Caught in the Middle of Causality: How the Structure of Reality Produces Incorrect and Divergent Understandings in Organizations

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The most up-to-date version of my job market paper can be found here:
https://mhsingell.github.io/files/Singell_JMP_current.pdf

ABSTRACT

I develop a model to explain how the structure of causal reality generates incorrect and divergent causal understandings in organizations. I focus on two key attributes of causal reality, whether it contains an event that is a root cause (a cause not caused by other events) and whether it contains an event that is an edge cause (a cause related to fewer events that its effect). Assuming that the division of work limits the scope of experience of an employee, where only slices of causal reality can be observed, my model predicts that when a causal reality contains an edge root cause, employees will form either divergent or incorrect understandings, depending on the division of labor. The model generates several propositions for how the structure of causal reality is likely to impact the formation of causal understandings in organizations where the scope of observation of events is limited.

INTRODUCTION

The structure of causal reality, the true pathway that connects causes to their effects, varies across organizations. For some organizations, there is one clear root cause that drives their performance. For others, a chain of events generates a series of outcomes. Forming a successful organizational strategy involves understanding the true causal relationships that have generated performance and modifying the antecedents of performance accordingly (McIver & Lengnick-Hall, 2017; Lippman & Rumelt, 1982; Schön, 1992; Ryall & Sorenson, 2021). But some causal structures of events are more difficult for organizations to disambiguate than others.

Consider what an organization basing a strategy on a causal understanding entails. Because a causal understanding is an individual's cognitive representation of the true causal relationships that exist between events (Carey, 1995), organizations themselves do not form or hold causal understandings. Thus, in order for an organization to base its strategy on a causal understanding, the organization must consider the causal understandings of its employees, which generates two difficulties. First, to the extent that employees hold different understandings, the organization may have difficulty reaching a convergent strategy. Second, to the extent that employees hold incorrect understandings, the organization may have difficulty reaching a correct strategy.

This paper explores how the structure of causal reality may determine whether employees hold incorrect or divergent understandings in organizations. I build my argument on a core assumption, that organizations limit the scope of event experience of their employees, such that employees only see slices of causal reality. This is based on organizational research, which shows that one consequence of the division of labor in organizations is that divided work tends to also generate divided experience for employees (Joseph & Gaba, 2020; Levitt & March, 1988; Heath & Staudenmayer, 2000; Clement, 2023).

While employees may only observe slices of events in their organization, they're unlikely to see independent slices of reality; the slices of causal reality observed overlap. This makes events in the middle of causal processes more likely to be observed in the organization than events that are at the ends of them. Because events that are observed more frequently look more like causes, causal inference in organizations is more likely to identify middle events as causes. I call this being "Caught in the Middle of Causality" in organizations.

While potentially myopic in nature, the understandings generated by this limited scope of event experience in organizations need not be incorrect, and thus need not drive performance differences. This is because, to the extent that events in the middle of a causal reality are root causes, the inference of middle events as causes will lead to a correct understanding of events. However, if an edge event is a root cause, then two possible outcomes are likely.

First, if employees focus their attention equally on all slices of causal reality, they're likely to converge on incorrect understandings. This is because an equal focus on event slices makes the middle event that overlaps in both slices be observed the most frequently, making the middle event look like the root cause. Second, if employees differentially focus their attention on slices of events, then divergent understandings are likely. This is because the employee who focuses on the slice of causal reality with the root cause will observe it the most frequently and thus correctly infer it, while the employee who focuses on the slice of causal reality without the root cause will observe the middle event most frequently and incorrectly infer the root cause. Thus, I show that the structure of causal reality can explain variance in the formation of causal understandings, because under the limited scope of experience in organizations, causal inference is likely to be "Caught in the Middle of Causality".

A MOTIVATING EXAMPLE

In order to illustrate how the structure of causal reality containing an edge root cause can generate incorrect and divergent understandings when the scope of observation of events is limited, I will use the example of Kodak's failure in navigating the switch to digital photography. After Kodak filed for bankruptcy in 2008, an interview with Carly Fiorina summarized the true causal reality Kodak was facing in the digital photography space, stating:

> "Kodak sat on a mountain of cash and profitability in their traditional photography business and I believe their thinking was **digital photography will eat into my traditional most profitable business**. I don't want that to happen. What I think **Kodak miscalculated about was they weren't in charge of whether that would happen**. **Consumers were in charge**." (Carly Fiorina interview, Lucas & Gorever, 2008; Lucas & Goh, 2009, emphasis added by author)

As emphasized above, while Kodak was concerned with the fact that digital photography would cannibalize their traditional film business, they missed that consumer demand would eventually drive the development of the technology. This causal understanding is formalized into a causal model below:

FIGURE 1: The True Causal Reality of Kodak's Digital Photography Failure

Consumer Demand for Digital → Develop Digital Technology → Cannibalize Film Business

The true causal reality that Kodak was facing in the digital photography space contains an edge root cause. The consumer demand for digital technology was the root cause of the

cannibalization of Kodak's film business, because this event was the origin of the performance issue for Kodak. However, the consumer demand for digital was also on the edge of the causal reality, and not directly related to the cannibalization of traditional film. It's this key feature of the causal reality that may have made it difficult for Kodak to successfully converge on a correct causal understanding.

Consider that the correct causal understanding for digital technology in the photography space was held by the engineering team at Kodak when the technology was developed there. In the 1970s, an employee of Kodak's, electrical engineer Steven J. Sasson, invented digital photography, and immediately saw its consumer potential (Deutsch, 2008). Because digital photography could increase the flexibility and quantity of pictures taken, Mr. Sasson thought that it might one day replace film. The causal understanding of Mr. Sasson and his engineering team is formalized in Figure 2 below:

FIGURE 2: Kodak Engineering's Causal Understanding of Digital Photography
Consumer Demand for Digital → Develop Digital Technology → Cannibalize Film Business

However, the business side of Kodak saw early on that digital technology was likely to cannibalize Kodak's current film business, and thus management's reaction was "that's cute, but don't tell anyone about it" (Deutsch, 2008). Underlying this statement was the business team's causal understanding of the development of digital technology for Kodak's key film business. If they developed digital technology, they would generate demand for the technology and cannibalize their film business. I formalize this causal understanding in Figure 3 below.

FIGURE 3: Kodak Management's Causal Understanding of Digital Photography
Consumer Demand for Digital ← Develop Digital Technology → Cannibalize Film Business

These divergent causal understandings, and Kodak's subsequent struggle to select the correct understanding, could result directly from the structure of causal reality containing an edge root cause and the division of work between the engineering and management teams. Over the decades that followed, the engineering team continued to push the development of the digital technology, correctly identifying the huge demand potential for the product. The management team, however, continued to be focused on Kodak's profits, which were threatened by the development of digital technology. Kodak's management, in over-indexing on the latter half of an edge root cause reality, over-observed the centrality of the development of digital technology for their film business. Getting "Caught in the Middle of Causality", Kodak's management thought that the middle cause of developing digital technology was the root cause of the reality, an understanding they based Kodak's strategy on, missing the actual root cause of consumer demand.

