the sentiment index decreases. But I don't know if this formulation is too ad hoc. It works, but--

[INTERPOSING VOICES]

HAZHIR So I think, yeah. So very simple feedback here is that you definitely just need to create a indicated sentiment index and then adjust towards that with the time delay rather than this convoluted formulation that throws everything into the formulation for the stock. So that's just housekeeping norms that you should follow.

RAHMANDAD:

Beyond that, the logistic function does make sense-- at its surface is sensible to me. It's not something I have looked into the literature for. So I don't know what are the alternatives people would have potentially recommended. But it is a robust function. So it works OK, keeps you in the bounds. So that's fine.

Where I'm a little bit less clear is this average square deviation of demand growth rate. So where does variance come from in this model? So does it simulate right now? Yeah. So right now, if you simulate it, you're starting in some kind of equilibrium, which is generally a good idea. But then that means-- so but how do you trigger any behavior that is non-equilibrium?

AUDIENCE: So there is the uncertainty switch to the bottom right here on the screen. No, sorry. It is a [INAUDIBLE] now.

HAZHIR Yep. I see. So if we turn it on--

RAHMANDAD:

AUDIENCE: Yes. And--

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: --value of 1 creates answer.

HAZHIR Yeah, you can see oscillations coming from-- so what does the uncertainty switch do? What is it that it triggers? It

RAHMANDAD: triggers some excess capacity.

AUDIENCE: Yes.

HAZHIR OK. And then that changes the capital stock. And then through that, everything starts to oscillate. And the

RAHMANDAD: oscillations create this standard deviation part. Now the calculation of standard deviation, I don't know how you have done it. Are you comfortable-- confident with how it is calculated in your model because that's not trivial?

AUDIENCE: I'm not sure. [LAUGHS]

HAZHIR Yeah. So when you have the mean-- so to calculate standard deviation you want to accumulate the second

RAHMANDAD: moment that is whatever you're tracking to the power of 2 and then look at the difference between-- so the expected value versus expected value of x to the power of 2, the difference between those two. So it's expected value of x to the power of 2 minus expected value to the power of 2. That is driving the variance.

So yeah, we can take a look at that. That's nothing complex conceptually. It's just making sure that the mathematically-- so you have a perception adjustment times square deviance of demand growth rate minus average squared deviance of demand growth rate. Yeah, that looks right. If this average squared deviance is the difference between-- yeah, I think this is correct. So this gives you basically variance.

The important thing is that the time constant should be the same for both of these. So this perceived average aggregate, yes, the time constant is the same. Good. OK. So the model seems to be doing something oscillatory. Now do you know where the oscillations are coming from? Have you tried to trace the oscillations?

AUDIENCE: I think there are some feedback loops running through these sentiments. But because as the buffer stocks increase, the aggregate demand increases. So there are definitely positive feedback loops running through sentiments. But it's another thing I would like to ask.

HAZHIR Yes.

RAHMANDAD:

[INTERPOSING VOICES]

AUDIENCE: So there must be something, some negative feedback loops running also. But I cannot define any at the moment because I don't know how to give the direction to the causal relations between volatility and--

[INTERPOSING VOICES]

HAZHIR Yes, so that's exactly what I was asking. That is, you really need to understand what is driving your oscillatory

RAHMANDAD: mode. So right now I select sentiment index, for example, you can do the causal strips. So which of the drivers of sentiment index are likely to be driving its behavior? It's pretty clearly effective growth.

And then you can look at effective growth. What is driving oscillations in effective growth, it's the expected perceived growth. And then that one is perceived average aggregate demand growth. That is a little bit more tricky. Let's see. Real aggregate demand, average aggregate demand growth rate, and it is coming from aggregate demand. Because this perceived average real aggregate demand is just a delay of this guy if I understand it correctly. So that would also come from the real aggregate demand.

AUDIENCE: Yes.

HAZHIR So then real aggregate demand is coming from nominal aggregate demand. Nominal aggregate demand is
RAHMANDAD: coming from-- these two different things could be driving it. But you look at the scale of these, by far the household desired consumption is the biggest driver.

So this planned investment expenditure is tiny compared to that. So the household is coming from nominal budget for living, that's coming from a standard of living, that's coming from household disposable income, that's coming from household income.

Now household income is largely wages. Dividends matter, but not as big of a deal. Interest income is not a big deal. So wage is really what is driving the income. Wages coming from labor demand. Labor demand is coming from production.

Production is coming from which of these two? So this is a little bit less clear. It's desired production versus production capacity. I think production capacity is also tied to desired production?

AUDIENCE: So it defines the ceiling for product.

[INTERPOSING VOICES]

HAZHIR Yes, exactly.

RAHMANDAD:

AUDIENCE: At the short term, capital stock is fixed. So at most, that must-- or might be produced.

HAZHIR Yeah. So OK, I'm going with desired production. This is one of the places that I'm not sure whether I'm tracing the
RAHMANDAD: right driver. Then desired production based on the average real aggregate demand. And desired inventory-- so I'm going with the average aggregate demand, even though the other one might be relevant as well. And this goes to real aggregate demand, which goes to nominal aggregate demand, which goes to--

[INTERPOSING VOICES]

HAZHIR We are now back to the household. So basically that feedback loop that we identified as the candidate goes
RAHMANDAD: through the household demand, which comes from household income. Household income comes from household wages. Household wages comes from the labor. Labor comes from the production. Desired production comes from household demand ultimately. So that's the feedback loop. That is the hypothesis for what is driving it.

Now we need to cut that feedback loop somewhere to see whether that changes the behavior significantly. So I could look at the-- somewhere about households.

AUDIENCE: And households is in the second view.

HAZHIR So we have consumption demand, for example, here. And household desired consumption. And then
RAHMANDAD: consumption demand is feeding back somewhere?

AUDIENCE: No, no, I think it is redundant. I forgot that.

HAZHIR So let's say household desired consumption, we just override the default behavior. And we just say, let's make it
RAHMANDAD: constant. So now I just made it constant at its base value. And now we can see whether anything else oscillates. Nothing else oscillates. So that hypothesis gets an additional boost from this experiment.