If the causal reality matched the Kodak management team's understanding of the digital photography space of Figure 3, the causal reality would not have contained an edge root cause. In this case, the over-focus of the managers on the cannibalization of its film business would have still generated the correct understanding, because the centrality of the development of digital technology for the film business would have matched the reality of its centrality for both consumer demand and traditional film demand. While suggestive in nature, the example of Kodak's failure to successfully appraise the digital photography market shows how a causal

reality that contains an edge root cause could generate incorrect and divergent understandings for an organization.

In the sections that follow, I develop a theoretical model to codify this intuition for how, under a limited scope of observation, causal realities that have an edge root cause are likely to generate incorrect or divergent causal understandings like those held in Kodak's failure to pursue digital photography. The basis of the argument is that because some causal realities contain edge root causes, and others do not, the potential for incorrect and divergent causal understandings, and the performance consequences of these understandings, varies by the structure of causal reality. To develop the intuition for what types of realities contain an edge root cause, I outline all possible causal realities that are not cyclical (as cyclical realities do not satisfy the conditions of having an edge or root cause) for three events and indicate which ones contain an edge root cause in Table 1.

Table 1: All Possible Non-Cyclical Causal Realities Between Events A, B, and C And Whether the Reality Contains an Edge Root Cause

	Example Graph	**Edge Root Cause**
No Cause	A B C	No
One Cause	A->B C	No
Repeller	A<-B->C	No
Collider	A->B<-C	Yes
Linear	A->B->C	Yes

In considering the implication of my findings for the divergent understanding formation between Kodak's management and engineering teams as detailed in Figure 2 and 3, my work suggests that in order to understand why these two groups disagreed on causal understandings and how best to resolve this disagreement in order to form a successful strategy, it is essential to think about both the underlying process generating events and the underlying organizational division of work influencing their experience of events. My work ultimately provides a set of theoretically grounded propositions and hypotheses for how the division of experience in organizations is likely to matter for the formation of causal understandings and provides a theoretical framework for more rigorous research of causal understandings in organizations.

THEORY

A Roadmap for Where We Are Going Together

In this theory section I develop my argument for how the systematic division that organizations place on the observation of reality for their employees interacts with the true causal reality to determine whether causal understandings correctly converge. The argument is structured such that I develop the intuition for a series of assumptions I make, and then show that the results of my argument based on these assumptions are likely to be "Caught in the Middle of Causality". The theory section progresses by answering a series of questions in order generate this argument, which I provide in a list below to give you (the reader) a sense for where we are going together.

- What is a causal understanding and why is it important for organizations?
- What is the nature of the true causal reality and an individual's ability to form a causal understanding of it?
- How do individuals form causal understandings from event observation?
- How do organizations impact the observation of causal reality for their employees?
- How does the structure of causal reality interact with employees' divided observation of this reality in an organization to generate incorrect or divergent causal understandings?

What is a causal understanding and why is it important for organizations?

A causal understanding is an individual's cognitive representation of the true causal relationships that exist between events (Carey, 1995); or, in other words, a causal understanding is an explanation for why events happened the way they did (Juarrero, 2011). In addition to being core to psychology and cognitive science's work on human reasoning (see Carey, 1995; Goodman et al., 2011; Chen & Bornstein, 2024), causal understandings are central to the function of organizations. This is because forming a successful organizational strategy requires a correct causal understanding of events.

One way to view a strategy is as a proposed set of causal relationships between events, where a strategy is really a theory of how the world works based on a causal understanding (Lazzarini & Zenger, 2023; Carroll & Sorensen, 2021). For example, consider the Kodak managers in our motivating example above, who are concerned about the cannibalization of their traditional film business. If Kodak's strategy is to stop development on digital technology in order to preserve film business sales, then implicit to this strategy is the causal understanding that the development of digital technology is what is ultimately going to disrupt the sales of traditional film. Thus, forming a strategy of what to do next relies on a causal understanding of what has happened previously.

If we accept that strategy formation is based on a set of causal understandings, then forming a successful strategy will be contingent on employees having a correct causal understanding. Particularly, because causal understandings are cognitive representations of causal relationships, organizations do not form or hold causal understandings, making the task of an organization forming a strategy based on a causal understanding one of considering the causal understandings that are held by employees. Continuing with our example, Kodak's strategy to stop the development of digital technologies in order to preserve film profits will only be effective if digital technology is at least a partial contributor to potential declines in film profits. If this causal understanding of the relationship between events held by employees is incorrect, the strategy formed is unlikely to be effective. This conceptualization of strategies as theories based on causal understandings is consistent with research that finds that managers that have a correct causal understanding of events are more successful at resolving problems when they arise (Milgrom & Roberts, 1992; Ryall & Sorenson, 2021).

Finding the correct causal understanding in order to generate successful future strategy for an organization may sometimes be a straightforward task. For example, returning to Kodak's failure to be successful in the digital film market, after the use of digital technology became pervasive in the photography industry, Kodak's employees causal understanding that they too should shift to digital film was logically straightforward (Prenatt et al., 2015). However, if there are consistent factors that generate either incorrect or divergent causal understandings, and these

causal understandings are core to the formation of successful strategies, then organizations ought to be uniquely concerned with uncovering these determinants.

Indeed, work in organizations has addressed several possible antecedents to incorrect and divergent causal understandings. For example, under causal ambiguity, where causal relationships are difficult to infer, trustworthiness is likely to matter for how much information and understandings are shared (Szulanski et al., 2004). Hidden events and factors may also make it difficult for managers to reach a correct causal understanding (Ryall & Sorenson, 2021). And while not necessarily directly based in causal relationships, a large body of work addresses how differences in mental representations may make the search for and formation of strategy less than ideal (Csaszar & Levinthal, 2016; Santos et al., 2021; Joseph & Gaba, 2020).

However, in considering the broad set of factors that might impact the ability for employees to converge on correct causal understandings, organizational scholars have yet to study in detail the structure of the true causal reality. To the extent that causal reality has been considered in work on organizational understandings, it has often been dismissed, with work citing that employees' interpretations and true events can never be disentangled, and that employees can even hold understandings that are in direct contrast to their experience (Weick et al., 2005; Levitt & March, 1988). While there are no doubt pathways of motivated reasoning and interpretation that generate causal understandings (i.e. see Tappin et al., 2020), work in causal induction suggests that one of the central reasons that causal models diverge when being inferred from observation is because of the underlying structure of the causal reality (see d-separation, Pearl, 2009).

In the next section I turn to this work in causal induction, introducing the structure of true causal reality and a series of assumptions about this reality, which I will build into a theoretical argument for why and how the structure of true causal reality is likely to matter for the inference of causal understandings in organizations.

What is the nature of the true causal reality and an individual's ability to form a causal understanding of it?

A true causal reality is the underlying process that generates the events that individuals, such as employees within an organization, experience. If there is a true causal reality that generates events, then an employee's causal understanding of the world can be defined as this individual's cognitive representation of the underlying true causal reality. While some work within organizations has asserted that there is no true causal reality (i.e. see Sköldberg, 1994; Rhodes & Brown, 2005), the argument in this research generally relies on the fact that humans can never observe the true causal reality independent from their interpretation or perception of this reality (see Weick et al., 2005). While I also assume that the true causal reality cannot be observed, it is analytically useful in my argument to distinguish between the existence of a true causal reality and the ability to observe it. These two first assumptions of the existence, but unobservability, of the true causal reality are formalized below.

Assumption 1: There is a true causal reality, i.e. there is a true causal process that generates events.
Assumption 2: The true causal reality is unobservable to individuals.

It follows from these two assumptions that individuals can seek to find the true causal reality but must infer the true causal relationship between events based on their observation of

the events, and not the observation of the process directly. Thus, the act of an individual forming a causal understanding, or a cognitive representation of the true causal reality, is an act of inference from the observation of events.

Proposition 1: When an individual forms a causal understanding, she uses her observation of a set of events to infer the causal relationship between them.

How do individuals form causal understandings from event observation?

If individuals must form causal understandings through inferring the true causal relationships between events based on their observations of them, the natural next question is how individuals perform this inference. To start, I differentiate between event occurrence and event observation. An event occurring means that an event has been generated by the true causal reality. An event observation means that an individual has observed the event that has occurred. While I differentiate between event occurrence and event observation, crucial to my argument is that individuals who are observing events do not differentiate between the occurrence of events and their observation of them. This is a simplifying assumption, but it is consistent with work on theories of causal induction, where inference of causal relationships based on the observation of even small sets of data is a uniquely human endeavor (Griffiths & Tennenbaum, 2009).

Assumption 3: An employee forming a causal understanding assumes that event occurrence is consistent with her observation of events.

With assumption 3 in hand, that individuals assume that their observation of events is consistent with actual event occurrence, I now turn to how individuals go from observing events to inferring relationships between them. General causal inference proceeds with basic principles about how causality should work. One such principle is that a cause can occur without its effect, but an effect cannot occur without its cause. While this is in some ways a strict assumption in our multi-modal complex world, it is also an assumption ingrained in the definition of the terms cause and effect. Simply put, a cause must occur before its effect, or else the labels of cause and effect are not analytically useful or correct (Gale, 1965). However, effects need not occur with their causes. For example, consider the relationship that a cloud causes rain. A cloud must be present in the sky for it to rain, but it need not be raining for a cloud to appear in the sky. I formalize this assumption below:

Assumption 4: A cause can occur without its effect, but an effect cannot occur without its cause (or causes).

The above assumption helps individuals who are seeking to form causal understandings, but cannot observe the true causal reality directly, make correct inferences about the causal relationships between events. However, we are not just interested in individuals forming causal understandings generally, but in employees forming causal understandings in the structured context of organizations. In considering what causality is like in organizations, and what principles of inference might help employees converge on correct causal understandings, I make one further assumption about the nature of causality. Specifically, while much work in causal induction thinks about deterministic causality, I suggest that the causality in organizations is most likely to be probabilistic.

Deterministic causality means that if A causes B, when A happens B happens. Probabilistic causality means that if A causes B, A occurring increases the likelihood that B occurs. In the context of organizations, we generally say that effective coordination is likely to increase performance (Okhuysen & Bechky, 2009) or that complex problems generally require more coordination (Heath & Staudenmayer, 2000). In fact, much organizational research has come to the conclusion that while there are things we generally believe to be the case, the complexity and variation in organizations yields very few absolutes and very many 'it depends'. Thus, when considering causality in the context of organizations, I assume that employees, consistent with the body of organizational research, will form causal understandings of causal processes that are probabilistic. I formalize this assumption below.

Assumption 5: If a cause occurs the likelihood of its effect occurring is S, where $S<1$.
(Note: S denotes the causal strength of the relationship between a cause and its effect)

A proposition about the formation of causal understandings by employees follows from these assumptions. Since an effect cannot occur without its cause (assumption 4), an effect must occur at a rate lower than its cause (assumption 5), and employees assume that their observation of events is consistent with the occurrence of events (assumption 3), it follows that causes should be observed occurring more often than effects.

Proposition 2: For an employee forming a causal understanding consistent with causal inference principles, causes should be observed occurring more often than effects.

How do organizations impact the observation of causal reality for their employees?

With a series of assumptions and a proposition developed for how employees might infer a causal understanding based on their observation of events, I now turn to how organizations might impact these employees' observation of the true causal reality. A key element of organizations is the division of labor; in order to complete the complex and information intensive tasks of an organization, work must be divided between employees (March & Simon, 1958; Mintzberg, 1989). While the division of labor improves an organization's ability to complete its necessary tasks, work on modularity and organizational design frequently points to the potentially unintended consequence of this division: the division of event experience in the organization (Clement, 2023; Dearborn & Simon, 1958; Joseph & Gaba, 2020).

In considering how to specifically operationalize the way in which organizations divide the event observation of their employees, I consider two dimensions along which organizations are likely to vary the work, and thus the event experience, of their employees: scope and frequency. First, the division of work is likely to generate an event experience for employees that is reduced in scope. When employees are given a set of related tasks that represent a subset of tasks the organization performs, they are also likely to have a reduced scope of visibility into events corresponding to the tasks that these employees are not performing. Thus, organizations are likely to provide employees with experience of events that are related to each other, but limited in that the event experience may not fully represent a complete set of events occurring in the organization. As Simon says, "structural boundaries and the division of labor reflect how the organization represents its problems and affect how individuals filter information" (Dearborn & Simon, 1958; Joseph & Gaba, 2020).

The structure of the organization then, which limits the scope of work to a small set of related tasks, may also limit the scope of events that an employee is likely to see at any given time, which in turn serves to create this employee's causal understanding of events in the organization as a whole. Thus, the core feature that I consider in operationalizing the way that organizations impact the observations of events for their employees, is the way in which organizations limit employees from getting a bird's eye view of the organization, limiting observation of events at any time. I formalize this assumption below:

Assumption 6: Organizations divide the scope of observation of the true causal reality for their employees, such that while many events may occur in the organization, employees in the organization will only ever observe a subset of related events occurring. 1

Footnote 1: To formalize this assumption for the model specifically, I constrain the observation of the scope of events to pairs of related events only, which greatly simplifies the calculations needed. However, theoretically, the scope of the observation of events need only be consecutive and one event fewer than all causes occurring in the organization, in order for this logical argument to hold.

This is the strongest assumption of my work, and it is also the most consequential. To consider why this assumption may be accurate for organizations, I return again to the motivating example. At Kodak, both the managers and engineers are forming causal understandings of digital photography. The problem that both sets of employees face in trying to understand digital photography is that they cannot focus on the whole set of events. Because the organization silos experience (whether by time, role, or department), neither the engineer nor the management team at Kodak is likely to observe the consumer demand changes directly with the cannibalization of the film business. This could in some ways help the engineer and the management team form correct causal understandings, because they are unlikely to identify spurious relationships between events, like general consumer demand directly causing the decline in film profits (a common problem in the divergence of causal models, see d-separation in Pearl, 2009). However, it also means that when observing events in the organization, the engineers and managers at Kodak both had the difficult task of connecting their observation of sets of events into a larger model of causal reality to generate their own causal understandings.