I just wanted to go through this because that's a process that you need to all follow and do to be able to identify what is driving your model's behavior. And in this case, it doesn't tell me that the hypothesis is absolutely correct because I didn't pick a link that is unique to that loop and nothing else. I just went into the loop and picked something, and that something might be overlapping with another loop that is important for this dynamic. But it gives me confidence that the household sector is really important.

And now if I don't want to use this-- let me see. Reset all overrides. Yeah, if I don't want to focus only on this one. I could go somewhere else, like where the households get their wages, and test that. So if you test different parts of the loop and you get the same result, that gives you more confidence that this is the loop that is generating the behavior.

OK, I think you all get the idea. This is really, really important. If you have a model, it is generating a behavior that you think is relevant, potentially interesting. You need to understand where that behavior comes from.

Now the reason in this specific case it is super important, is that your whole hypothesis was about basically volatility driving these dynamics. And right now volatility doesn't play a role in your primary loop. In fact, my hypothesis is that if we disable the volatility side of the dynamics-- so if we turn on this switch back here-- where was the switch?

AUDIENCE: And also [INAUDIBLE] switch.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: Purple.

HAZHIR Here, I think. So now we have this pathway going. If I just take this demand growth rate standard deviation and
RAHMANDAD: just say, ah, make it a constant, you see? I cut this pathway. The dynamics are there. It is not stopping your structure. In fact, it's not even obvious is if the effect of growth will be also critical, although this is a little bit harder to say. Yeah, so this one does matter because it also cuts the shock to the system that came from the sentiment index.

So anyway, the point is that, right now, the mechanism that is generating oscillations is more about the balancing loop of households changing their consumption, which changes the demand for the goods, which changes the labor needs and the wages that the households get, which changes the households needing goods. That's the dominant feedback loop here. That dominant feedback loop has nothing to do with your story that was related to dynamics of sentiments and volatility.

So I'm not saying those don't create oscillations or can't create oscillations, but I'm saying your model has so many other moving parts that it is generating oscillation for reasons that you didn't care about as much, that are orthogonal to what you were defining as your problem.

OK, I hope this was helpful.

AUDIENCE: Yes, definitely. Thank you very much.

HAZHIR Let's take a break. We went a little bit over time, but let's take 10 minutes and come back.

RAHMANDAD:

OK, I think we can get back together. I think it's kind of-- we can get started. I just opened Jake's model, which is on production of movies and series and competition between different locations for production. And the model basically has the story of two primary drivers of attractiveness of locations being talent, human capital, actors, and set designers, and all the kind of crew that make a movie, and local production infrastructure, which could be physical infrastructure and technology. Yeah.

So those two, whether you have better options than alternative places makes you more attractive or less attractive. And then that determines what fraction of movies will decide to go with your location versus other locations. But then that creates attractiveness drive for talent to go to places that are getting a lot of production happening and for investment into the infrastructure for places that are getting. So that creates reinforcing loops that can generate bifurcation into-- that's the story.

AUDIENCE: Does talent move away in this version of the model?

HAZHIR So--

RAHMANDAD:

AUDIENCE: The talent doesn't move here. No. It's the idea is that you'll have a local talent experienced workforce. It's not even necessarily number of people. It's person hours who have experience.

HAZHIR So this is actually a little bit of a how we define these resources is important. So one definition is number of
RAHMANDAD: people. The other is number of experience hours in the geography. And both of them are kind of a little bit leave me a squeamish, because people without experience is not perfect, and experienced others is too much giving credit to more experience because the return on experience is diminishing pretty rapidly.

So if you want to capture both of them, one way, is to have a co-flow of people and the experience that they have. So that when people join, they join with limited experience. But then when they are in, they are gaining experience based on how many other productions they are engaged in. You could do that. I'm not saying you should do that. I'm just saying kind of conceptually, that gives you the flexibility.

If you are not doing that, then maybe I would go with people, experienced people or something like that, so that I focus on what is the bottleneck is the number of experienced people or capable people.

And then we were talking about-- OK, so the way Jake has formulated these is that for each component-- so you have a talent component, the way it is formulated is your local talent for that location. So this is subscripted by locations divided by total talent. And one feedback that I gave him on the previous week's version of the model was that maybe you can consider a denominator, a normalizing factor that is not tied to the total talent.

And the argument there is the real attractiveness of Los Angeles versus New York, the attractiveness of Los Angeles per se is based on whether you have talent or not. It doesn't depend on whether New York has talent or not. So if talent in New York doubles, the attractiveness of Los Angeles alone should not change. The relative attractiveness certainly changes. But that relative attractiveness is already captured because now New York has twice as many talents, and therefore, it gets a bigger talent component coming from that numerator.

You don't need to adjust the denominator. That was the argument I was making. And the reason it matters is that, in the current formulation, the talent component remains a 0 sum game. That is essentially the sum of the talent component across all of them, gets to 1. And for allocation problems, that's OK. You all, ultimately, you are allocating across a fixed amount of production among different places, so it will work fine.

But if you had a situation where the production start was going to depend on availability of talent, and location, and so on, and you could increase or decrease the production start rate based on the availabilities, then things start to change. Then the absolute values matter more. And tracking those absolute values or normalized absolute values would be more useful in that sense.

So again, not a big deal. And for your allocation problem it just works fine. But for thinking about the future of this model, I would have thought about. And very similar feedback on the other part, which is the local production infrastructure. And right now, you have decays for them, which are fine. Each of them can have a decay time.

AUDIENCE: Another question [INAUDIBLE].

HAZHIR Sure.

RAHMANDAD:

AUDIENCE: Because I do feel like the tax credit is such an important--

[INTERPOSING VOICES]

AUDIENCE: --would be, do I need to have an overall idea of costs associated with using local--

[INTERPOSING VOICES]

HAZHIR So this is a very good question. And I think this is really at the heart of this allocation problem is how productions
RAHMANDAD: decide where to locate. And that production deciding where to locate is a cost-benefit analysis, some kind of an optimization problem that I have two portfolios, one with this talent pool, this infrastructure and this tax credit, and maybe five other factors. And this is the other one. So how do I decide to allocate between them?