The second way in which the organization's division of labor is likely to impact the observation of events for employees is by modifying the frequency of observation of events. In my work I consider two possible ways organizations could modify this frequency of observation. The first, is a base case, where employees in the organization see all slices of events equally, which could represent small organizations, organizations with generalist employees, or organizations with high transparency (i.e. Ferreira & Sah, 2013; Ball, 2014).

Assumption 7a: Employees in an organization are equally likely to observe any set of related events.2

Footnote 2: To formalize this assumption for the model specifically, the constraint of the observation of the scope of events to related events only means that employees are equally likely to observe any pair of related events.

Under assumption 6 and 7a, the "Caught in the Middle of Causality" problem in organizations is clearest. Because events are observed in sets with their directly related events, and events in the middle of causal processes are related to more events, occurrence of an event in the middle of causal reality is more likely to be observed by an employee than occurrence of an event at the edge of causal reality. With equal frequency of observation of event sets this is necessarily the case, and when a causal reality is structured such that a middle event is not a root cause, under assumption 6 and 7a incorrect understandings will be likely.

However, the other, potentially more likely, way that organizations may impact the frequency of observations of their employees is through unequal observation of slices of causal reality. Specifically, because organizations tend to have employees specialize on specific tasks and not others (Dearborn & Simon, 1958; Heath & Staudenmayer, 2000; Thompson, 1961), employees are likely to observe events related to their assigned work at a higher frequency than those events outside the scope of their work. Returning to our motivating example, the management team and the engineers are responsible for different tasks in the organization, which likely leads them to experience different sets of events at different frequencies. Kodak's managers may be responsible for maintaining profits of Kodak, which were majority driven by traditional film, and thus may have experienced this event and its causes more frequently than the other events in the organization. The engineers, on the other hand, are uniquely concerned with the development of the digital technology, and thus may experience this event and its causes more and more saliently than other events. I formalize this below:

Assumption 7b: Organizations focus employees on events related to their work focus, such that while employees may observe events that are not associated with their work focus, employees in the organization will observe sets of events in their work focus more frequently.3

Footnote 3: To formalize this assumption for the model specifically, the constraint of the observation of the scope of events to related events only, generates a pair of events equation such that, employees in an organization will observe the pair of events that they are responsible for at a rate higher than that of all other pair of related events, where the focus pair of events e_1 and e_2, for an employee i is observed at a rate $f_{i,focal}(e_1 \& e_2)$ and all other events are observed at a rate $\frac{(1-f_{i,focal}(e_1 \& e_2))}{k_r-1}$, such that focus on all pairs of events sums to 1.

Under assumption 6 that the scope of experience of events is limited, the modification of the frequency of observation of events by organizations in 7b could either exacerbate or attenuate the formation of incorrect causal understandings generated by being "Caught in the Middle of Causality", depending on both which pair of events an employee is focused on and the structure of the causal reality. I generate a set of hypotheses for when the combination of focus on events and structure of causal reality are likely to generate either incorrect or divergent causal understandings for employees below to specify these conditions.

How does the structure of causal reality interact with employees' divided observation of this reality in an organization to generate incorrect or divergent causal understandings?

In this theory section, I've developed a series of assumptions about how employees will infer causal understandings from their observation of events and how organizations will influence these employees' observation of events. I have also referenced the problem of being "Caught in the Middle of Causality", where because organizations limit the scope of observation

of events to subsets of related events, middle events of causal reality will appear at a higher frequency than edge events. In this final section of theory, I connect the assumptions and propositions made about employees inferring causal understandings under the divided observation of events in organizations to the "Caught in the Middle of Causality" problem in order to generate two hypotheses about when employees are likely to come to incorrect or divergent causal understandings in organizations.

Because organizations limit the scope of event experience, forcing employees to observe subsets of related events only, not the entire birds eye view of the causal reality, employees' observation of a focal event will be a function of how many other events the focal event is related to. The reason I call this the "Caught in the Middle of Causality" problem is because 'middle' events (events that are related to more events than their causes) are likely to be observed more frequently than edge events (events that are related to fewer events than their effects). However, whether this "Caught in the Middle of Causality" problem will generate incorrect or divergent causal understandings depends on the structure of the true causal reality.

Consider the assumptions made above about employees inferring causal relationships from an unobservable true causal reality. As long as an employee's observation of events is consistent with actual occurrence of events (assumption 3) such that causes are observed occurring more than effects (proposition 2, off of assumption 4 & 5), the fact that organizations divide the observation of events for employees should not interfere with coming to a correct causal understanding of events. However, for certain causal realities, the limitation of the scope of event experience by organizations generating the observation of middle events at higher than occurring frequency will lead employees to observe effects occurring more than causes, which will lead to an inference of incorrect causal understandings.

Specifically, when the true causal reality has a root cause in the middle of causal reality (for example A←B→C), even though employees will observe the middle root cause B at a rate higher than its actual occurrence, the relative rate of observation of events will be consistent with event occurrence (satisfying assumption 3), such that causes will still be observed occurring more than effects (satisfying proposition 2, off of assumption 4 & 5). However, when causal reality contains an edge root cause, the observation of the middle event occurring more often than an edge event means the employee is observing an effect occur more than a cause (breaking assumption 3,4, &5 and proposition 2). Under this edge root cause event observation, the inference of causal reality by employees is likely to be incorrect. To generate the intuition for what I mean by an edge root cause reality, I reproduce Table 1 below, with all possible non-cyclical realities for three events labeled as containing an edge root cause or not.

Table 1: All Possible Non-Cyclical Causal Realities Between Events A, B, and C And Whether the Reality Contains an Edge Root Cause

	Example Graph	**Edge Root Cause**
No Cause	A B C	No
One Cause	A->B C	No
Repeller	A<-B->C	No
Collider	A->B<-C	Yes
Linear	A->B->C	Yes

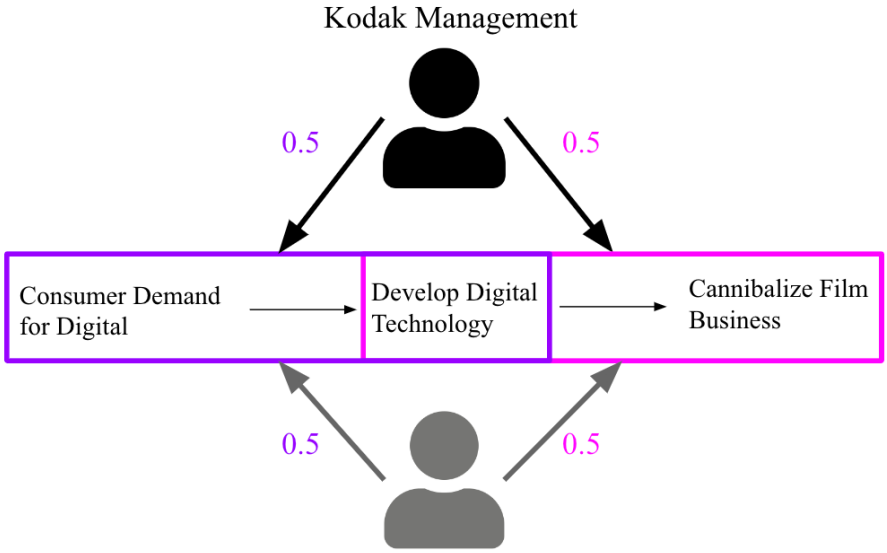
The implication of this "Caught in the Middle of Causality" problem for the causal understandings formed by employees across an organization generates two distinct hypotheses under the two different assumptions of equal and unequal observation of pairs of events (assumption 7a and 7b respectively). First, under the equal observation of pairs of events assumption (7a), all employees are equally observing slices of reality. For edge root cause realities, this means that all employees are over-observing middle event occurrence above the rate of actual occurrence, and thus likely seeing an effect occur more than a cause. This means that under equal frequency of event pair observation all employees are likely to converge on a causal understanding for non-root cause realities, however this agreed upon causal reality is likely to be incorrect. Thus, I hypothesize:

Hypothesis 1: When organizations divide the scope of employee experience and divide the frequency of event experience for their employees equally, causal realities that have an edge root cause will generate incorrect causal understandings.