Right now you have an ad hoc attractiveness that just divides and allocates. That's OK. It's a good first cut. I'm not going to say you shouldn't use that. But if you wanted to go the route of a little bit more rational decision-making process, you need to define a production function of sorts that says, OK, what would be the net quality, net profitability of my production, given this level of talent, this level of production infrastructure, and this level of tax credit.

So if you can write a profit function and that profit function has costs and has benefits, then you can solve for-- between those different alternatives which one gives you the highest profit. So you can have expected profits from the five different locations based on calculating those profits. And you say, OK, and then you have a sensitivity parameter that says, how sensitive I'm to that expected profit?

If I allocate 100% to the location that gives me the most profit, or I allocate 80% to that and 20% to the second one, or some kind of a other mix, and that could be a simple logistic function for distributing between these players. So that would be a little bit more rational.

AUDIENCE: How would I do that sort of idea without-- it feels to me like then I would need a dozen additional parameters that tied specifically to benefit and cost [INAUDIBLE]

HAZHIR So right now you have those parameters embedded in how these sensitivities are happening. So there's
RAHMANDAD: sensitivity of the talent and sensitivity of infrastructure. And then you have this tax credit sensitivity. So these three are the drivers right now. In that alternative world you can basically have these three parameters determine the contribution of these guys to a profit function. And then you get the same result out of it.

So the number of free parameters shouldn't necessarily change much. It is just where do they show up. Do they show up in a final decision function the way you currently have, or do they show up inside your profit function and then the decision comes from the profit function.

AUDIENCE: So you're saying that there would just be one contribution to profitability?

HAZHIR Something like that.

RAHMANDAD:

AUDIENCE: Like a cost and the [INAUDIBLE].

HAZHIR So you could shift it into a cost and benefit. So the way I would potentially shift it into cost and benefit, I would
RAHMANDAD: say, OK, I have some kind of a production revenue side, which might be, let's say, a Cobb-Douglas function that says it is your talent to the power of alpha multiplied by your infrastructure to the power of beta. And these both can be normalized using the normalization process. The component that you have already can do that for you.

And then so that's your revenue side. This can be multiplied by some kind of a additional parameter that says how much each unit of production turns into unit of dollar minus your costs. The costs in this case could be your tax. So you can just add the tax part to your cost function. That would be a very simple OK starting point.

Then you will have this alpha and beta, that multiplier for what the transformation of production units into dollar units. And the tax is already in the dollar units. So you have three free parameters for that profit function. It would work fine.

Then out of that you calculate expected profitability from each of the locations. Then there is a distribution of the demand to locations based on that expected profitability. That distribution has another free parameter that says how sensitive they are to profitability. And basically it becomes profitability-- it could be even, yeah, E to the power of profitability multiplied by that sensitivity parameter divided by sum of E to the power of profitability multiplied that by sensitivity for all of the locations. Does that make sense?

AUDIENCE: I think so. Yeah.

HAZHIR So what you're doing is OK. It's nothing wrong. I just was, to try to make it a little bit more structured, it helps to
RAHMANDAD: think in terms of profits and making a decision based on different profitable things.

AUDIENCE: Yes.

HAZHIR And then you said you added the adjustment based on crowding--

RAHMANDAD:

AUDIENCE: Congestion.

HAZHIR --congestion. So let's see. So basically now you have-- OK, this is congestion modifier that changes the
RAHMANDAD: attractiveness for each location. So in the formulation we've talked about, so profitability would go down if you have more congestion. So basically you can think of a congestion effect on your revenue side. Or you can think of it as a cost. So that would have another parameter.

Or it could be a multiplier of your revenue. That is, if you have to wait longer you lose the optimal window of opportunity, something like that. Or it's just your cost of capital. So that congestion multiplier can be multiplied by your revenue side. That Cobb-Douglas function, that's one way to do it. A bit ad hoc, but not too bad, I think.

AUDIENCE: Yeah, or just raises the cost of using the infrastructure [INAUDIBLE].

HAZHIR Yeah, so right now, in that formulation, we didn't talk about cost of using the infrastructure. That would be
RAHMANDAD: another way to do it. That is to have explicit prices for both of these talent and infrastructure, and when the demand exceeds supply, the prices are changing. Then you don't need the explicit-- there's a separate congestion modifier. You just have higher prices in this location.

So that would require you to model the prices endogenously and explicitly but then removes the need for capturing congestion as explicitly. Congestion effect will show up in the price change.

That is probably closer to what an economist likes to see. It's a little bit more work on the modeling side and a little bit more complexity. So I don't know.

AUDIENCE: I mean, can you do that without the data?

HAZHIR So all of these we are talking about doing things without data right now. Basically you can do all of that. Then
RAHMANDAD: there is the question of, OK, I've built a model, I have a price in it, but my price behaves very weirdly, or my wages for talent is behaving very weirdly. What should I do?

Then perhaps it is just parameters. That is, your price elasticity might be too sharp. You should reduce that. So maybe by changing parameters you get it into a mode that you say, OK, now these ranges of 20%, 30% difference in wages between LA versus Toronto is reasonable. So let me go with that. That's a good range. And I think that's doable. Probably if you play with it a little bit you will get it to that range as well.

I'm not necessarily pushing you towards doing the full price part. If you go that route, then your Cobb-Douglas production function or any other production function would have a cost side to it and a revenue side to it, and the net profit that comes out of that whole piece will inform which of the locations people will be picking.

Also then it may change the whole production decision of whether you do production or not. And that becomes even a more involved thing if you want to make the production decision also endogenous. But you could make it endogenous. If every location I'm going to lose money, I'm not as stupid to do this movie at all. So you could capture that as well.