To visualize hypothesis 1, I use the motivating example to generate Figure 4 that outlines the expected convergence on an incorrect causal understanding based on observation of events in the organization.

FIGURE 4: HYPOTHESIS 1

Kodak Management and Engineering Causal Understandings under Assumption 6 and 7a



Both Management and Engineering Converge to Incorrect Understanding:
Consumer Demand for Digital ← Develop Digital Technology → Cannibalize Film Business

Second, consider organizations who divide the scope of experience, but have employees specialized on different tasks and thus have employees observing different pairs of events at different frequencies. For employees who only see subsets of related events, but are focused on the subset of events that contains the root cause of the causal reality, even though edge root cause

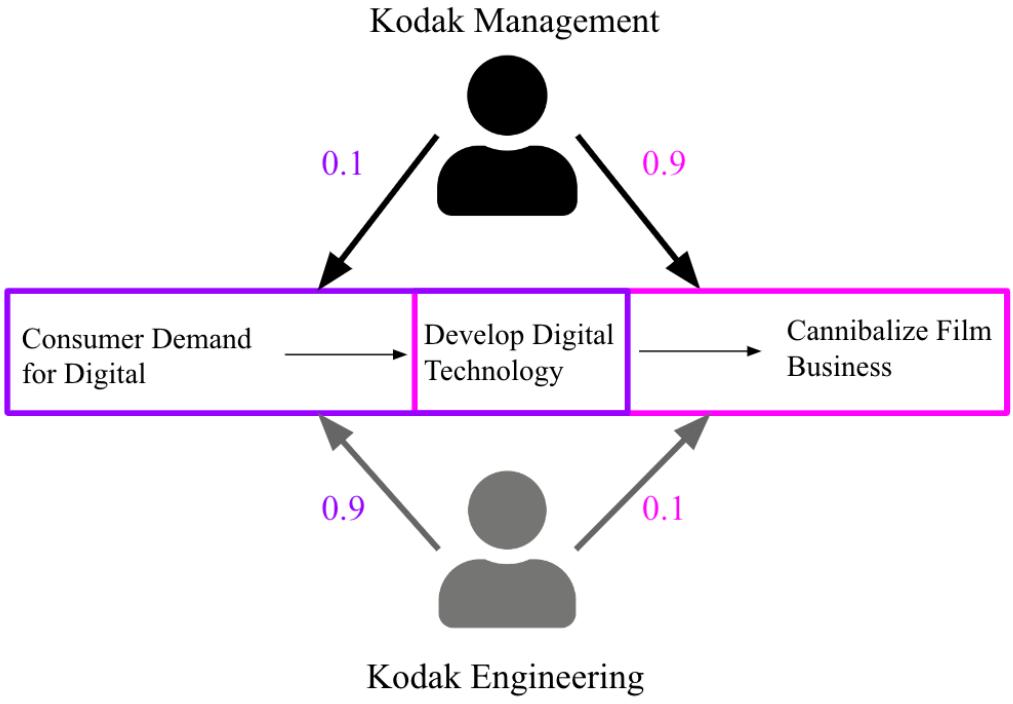
realities modify the frequency of observation of the middle event, because these employees mostly focus on the slice of reality containing the root cause, which occurs at a frequency higher than its effect (assumption 5), they are still likely to form the correct causal understanding. However, for employees who see slices of reality that do not contain the root cause, the modification of the frequency of observation of edge root cause realities is likely to be especially problematic in generating the observation of an effect at a higher rate than a cause, and these employees are likely to form incorrect causal understandings. Thus, the implication of an unequal observation of events in an organization under edge root cause realities is a divergence in causal understandings amongst employees, which I hypothesize below.

Hypothesis 2: When organizations divide the scope of employee experience and divide the frequency of event experience for their employees unequally, causal realities that have an edge root cause will generate divergent causal understandings.

To visualize hypothesis 2, I use the motivating example to generate Figure 5 that outlines the expected divergence on causal understandings based on observation of events in the organization.

FIGURE 5: HYPOTHESIS 2

Kodak Management and Engineering Causal Understandings under Assumption 6 and 7b



Divergence of Understandings between Management and Engineering Expected

Management, Incorrect Understanding:

Consumer Demand for Digital ← Develop Digital Technology → Cannibalize Film Business

Engineering, Correct Understanding:

Consumer Demand for Digital →Develop Digital Technology → Cannibalize Film Business

To test the hypotheses above against my developed assumptions and propositions, and to provide a set of mathematically grounded predictions for the role of edge root causal realities in generating divergent and incorrect causal understandings under the division of experience in organizations, I develop a mathematical model using the set of assumptions I've outlined above.

MODEL

In this section I mathematically test whether edge root cause realities are likely to generate a trade-off between correct causal understandings and division of labor in an organization. To do this, I operationalize my conception of the division of experience in organizations into a causal model and test the likelihood of incorrect and/or divergent causal understandings across different causal realities. The above section outlined and defended several assumptions about the individual inference, organizations, and the true causal reality, which I present in Table 2 below. From these two assumptions, two propositions about how causal understandings will be inferred by individuals followed, which are presented in Table 3.

My model developed below shows that because edge root cause realities break assumption 3, that an employee's observation of events is consistent with actual event occurrence, proposition 2, that causes should occur more than effects, is not valid. This generates incorrect or divergent causal understandings for employees at high causal strengths, depending on whether the frequency of event experience is equal or unequal for employees (assumption 7a or 7b). My causal modeling method provides a proof of concept that when organizations divide experience, edge root cause realities will generate either incorrect or divergent causal understandings as predicted in hypotheses 1 and 2, presented in Table 4 below.

Table 2: Assumptions

Number	Assumption
1	There is a true causal reality, i.e. there is a true causal process that generates events.
2	The true causal reality is unobservable to individuals.
3	An employee forming a causal understanding assumes that event occurrence is consistent with her observation of events.
4	A cause can occur without its effect, but an effect cannot occur without its cause (or causes).
5	If a cause occurs the likelihood of its effect occurring is S, where $S<1$. (Note: S denotes the causal strength of the relationship between a cause and its effect)
6	Organizations divide the scope of observation of the true causal reality for their employees, such that while many events may occur in the organization, employees in the organization will only ever observe a subset of related events occurring.
7a	Employees in an organization are equally likely to observe any set of related events.
7b	Organizations focus employees on events related to their work focus, such that while employees may observe events that are not associated with their work focus, employees in the organization will observe sets of events in their work focus more frequently.