It becomes a little bit more complex because now it is not just an allocation problem, it is the total demand problem as well. But that total demand depends on what are the options available. So I think the basic core components there are there. You can push it in these directions if you want.

Let's just take a look at the congestion part because we didn't look at it. Is it a different view or here?

AUDIENCE: No, it's just above. It's at the top.

HAZHIR Yeah. Got it. So congestion modifier right now is looking at the infrastructure, capacity, and infrastructure
RAHMANDAD: utilization. So for utilization to make sense, you need some unit of production per capacity per infrastructure unit that is normal. And then if you have more than that you get into the congestion space. So that, yes, you have that needed per infrastructure. So that works.

And then you have a sensitivity. And what is the minimum congestion modifier? So you're saying there is a maximum of this minimum and E to the power of this guy. So you don't want this congestion modifier to go below a minimum.

And then congestion modifier, where did it operate? So it operated on the attractiveness. So it was multiplied by that. So at low level of congestion modifier means the attractiveness of this location has gone down. So putting a lower bound on it is basically saying, it can't go below that level because of congestion. That's OK.

But then you want to also make sure you have an upper bound. That is, the congestion should not go above-- this modifier should not go above 1, perhaps, because you can't make it more attractive than just some maximum by just not having congestion. So whether that comes from this-- so you have max of 0 and infrastructure utilization. So if infrastructure utilization is 0, this becomes 0 congestion sensitivity, multiplied by that 0, and then minus 1.

AUDIENCE: It's the utilization. Here you can go above. That's the only thing here.

HAZHIR Yes. So if utilization is 0, this whole thing gets minus 1.

RAHMANDAD:

AUDIENCE: Then it'll go to 0. Max.

HAZHIR So but max 0 of this guy-- OK. This is the parentheses for max. OK. This is the parentheses for E to the power. So
RAHMANDAD: inside the E to the power parentheses we have congestion sensitivity, some number multiplied by a number that is 0. So then it is 0 and it is 1. So that gives you the modifier of 1. Got it.

Yeah, it's perhaps working fine. I'm not seeing any problem here. OK, good. I think that is, for what you are doing right now, this is working OK.

Now you had imported data for LA production days. Pretty interesting to think about how this data might go with what you are building. Part of the challenge is you're showing the LA part, but you're not showing anybody else. So--

AUDIENCE: I do have data on total productions that I have, and I also don't know how to use that as the input flow of production, but I do have that.

HAZHIR OK, so that's a little bit of a technical Vensim thing. So the technical Vensim thing, you need to make that as so

RAHMANDAD: you can import it into the DSS Vensim, you can import that data just by going to--

[INTERPOSING VOICES]

HAZHIR --Tools somewhere. Oh, you already have it.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR What's the variable name?

RAHMANDAD:

AUDIENCE: It should be both of these. But [INAUDIBLE]. I don't know.

HAZHIR Oh.

RAHMANDAD:

[INTERPOSING VOICES]

HAZHIR OK. What is the exact name you have in the-- movies?

RAHMANDAD:

AUDIENCE: Yeah, I think that's the name of the column. And then--

HAZHIR Yeah. So if you have it here and you look at it. So if the spelling is correct, it will show up. It's just as simple as

RAHMANDAD: this.

AUDIENCE: Can we run it again?

HAZHIR Oh, maybe we should run it again. Well, I should make it a data variable. So it should be data.

RAHMANDAD:

AUDIENCE: And then too much.

HAZHIR Hmm?

RAHMANDAD:

AUDIENCE: Might be capitalized? I don't know if that matters.

HAZHIR It didn't show up, but interestingly, it didn't also give us an error.

RAHMANDAD:

AUDIENCE: It actually gave--

HAZHIR Ah, I just--

RAHMANDAD:

AUDIENCE: Maybe put both of them [INAUDIBLE].

HAZHIR Yeah, so now it is aborting. So it didn't do the simulation because it didn't find movies in the VDF file in-- well, we
RAHMANDAD: should say where to read it from as well. So data is coming from where? So--

AUDIENCE: The two.

HAZHIR This one?

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR OK. Oh, it did work. So now you have the movies built into it.

RAHMANDAD:

AUDIENCE: How did you do that?

[LAUGHTER]

HAZHIR So there are two steps to it. So one was just defining the variable with the same exact name. The second was I
RAHMANDAD: went into the simulation control, inside simulation control to data. So I loaded the data set that you have as input into it.

AUDIENCE: Got it.

HAZHIR And then once you have that you also make sure this variable is defined-- its equation type as a data equation.

RAHMANDAD: So that way Vensim knows it has to read some data for this variable from one of those data files that you have introduced as the source of the data. That's how it does it.

AUDIENCE: Thank you.

HAZHIR Sure. And now you can just use it as an input into your capture. It's very straightforward. OK, I'll save this. You

RAHMANDAD: have it there.

AUDIENCE: Thank you.

HAZHIR Sure. OK, so let's see. I think we have Ali, Jason, and Hassan. So let's see if we can go through all of them in the

RAHMANDAD: time we have. Try that.

OK, Jason.

AUDIENCE: Yes.

HAZHIR Tell us what you have done since last week and how--

RAHMANDAD:

AUDIENCE: Ah, totally changed. Well, this week I'm looking at supply side. Last week, I made a first pass at consumption. But I think I have a clearer story for this supply generation side. And then next time I'm going to try again on the demand side.

HAZHIR So you basically are not covering demand right now separate as an endogenous thing.

RAHMANDAD:

AUDIENCE: Not yet.

HAZHIR OK.

RAHMANDAD:

AUDIENCE: But I think I feel pretty good about the way forecast feeds into generating the protection level. So--

HAZHIR OK. What's protection level?

RAHMANDAD:

AUDIENCE: Right. So the idea is the following. The demand that's willing to pay more for a flight comes closer to the time of flight departs. And therefore the revenue manager, the person who is setting fares and protecting seats for bookings that come later has to protect some seats for those higher fares.