Table 3: Propositions

Number	Proposition	Necessary Assumptions
1	When an individual forms a causal understanding, she uses her observation of a set of events to infer the causal relationship between them.	1, 2
2	For an employee forming a causal understanding consistent with causal inference principles, causes should be observed occurring more often than effects.	1, 2, 3, 4, 5

Table 4: Hypotheses

Number	Hypothesis
1	When organizations divide the scope of employee experience and divide the frequency of event experience for their employees equally, causal realities that have an edge root cause will generate incorrect causal understandings.
2	When organizations divide the scope of employee experience and divide the frequency of event experience for their employees unequally, causal realities that have an edge root cause will generate divergent causal understandings.

Event Occurrence vs. Event Observation

The core distinction that allows me to uniquely apply a causal modeling approach to causal understandings in an organizational setting is the differentiation between event occurrence and event observation. An event occurrence means that an event has been generated by the true causal reality. An event observation means that an individual has observed the event that has occurred. While traditional work in causal modeling would tend to equate event occurrence and event observation, because I assume that organizations structure the experience of employees, limiting the scope of the observation of events, events can occur in the organization without being observed by an employee. For example, consumer demand for digital technology can occur in the organization without the Kodak managers being aware of it. Thus, my general equation for the probability of an event (e_n) for a given employee (i) in an organization is the likelihood of the occurrence of the event $P(c_{e_n})$ times the likelihood that the event is observed occurring $P_i(b_{e_n})$.

$$P_i(e_n) = P(c_{e_n}) * P_i(b_{e_n}) \quad (1)$$

In the below sections I break down how I calculate the likelihood of both event occurrence and event observation.

Event Occurrence: The Likelihood of an Event Given a True Causal Reality and a Probabilistic Causal Strength

Event occurrence in an organization is a function of the true causal reality. One way to understand event occurrence is to conceptualize the possible worlds that a causal reality could create. For all event-generating process with three events (A,B,C) for example, there are eight possible worlds that could occur ranging from all three events not occurring (A:0, B:0, C:0) to all

three events co-occurring (A:1, B:1, C:1). I outline all possible worlds for three event causal realities in column 1 of table 5. However, for any specific causal reality with three events, the likelihood of each possible world differs.

For example, consider the true causal reality being a linear graph, as in Figure 1, where Consumer Demand for Digital →Develop Digital Technology → Cannibalize Film Business (A→B→C). If I assume, as I have above, that effects cannot occur without their causes (assumption 4) then for a linear causal reality, some possible worlds will not be possible, because B occurring without its cause A is not possible. In column 2 of Table 5, I identify which of the 8 possible worlds are possible for the linear graph under counterfactual causality.

Table 5: Likelihood of Event Occurrence for 3 Event Linear Graph (A→B→C) in the Possible Worlds Framework

Possible Worlds	Possible for Linear Graph	Likelihood of World for Linear Graph	Likelihood for Linear Graph at S = 0.9
A:0, B:0, C:0	Yes	(1-S)	0.1
A:1, B:0, C:0	Yes	S*(1-S)	0.09
A:0, B:1, C:0	No	0	0
A:0, B:0, C:1	No	0	0
A:1, B:1, C:0	Yes	S*S*(1-S)	0.081
A:0, B:1, C:1	No	0	0
A:1, B:0, C:1	No	0	0
A:1, B:1, C:1	Yes	S*S*S	0.729

After understanding which worlds of event occurrence are possible, the next step of my model is to calculate how likely each world of events is to occur. The assumption that causality in organizations is probabilistic (assumption 5), i.e. that A causing B means that A occurring increases the likelihood of B occurring, is core to executing this calculation. I use the variable causal strength (S) to identify the amount that a cause increases the probability of its effect by. For example, if the causal strength (S) of the relationship between consumer demand for digital and the development of digital technology is 0.7, then consumer demand for digital increases the likelihood that digital technology is developed by 70%. Using this framework, the likelihood of an event occurring given its cause has occurred is S, and the likelihood of an event not occurring given its cause has occurred is 1-S. I assume that the likelihood of an independent cause occurring is also S, which can be interpreted as an unobserved cause of the independent cause occurring. I use this basic logic to generate the likelihood of each possible world for the linear graph in column 3 of Table 5.

Table 5 shows the general intuition that event occurrence in an organization is a function of the structure of the true causal reality and the causal strength between related events. While I show the intuition for these calculations for a linear graph with three events above, this framework can be generalized to any number of events and causal realities, as I formalize in equation 2 below, where the probability of any possible world (w) is a function of the causal strength of the relationship between events (S), the number of events that occur in the possible world (j), the number of independent causes that do not occur in the possible world (i.e. events that do not have a cause in the world, k), and the number of effects of events j that do not occur in the possible world (m).

$$P(w) = S^j * (1-S)^k * (1-S)^m \quad (2)$$

With equation 2 formalized to give the likelihood of a possible world given a causal strength (S) and event-generating process (which determines the values of j, k, and m), to find the likelihood of an event occurring $P(c_e)$, I only need to sum all possible worlds where event e occurs, which I formalize in equation 3, where d is the number of possible worlds.

$$P(c_{e_n}) = \sum_0^d w_d[e_n] * P(w_d) \quad (3)$$

I can also calculate the probability of any two events (e_1, e_2) co-occurring together, $P(c_{e_1 \& e_2})$, by summing possible worlds where both events occur, as formalized in equation 4.

$$P(c_{e_1 \& e_2}) = \sum_0^d w_d[e_1] * w_d[e_2] * P(w_d) \quad (4)$$

The above formalization of my model of possible worlds gives me a way to measure the likelihood of event occurrence in an organization $P(c_e)$ given an event-generation process and strength of causal relationship (S). This portion of the model is similar to work developed in causal modeling (i.e. see Pearl, 2009), but adapted to an organizational setting. In equation 2, I also find a calculation supporting our intuition for why edge root cause realities may generate incorrect or divergent causal understandings. Edge root cause realities are more likely to generate a smaller number of possible worlds, and when causal strength is high, these graphs are most likely to either generate complete co-occurrence or no occurrence of all events. This uncertainty creates the opportunity for errors in causal understandings, which the division of experience is likely to produce.

However, my key assumption about organizations, that they divide the experience of events for employees, is not incorporated into the occurrence of events, but rather into the observation of events that have occurred $P_i(b_{e_n})$, thus I turn to formalizing the observation of events next.

Event Observation: The Likelihood of an Employee Observing an Event Occur Given the Divided Experience in the Organization

Event observation in an organization is a function of the degree to which experience is divided in the context. For example, if the Kodak engineer is tasked with researching alternative film technologies, the organization can be said to have structured the experience of the engineer to focus on this event and its related cause. This means that the engineers are both more likely to see the development of digital technology and the potential for consumer demand for the product occurring, but it also means that they are more likely to see these events not occur. What the structuring of experience functionally means in an organization is that employees are focused on observing specific sections of the event-generating more than others. One nice metaphor to consider this concept through is the tale of the inebriated man searching for his keys only where the lamp had lit up the street, because it was the only place that he could see. Organizations allow for selective observation of events by 'turning on the streetlight' for certain people on certain events, creating variance in the observation of events given a set of occurrences of events.

To formalize this idea of the structure of experience, consistent with our assumption that organizations limit the scope of experience observable to subset of related events only (formalized for the model as pairs of related events only, see assumption 6, and footnote 4

below), the likelihood that an individual observes a pair of events (e_1, e_2) occurring in an organization is simply the likelihood that the employee's (i) experience in this organization focuses them on observing this pair ($f_{i,e_1\&e_2}$).

$$P_i(b_{e_1\&e_2}) = f_{i,e_1\&e_2} \quad (5)$$

Footnote 4: As noted in footnote 1, the model formalizes the set of events an employee can observe as a pair of related events only. Making the operationalization of assumption 6 for the model as follows: Organizations divide the scope of observation of the true causal reality for their employees, such that while many events may occur in the organization, employees in the organization will only ever observe pairs of related events occurring. However, as long as the scope of events remains smaller than the number of causes, the argument holds.

In order to find the likelihood of observing any particular event (e_n) given the siloed, pairwise focus of events in organizations, I can simply sum all the pairwise focuses that include event (e_n), giving equation 6 below.

$$P_i(b_{e_n}) = \sum_{y=0,y\neq n}^{N} f_{i,e_n\&e_y} \quad (6)$$

This event observation portion of my model formalizes the assumption that organizations divide the event experience of their employees to specific sets of related events, providing a variable of event focus ($f_{i,e_n\&e_y}$) that maps an organization's division of labor to an observation window for individuals to observe events within the organization. Functionally our event focus variable operationalizes how the division in organizations allows their employees to see only slices of events at any given time, where the engineer may be more likely to experience the development of digital technologies and its associated events, while the management team may be more likely to experience the threat to their film business and associated events. When I assume that employees focus on pairs of events equally as in assumption 7a, this assumption can be formalized by equation 6 being equal for all pairs of events within a single employee (i). When I assume that employees focus on different pairs of events differently as in assumption 7b, this assumption can be formalized by the value of equation 6 varying from equal across different employees (i).

In Table 6 I summarize the parameters of my model that I can vary to generate different likelihood of events.

Table 6: Model Parameters

Parameter	Name	Description	Possible Values	Category of Variance
S	Causal Strength	Given that the cause occurs, the likelihood of also observing the effect.	[0,1)	Causal Reality
$f_{i,e_1\&e_2}$	Event Focus	The proportion of employee i's focus that is directed by the organization onto events e1 and e2.	[0,1]	Organization
j	Events, Occurring	Number of events that occur in a possible world.	[0,N]	Causal Reality
k	Independent Events, Non-Occurring	Number of events that do not have causes that do not occur in a possible world.	[0,N]	Causal Reality
m	Effect of Events j, Non-Occurring	Number of effects of events j that do not occur in a possible world.	[0,N-1]	Causal Reality

Now that I have developed a model to calculate the likelihood that employees within an organization will observe events, I can turn to how these employees will form causal understandings from these events.

Forming a Causal Understanding of Events from Event Observation

In order to form a model about how an employee will form a causal understanding from event observation, I reference several assumptions and propositions generated in the theory section above. Consider proposition 2, which states that for an employee forming a causal understanding consistent with causal inference principles, causes should be observed occurring more often than effects. The first part of proposition 2 specifies that an employee would need to be trying to form a causal understanding consistent with causal inference principles in order for the second piece of the proposition to be relevant. In the model, I formalize this contingency into an additional assumption, which is that employees are seeking to form the correct causal understanding of events, which means that employees will choose the causal understanding that is the most likely to be correct based on the observed probabilities and causal inferences principles.

Assumption 8: Employees seek to find the correct causal understanding of events through the application of causal inference principles (assumption 3-5).

There is much work in organizational research that references motivated or situated interpretation when it comes to making sense of events in organizations (see sense-making literature, i.e. Weick et al., 2005). However, if successful strategies are based on correct causal understandings, and employees are either motivated or incentivized to generate successful

organizational outcomes, this assumption may represent a reasonable set of true scenarios in organizations.

Next, the assumptions 1-5 and their implications proposition 1 and 2, plus the newly minted assumption 8, gives the model a clear way to decide how employees will select their causal understandings. The second half of proposition 2 states that causes should be observed occurring more than effects, and assumption 8 says that employees will select the causal understandings that is most likely to be correct given their causal inference principles. Thus, if event 1 is observed occurring more than event 2, then an employee (i) will conclude that event 1 causes event 2. I formalize this logic into equation 7 below.

$$\begin{gathered} if\ P_i(e_1) > P_i(e_2)\ \ then\ e_1 \rightarrow e_2 \\ if\ P_i(e_1) < P_i(e_2)\quad then\ e_2 \rightarrow e_1 \\ if\ P_i(e_1) = P_i(e_2)\quad then\ e_1 \rightarrow e_2\ or\ e_2 \rightarrow e_1 \end{gathered} \tag{7}$$

By operationalizing my assumption about employees wanting to find the correct narrative and employing causal inference principles to do so, I can form equation 7, which provides a clear way that employees go from observing event co-occurrence to forming causal understandings of these events. In equations 8 and 9, I formalize how the probabilities in equation 7 can be derived from the event probabilities I calculate in equations 1 through 6.

$$P_i(e_1) = P_i\left(b_{e_1}\right) * \sum_0^d w_d[e_1] *\ P(w_d) \tag{8}$$

$$P_i(e_2) = P_i\left(b_{e_2}\right) * \sum_0^d w_d[e_2] *\ P(w_d) \tag{9}$$

When Employees Form Incorrect and Divergent Causal Understandings: True Causal Realities with an Edge Root Cause

The structure is now in place for the model to measure when the division of work enacted by organizations ($f_{i,e_n\&e_y}$) will generate incorrect causal understandings (presented as $P_i(e_2) > P_i(e_1)$ when $e_1 \rightarrow e_2$). Since an incorrect causal understanding occurs when e_1 causes e_2, but e_2 is observed more than e_1, I formalize the likelihood of forming an incorrect understanding in equation 10a and 10b below, where equation 10a represents when an incorrect causal understanding would occur given that the true causal reality has the relationship $e_1 \rightarrow e_2$, and equation 10b represents when an incorrect causal understanding would occur given that the true causal reality has the relationship $e_2 \rightarrow e_1$.

$$P_i\left(b_{e_2}\right) * \sum_0^d w_d[e_2] *\ P(w_d) >\ P_i\left(b_{e_1}\right) * \sum_0^d w_d[e_1] *\ P(w_d)\ \text{, when}\ e_1 \rightarrow e_2 \tag{10a}$$

$$P_i\left(b_{e_2}\right) * \sum_0^d w_d[e_2] *\ P(w_d) <\ P_i\left(b_{e_1}\right) * \sum_0^d w_d[e_1] *\ P(w_d)\ \text{, when}\ e_2 \rightarrow e_1 \tag{10b}$$