So the protection level is, how many seats should I allocate when a flight is born to these higher fare markets before the flight even is published. And now if you have more demand in the early days, you might sell out of the low fares, but you have 20 or x whatever seats-- n number of seats is set apart for those later flights.

HAZHIR So the protection level is in seats or seats per flight. I assume they are kind of the same in this model because

RAHMANDAD: you're not looking at multiple flights.

AUDIENCE: Yes.

HAZHIR So you start with an initial protection level, which is--

RAHMANDAD:

AUDIENCE: Whatever is indicated by the forecast. So this is based on-- so what is this mapping onto? What am I trying to get to here? There's a forecast which is generated by ticket sales. And then based on that forecast, you make a decision about how to set your protections for subsequent flights. Those protections are going to influence--

HAZHIR Subsequent flights or this flight?

RAHMANDAD:

AUDIENCE: Subsequent flights. And then those protection levels will determine future sales, which determine future forecasts. And you can get this spiral bound behavior where if you have a wrong initial belief or you misinterpret the booking screen, you can have very poorly aligned protection levels to your sales.

HAZHIR So let me just make sure I'm understanding protection level correctly. So you have a 300-seat flight a year before

RAHMANDAD: the start. A protection level of 250 means I'm opening 50 of those seats for sales.

AUDIENCE: For low-ticket sales.

HAZHIR For whatever my current price is, correct?

RAHMANDAD:

AUDIENCE: Yes.

HAZHIR And then where does your-- so basically you have control over two things. How many seats are open for sales

RAHMANDAD: and what is your price at that point in time. Are you capturing both of those or you're focusing only on the protection level?

AUDIENCE: Right now I'm focusing only on protection, so I'm assuming there's only two price points on the plane, high pair and a low pair, and they're fixed for the life of the flight. We know that's not true, but let's assume those are the two kind of published levels. And I can take a booking of \$100 today with certainty. Or I can wait for the possibility of \$1,000 booking in 300 days from now. So those are the fare levels.

HAZHIR Yes, but these fare levels, they are not available to customers at all the time. Or are they?

RAHMANDAD:

AUDIENCE: They are until the low fare sells out. That's what the protection level does.

HAZHIR I see. So I, as a customer, I can always buy at high fare.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR But I can only buy low fare within the protection level--

RAHMANDAD:

AUDIENCE: If it's available.

HAZHIR That is allowed. That is available to me. OK, got it, got it. So

RAHMANDAD:

AUDIENCE: This is how they do it.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: I mean, it gets really complicated--

HAZHIR Because you have 20 levels. So it's not just--

RAHMANDAD:

AUDIENCE: Yeah, you have 20 levels. The price points are actually dynamic too because there's a separate pricing process based on competitive dynamics. And then those price points come in. And then there's an availability and optimization process that sets those protection levels.

The whole point, though, is that the estimate of high-fare demand is through the filter of previous availability decisions. And it just continues feeding back forever. There's no check on forecast accuracy. There's no counterfactual setting. You make these availability decisions and then it just, the errors accumulate.

HAZHIR So let's see how that is implemented. That sounds good in theory, but let's see.

RAHMANDAD:

AUDIENCE: So let's really focus just on the supply side, the right-hand side going from forecast into protection level.

HAZHIR So this forecast of high-fare demand is saying what exactly? It is saying how many total will be available will be--

RAHMANDAD: how many total high-fare demand will come for this flight or?

AUDIENCE: Yes.

HAZHIR So it is not from this point on. But this is for the whole history of that flight.

RAHMANDAD:

AUDIENCE: Right. So how many units of high-fare demand can I expect for a particular flight? Yeah.

HAZHIR OK. Then what happens.

RAHMANDAD:

AUDIENCE: It's a smooth-- So then that gives you an average.

HAZHIR But that is coming from this high-fare sales.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR And high-fare sales is in seats per month.

RAHMANDAD:

AUDIENCE: Seats per flight. So I haven't formulated sales yet. I don't have sales yet. This is just--

HAZHIR So what is this then? I'm just not-- I feel that there is a little bit of a unit inconsistency or unit confusion for me to

RAHMANDAD: reading through this because sales for me is in unit-- it's seats per month or something like that. It is a flow of things that are being sold, and then you are getting that-- you're using sales. I mean, this is called sales. Maybe it is not what you-- maybe it is cumulative sales or something else. I don't know what it--

AUDIENCE: It should be-- so I have the--

HAZHIR And demand for me is also in the units of seats per month or something. Unless you have a different conception

RAHMANDAD: of demand. Because otherwise I get very confused what period of time we are talking about. Because you are running through the life of a single flight from 300 days before, or 360 days before until the date.

AUDIENCE: Yeah.

HAZHIR And during this time, when you use the units of seats, I'm not sure what you're talking about for a flow variable

RAHMANDAD: like demand or sales.

AUDIENCE: Right.

HAZHIR If you're talking about the number of seats remaining, which is a stock variable, I fully follow that, or the number

RAHMANDAD: of seats that have been sold, I can fully follow that. But as soon as you talk about sales or demand with a unit of seats, I get confused.

AUDIENCE: Yeah.

HAZHIR Do you know what you're doing here or you're also confused about it? That's the question.

RAHMANDAD:

AUDIENCE: So I might be-- I think I do have some confusion because I haven't formulated the demand side.

HAZHIR No, but you can have an exogenous demand. Just call it exogenous demand. What is the unit of that variable?

RAHMANDAD:

AUDIENCE: Right. It is-- OK. It's units of demand, per this is the main confusion. It's people don't demand a particular flight. They demand a fare service x days from now. So it's units per kind of booking interval.

HAZHIR So I go online. I'm going to click to try to buy this flight. How many people like that happen every day is what I'm

RAHMANDAD: calling demand. Now you can have it demand for that whole competition between five different flights on the same route for the same day, then you can, yes, have a separate allocation. But right now we are focusing on a single flight.

AUDIENCE: I'm not. So it's kind of evolved. I'm trying to forecast how many units of high-fare demand-- I see what you're saying.

HAZHIR So I think this confusion is pretty fundamental to this. That is, without solving that, you can't really build a model

RAHMANDAD: of supply and demand here if the units of supply and demand are not per unit of time. The version of the model you had last week seemed to be more consistent on the demand side, how it was thinking about it.

Right now, the protection level is problematic for me because the protection, what you can protect, depends on how many you have already sold, if I understand it correctly.

AUDIENCE: If you have a [INAUDIBLE] So right.

HAZHIR So you have seats that are unsold.

RAHMANDAD:

AUDIENCE: Yes.

HAZHIR They can be protected. But once you have sold a seat it is out of the protection consideration. It is already sold.

RAHMANDAD: So the protection level, if by that you mean how many seats are sellable or not sellable from those that are generally still not sold, that should depend on how many you have sold. And right now, you don't have that. So you just are changing this thing without having any constraint.

AUDIENCE: Because these are for different flights. The flight is born with a protection level. And in this current iteration, that protection level is fixed for the life of the flight. In reality it's a dynamic process.

HAZHIR So I'm now confused. You said these are for different flights. What do you mean?

RAHMANDAD:

AUDIENCE: Because, OK, I think, yeah, this is the [INAUDIBLE] I think I need to get my units of demand correct, and then I can more clearly lay out how this--

HAZHIR But are you modeling a single flight over the year before it, or now you're not doing that?

RAHMANDAD:

AUDIENCE: I'm modeling multiple. Every day a new flight is born. And so I'm modeling multiple flights over their entire lifetime.

HAZHIR
RAHMANDAD: So each flight has [INAUDIBLE]? Each flight is one protection level?

AUDIENCE: Yes.

HAZHIR
RAHMANDAD: But why did you switch to this level of analysis? Because last week you had a single flight over its one-year period.

AUDIENCE: I switched--

HAZHIR
RAHMANDAD: That I was following. Now I'm not following what you are doing.

AUDIENCE: So the idea is, I feel like I need to have both horizons accounted for if I want to capture this feedback effect. Because the goal is to show how these incorrect assumptions can--

HAZHIR
RAHMANDAD: So I'm OK with switching the level of analysis if that's justified. But I need to then understand what exactly this level of analysis is. So you have multiple flights. And based on the previous flights and their protection levels, you were getting some total fares, high-fare versus low-fare of the demand. And then based on that you're changing your protection level for the next flights.

AUDIENCE: Yes.

HAZHIR
RAHMANDAD: So that's the story you are telling here. OK, so I was confused at the beginning. I was starting with the assumption that you are looking at a single flight. So a lot of my comments and questions might be misplaced now given what you were trying to do.

AUDIENCE: Sorry. It's hard for me-- yeah.

HAZHIR
RAHMANDAD: OK. So now with that definition of protection level, the total sales you haven't yet formulated, you said.

AUDIENCE: Right, because then I need some kind of rule for what I call diversion itself. So a diversion is when someone who's willing to pay a high fare--

HAZHIR
RAHMANDAD: Got it.

AUDIENCE: --ends up buying down because it's available. So you could be a flexible customer, but you--

[INTERPOSING VOICES]

AUDIENCE: --at the end.

HAZHIR
RAHMANDAD: Got it.

[INTERPOSING VOICES]

AUDIENCE: So I haven't done that yet.

HAZHIR Got it.

RAHMANDAD:

AUDIENCE: But the point is that we know that behavior happens.

HAZHIR Yes. So basically you need now some input in terms of customers who are willing to pay the high fare versus

RAHMANDAD: customers who are only willing to pay the low fare.

AUDIENCE: Yes.

HAZHIR You need these two types of customers.

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR They, for each flight, they would have a realization, a random realization that you don't know, but you try to

RAHMANDAD: make a forecast based on what you could observe in the previous round.

AUDIENCE: Yes.

HAZHIR And then I'm talking about rounds, even though this is continuous time, but it's OK to think about it. You can

RAHMANDAD: make that translation. And you then adjust your high-fare versus lo-fare for demand projection based on the observed values of realized sales.

AUDIENCE: Yes.

HAZHIR And then you change the protection level accordingly.

RAHMANDAD:

AUDIENCE: Yeah, and the rule for changing-- setting the protection level and the delays, because the thing is, you take in bookings during the daytime and then overnight, you run this optimization process where you reset the protection levels for tomorrow. I realize now, because I haven't right now, that the protections aren't dynamic yet over the life of the flight. That's not fully captured. But yeah, I like the-- so I feel good going from demand and protection.

HAZHIR Yes. Now there is this kind of a source of confusion for you, that will persist, that comes from two different levels

RAHMANDAD: of analysis, one as the single flight versus a portfolio of flights. So single flight is easier, more operationally specific to go to the details of it because you can say what is happening for every part of it. But then it doesn't give you the multi-flight feedback that you are looking for.

AUDIENCE: So demand isn't really for a single flight.

HAZHIR So the approximation that the demand is for a single flight is not a bad approximation, because somebody wants

RAHMANDAD: to go somewhere on some date. Now, yes, people have some flexibility around those dates and some flexibility whether they take the trip or not, but all of those can be collapsed into a realized demand, which you were trying to model in the previous week version.

AUDIENCE: So how do you think? So because of this problem of single-flight booking over time versus having multiple flights booking over time, I think I need to have both kind of--

HAZHIR So for your longer-term question of connecting a single-- this decision of protection level setting to the
RAHMANDAD: experience across multiple flights, you need multiple flights. Otherwise you can't close that loop. That goes through learning from your experience. So for that reason this version is fine. It is helpful.

AUDIENCE: Yeah.

HAZHIR But I'm worried whether you can manage this kind of a more abstract level of formulating the protection level as
RAHMANDAD: it continuously changes from feedback across multiple flights, whether that is going to be easier to manage or, I mean, it wouldn't be easier whether you would come up with something that works fine for you.

Or you may take the longer route of building a single-flight model, fully getting that to work, then moving from that into something more aggregate, or perhaps even not more aggregate, but kind of a sequential that, OK, I did this. Now, from this I learned for the next flight, and then from the next flight I learned from the next flight after that or something like that. So that way you would capture the feedback across multiple flights. So that's another way of doing it.

I think given how much confused we have been so far, go with the one that you can conceptualize very clearly and cleanly, even if that is only for a single flight. I don't think-- until you can do the single flight well, it would be very hard to go into the higher level of aggregation.

AUDIENCE: But I don't think the single-flight case is going to have the feedback I want.

HAZHIR It doesn't. Don't capture that feedback in your first round. It's not working. Right now you don't have the sales.
RAHMANDAD: You don't have the demand. You don't have even the protection level right for the single flight. So I would get the single-flight mechanics right with the demand changing dynamically, what you were doing last week, and with the protection level changing dynamically, as what you're doing this week. Now, if you want to keep the price only at two tiers, that's fine.

AUDIENCE: OK.

HAZHIR OK. We can--
RAHMANDAD:

AUDIENCE: No, no. It makes sense.

HAZHIR Yeah, we can have a little bit more chat later, the two of us. I want to get to at least a couple more models. So
RAHMANDAD: let's see. We have Hassan's-- so eligibility 1, 2, 3. Which one should I open up?

AUDIENCE: Can we look at the first one and the third one after that?

AUDIENCE: [INAUDIBLE]

HAZHIR Just pick one. We have 10 minutes.
RAHMANDAD:

AUDIENCE: OK. Sure. Let's take a look at one and then I'll-- so I've been quite lost with this model. I think you've seen the previous iteration. I tried to do some compartmental thing. Then I started imagining as simple as a co-flow as I can, which is patients dependent on their smoking behavior will become eligible for screening, and then dependent on their actual health, which is the nodules, they may show symptoms or show positive in whatever they show up for screening.

But then this triggered the idea that this co-flow, what it has with it is that it's not average attributes for [INAUDIBLE].

HAZHIR Wait. So you're talking about population of people who maybe smoking or not smoking and then be eligible for
RAHMANDAD: this screening test. And then when they are screened they could be put into the category of diagnosed but incorrectly diagnosed or--

AUDIENCE: I'm not even going there yet.

HAZHIR So they can be screened.

RAHMANDAD:

AUDIENCE: If they are screened they either get a negative, you could go home, or they are sent to treatment.

HAZHIR Sent to treatment.

RAHMANDAD:

AUDIENCE: Then there's either something in between the two, but [INAUDIBLE].

HAZHIR Yes. OK, so for that, why are you using co-flows? I'm not following what the co-flows do for you.

RAHMANDAD:

AUDIENCE: Because the chance of developing lung cancer depends on smoking history.

HAZHIR OK.

RAHMANDAD:

AUDIENCE: Which means if people have smoked for more and for longer there's a higher chance of developing [INAUDIBLE].

HAZHIR So this SP PY, what is it?

RAHMANDAD:

AUDIENCE: So smoking population, PY is pack years.

[INTERPOSING VOICES]

HAZHIR So you are capturing-- you're trying to track how--

RAHMANDAD:

AUDIENCE: Much smoking.

HAZHIR --much smoking these people are doing.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR This is actually an important kind of a general lesson here. So here Hassan is trying to do two things. One is to
RAHMANDAD: have a flow of people between different states, but also tracking their frequency of doing some activity that impacts their ability to move up and down.

There are two ways to manage this type of a problem. One is to break the population from the beginning into high smokers, low smokers type of a situation so that you always have these high smokers being their own flows, moving across different states.

AUDIENCE: Could we have flows--

HAZHIR You could have. So high smokers can become lower smokers, not really if it is-- but low smokers can become
RAHMANDAD: high smokers.

[INTERPOSING VOICES]

HAZHIR Yes, so that can always happen.

RAHMANDAD:

AUDIENCE: Because it starts to--

HAZHIR Yes, so basically start-- The alternative that you're trying to do, which is using co-flows becomes tricky. I don't
RAHMANDAD: recommend it in this case. In simpler cases, it is possible. But when you have these many different groups that people be non-screened, screened, under treatment, the density of people in terms of the smoking levels will change.

AUDIENCE: Yeah.

HAZHIR That is, those who have smoked more are more likely to get a screen, more likely to get treatment. And getting
RAHMANDAD: the co-flows right, that is, distributing the protection in the correct way, becomes extremely hard. There are ways for simpler cases to do it, and I have a few papers that actually introduce those, but I don't recommend it for this case. It is too complex to do it that way.

AUDIENCE: I've actually practiced a little bit with an exponential distribution assumption and a truncated--

[INTERPOSING VOICES]

HAZHIR Yes, you can try to do those, but don't do it. I've done enough of this mess to know that it is too complex to try
RAHMANDAD: this pass. So it will take you in the wrong direction. Go with the simple alternative that says people have different levels of smoking history, whatever is important. If it is the cumulative history, you can have people who have had under 1,000 packs in their life, 1,000 to 5,000, 5,000 to 10,000, whatever is the categories that make sense.

AUDIENCE: But my question still persist, which is if I have this low-smoking population, some of them through time, become high smoking.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: How do I pick how many of them are moving on to that?

HAZHIR That's based on how many packs per day they are smoking because. It's not a co-flow. Now you have a number

RAHMANDAD: of these people that every year go to the next category. You need to make some assumption about the distribution of people in these categories. But that's doable.

AUDIENCE: Just to ask one more question. So the second line of co-flows I have down there, which is we know that the rate of developing nodules depends on that accumulated smoking history.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: So if I have two stocks, one of them are low-smoking intensity, the other one is high smoking. So each one of them will have different rates of nodules being built in there.

HAZHIR Why do you need to track the nodules separately? If it is tied to your cumulative smoking and you are capturing

RAHMANDAD: your cumulative smoking--

AUDIENCE: So the nodule size is not dependent on the smoking, the nodule growth rate is depending on smoking, which then the chance of someone showing symptoms depends on the nodule size, and the chance of them being tested positive when they go through screening, it depends upon the size. That's what I was thinking.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: Cancer doesn't grow on itself like [INAUDIBLE]?

AUDIENCE: Lung cancer is, the biggest driver is smoking. So there's nothing else but smoking, essentially.

HAZHIR Yeah. So there might be an argument for doing the co-flow for that.

RAHMANDAD:

AUDIENCE: [INAUDIBLE] lung health?

HAZHIR Yeah, basically tracking these nodules that are evolving. And it should be completely parallel to the population

RAHMANDAD: groups. For each population group you're tracking their nodules. But you need to be careful because when you get to route people into different states, you can't easily make it dependent on the nodules. You need to make it dependent on the stocks that they have. That is, the nodules should flow with the average.

Now, if you don't like that, that is, you say, that's not how things happen in the practice, then you may need to reformulate the population groups based on nodules, not based on the history of smoking or how many packs they have had or something like that. OK, so that would say, I would have populations with this number of nodules and populations with this number of nodules and then--

AUDIENCE: So stratifying them first.

HAZHIR Stratifying them based on nodules in the first place. Or if you need both history and nodules, a two-dimensional

RAHMANDAD: stratification, a matrix, that so that the movement on the nodule space is tracked based on the physics of your stocks and flows. That's my recommendation. Don't go with the co-flow if the rates of outflows will depend on it. Yeah.

AUDIENCE: So now that I think about it, why can't we go with the individual level testing [INAUDIBLE]? Because we can keep track of the stock of the nodule, the stock of the cancer history.

HAZHIR Yeah, absolutely. You can do that. So that would be an agent-based alternative. You can turn that agent base--

RAHMANDAD: you can do it in Vensim. But it's not the optimal place to do agent-based models. But yeah--

[INTERPOSING VOICES]

HAZHIR --you would have a subscript of people basically. Now you could have representative agent type of a model that

RAHMANDAD: you would say-- it's actually a little bit tricky what you want to do it, because ultimately you care about the distribution of people and you can simulate as many people as you want that go through this and probably stochastically they move into different-- so that's a full-blown agent-based model. Some hybrid that tries to do that, but with less complexity, I don't know. That would be beyond what we can--

AUDIENCE: [INAUDIBLE] do right now. Then try to build upon.

HAZHIR Yeah, I would say really it is either stratify the population based on the dimensions that you need, which is in

RAHMANDAD: case maybe nodules and history of smoking. Then you would have a dimension for nodules, a dimension for history of smoking.

And then within each of those two-- that is, once those two are set, what are the dimensions, the things that are once you set those dimensions, then the probability of movement is not going to-- I mean, only depends on those two things. That's the key.

AUDIENCE: Thank you.

HAZHIR Sure. So I think we're almost out of time, but let me just do a quick look at Ali's model as well. So your model

RAHMANDAD: started more advanced, Ali. So what were you working on this week?

AUDIENCE: I got a start with the punishment tier, punishment mechanism. So I duplicated the stock management.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: And it's not sophisticated. So it's just, I get two digits at the top. This is the first agent and this, at the bottom, it's the second. But they're using the same resource. If you zoom out, at the very top I have the resources.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: And they are--

HAZHIR So all of that I saw yesterday.

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR Sure. So the question was, this week you were focusing on the--

RAHMANDAD:

AUDIENCE: Yeah, I wanted to capture the peer punishment.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: And it's a little bit tricky. So in the literature it's like people saying that, OK, let's punish the deviators from the agreed-upon levels of extraction of that resource. So I have done that so far. And it's continuous. There's no lag in between. And it seems to work. But not [INAUDIBLE].

HAZHIR So I think just big picture, it is a tough problem because the punishment question is very much a game theory

RAHMANDAD: type of a situation that you need to account for what the response of the other side might be. And in the typical SD models, we don't have the language for capturing those very well.

Now you can think of these as strategies. That is, I have a couple of parameters that allow me to connect my current state of the world, how I see the other side and how I see myself, to whether I punish them or not. So if you define those two parameters, let's say, each actor can be defined with a strategy that consists of those two parameters.

Now I have now two actors. Each of them, they have these two-dimensional strategy spaces that are those two parameters. They are playing with each other or they are going against each other.

Now, given the other side's strategy, I can optimize my two parameters. So I can run an optimization that changes my strategy to be the best response given the strategy space I have defined. It's a linear functional form or something simple-- to what the other side does. Then the other side can optimize their response to me given what I'm doing.

And if you do this a couple of times, you can converge-- maybe a few times-- you can converge to a Nash equilibrium type of a strategy that says, OK, this is stable. That is, both sides will converge to this strategy if their structure of decision-making followed that functional form you have put into your model. So that becomes one solution concept that you can use here.

Otherwise, just ad hoc formulation, what you have already is doing something like that. That is, you have some parameters that generate a response in terms of punishment based on the state of the system. So you already have the first component. Now you could optimize the way I told you, but the optimization is tricky. You have to go through it iteratively. The first one does optimize on their two, three parameters. The second one is fixed.

AUDIENCE: Right.

HAZHIR Then the second one looks at the-- so I have a 2011 paper in SDR that has the machinery for doing that inside

RAHMANDAD: Vensim. You can check it out. You can write some scripts that do that in an automated way. That's the solution type that you can use.

AUDIENCE: Thank you. Thanks a lot. Yeah, this is all happening simultaneously.

HAZHIR Yes, but right now you are making the assumption that both use the same strategy.

RAHMANDAD:

AUDIENCE: Yes.

HAZHIR

And then you just look at the solution that comes out of it, and you're not trying to be internally consistent. An

RAHMANDAD:

internally consistent strategy is one that if I use, I can't improve upon it by deviating from that strategy. I can't improve upon my-- and as such, what you do here might be completely stupid in terms of, yeah, there are-- I can easily improve upon this by less or more punishment, and you're not capturing that. So this is to push it into the next level.

OK, great. I think we are out of time. And there will be a seminar happening here in five minutes, so thank you.

[LAUGHS]