Both equations 10a and 10b can be rewritten to reflect the relative ratios of event occurrence and event observation for events 1 and 2, where the relative event observation of the two events (represented by $P_i\left(b_{e_1}\right)$and $P_i\left(b_{e_2}\right)$)is not consistent with the actual relative event occurrence of the two events (represented by $\sum_0^d w_d[e_1] *\ P(w_d)$ and $\sum_0^d w_d[e_2] *\ P(w_d)$), incorrect causal understandings are likely to be formed. I rewrite equation 10a and 10b as equations 10a2 and 10b2 in this form below.

$$\frac{P_i(b_{e_2})}{P_i(b_{e_1})} > \frac{\sum_0^d w_d[e_1] * P(w_d)}{\sum_0^d w_d[e_2] * P(w_d)} \text{ , when } e_1 \rightarrow e_2 \quad (10a2)$$

$$\frac{P_i(b_{e_2})}{P_i(b_{e_1})} < \frac{\sum_0^d w_d[e_1] * P(w_d)}{\sum_0^d w_d[e_2] * P(w_d)} \text{ , when } e_2 \rightarrow e_1 \quad (10b2)$$

Note that this specification of incorrect causal understandings is a direction contradiction to one of the assumptions that the employee is making in her attempt to form a causal understanding, which is that the employee's observation of events is consistent with event occurrence (assumption 3). Functionally what equations 10a2 and 10b2 formalize is that when an employee assumes that her event observation is consistent with event occurrence, but when event occurrence is not consistent with the employee's event observation, then an incorrect causal understanding is likely.

I can now calculate when the pattern of observation of events, whether equal or unequal as specified in assumption 7a and 7b respectively, will be likely to generate incorrect or divergent causal understandings. First, consider the case where employees are equally as likely to see all slices of causal reality. This formally means that for any pair of events that are related, the likelihood of observing this pair is one over the total number of relationships in the causal reality (k_r), which is shown in equation 11.

$$f_{i,e_n \& e_y} = \frac{1}{k_r} \quad (11)$$

Now consider what the implication of this is for the observation of a single event by an employee (i). Since each pair of events has an equal likelihood of being observed by employee (i) in assumption 7a, the likelihood of observing any single event (e_n) is just the number of pairs of events that event (e_n) is in. I formalize this into equation 12 below, where l_{e_n} is the number of relationships that event e_n is in.

$$P_i(b_{e_n}) = \sum_{y=0, y \neq n}^{N} f_{i,e_n \& e_y} = l_{e_n} * \frac{1}{k_r} \quad (12)$$

I now plug in equation 12 into equation 10a2, which specifies when the true relationship $e_1 \rightarrow e_2$ or $e_2 \rightarrow e_1$ will be mistaken, and the employee will come to an incorrect causal understanding, labeling this equation 13.

$$\frac{l_{e_2}}{l_{e_1}} > \frac{\sum_0^d w_d[e_1] * P(w_d)}{\sum_0^d w_d[e_2] * P(w_d)} \text{ , when } e_1 \rightarrow e_2 \quad (13a)$$

$$\frac{l_{e_2}}{l_{e_1}} < \frac{\sum_0^d w_d[e_1] * P(w_d)}{\sum_0^d w_d[e_2] * P(w_d)} \text{ , when } e_2 \rightarrow e_1 \quad (13b)$$

What equation 13a shows is that when $e_1 \rightarrow e_2$, but event 2 (e_2) is in more relationships than event 1 (e_1), such that $l_{e_2} > l_{e_1}$, even though the true causal reality will have event occurrence such that the cause (e_1) occurs more than its effect (e_2), employee observation in the organization will generate inconsistent observation with event occurrence, generating incorrect causal understandings.

In considering which true causal realities will satisfy event 2 (e_2) being in more relationships than event 1 (e_1), such that $l_{e_2} > l_{e_1}$, edge root cause realities will necessarily satisfy it. I now formally define what an edge root cause reality is. First, edge root cause realities are realities where the root cause is contained in the event set, such that if $l_{e_{rootcause}} = z_{e_{rootcause}} + t_{e_{rootcause}}$, where $z_{e_{rootcause}}$ is the number of causes of the root cause and $t_{e_{rootcause}}$ is the number of effects of the root cause, $z_{e_{rootcause}} = 0$. Second, edge root cause realities have an effect that has more relationships with other events than the root cause, such that $l_{e_{effect}} > l_{e_{rootcause}}$. Thus, realities where $l_{e_{effect}} > l_{e_{rootcause}}$ and the effect and root cause co-occur will necessarily satisfy equation 13 and generate incorrect causal understandings at high enough causal strengths. I formalize my definition of edge root cause realities in equation 14 below.

Formal Definition of Edge Root Cause Realities: Equation 14

$$l_{e_{rootcause}} = z_{e_{rootcause}} + t_{e_{rootcause}} \quad (14)$$
$$z_{e_{rootcause}} = 0$$
$$l_{e_{effect}} > l_{e_{rootcause}}$$

Where $z_{e_{rootcause}}$ is the number of causes of the root cause and $t_{e_{rootcause}}$ is the number of effects of the root cause.

What my model then shows is a mathematical proof that under equal observation of pairs of events in an organization, employees are likely to generate incorrect causal understandings for edge root cause realities, confirming the intuition of hypothesis 1.

Now, consider the second case of organization's dividing event observation, such that employees observe different pairs of events at different frequencies (assumption 7a). This formally means that for any pair of events that are related, the likelihood of observing pairs of events is a specified in assumption 7a, reformalized as equation 15 & 16 below:

$f_{i,focal}(e_1 \& e_2)$, where events e_1 and e_2 are the events that employee (i) are focused on (15)

$f_i(e_n \& e_y) = \frac{(1 - f_{i,focal}(e_1 \& e_2))}{k_r - 1}$, where events n and y are any events but the focal pair (16)

In considering what the implication of this focus is for the probability of observing a single event n for employee i ($P_i(b_{e_n})$), I plug our formalizations in equation 15 and 16 into equation 6 to get the following equation 17:

Where if event e_n is in the focal pair with event e_x then:

$$P_i(b_{e_n}) = f_{i,focal}(e_n \& e_x) + \sum_{y=0, y \neq n,x}^{N} f_{i,e_n \& e_y}$$
$$= f_{i,focal}(e_n \& e_x) + (l_{e_n} - 1) * \frac{(1 - f_{i,focal}(e_n \& e_x))}{k_r - 1} \quad (17a)$$

And if event e_n is not in the focal pair, but another event e_y is, then:

$$P_i(b_{e_n}) = l_{e_n} * \frac{(1 - f_{i,focal}(e_y \& e_x))}{k_r - 1} \quad (17b)$$

I now plug in equation 17 into equation 10a2, which specifies when the true relationship $e_1 \rightarrow e_2$ will be mistaken, and the employee will come to an incorrect causal understanding, labeling this equation 18. However, the equation will differ depending on whether event 1 or event 2 are a part of the focus pair of events, thus I formalize equation 18a, where event 1 (e_1) and event 2 (e_2) are both in the focus pair of events and 18b where event 1 (e_1) is not a part of the focus pair of events, but event 2 (e_2) is.

$$\frac{f_{i,focal}(e_1\&e_2) + (l_{e_2}-1)*\frac{(1-f_{i,focal}(e_1\&e_2))}{k_r-1}}{f_{i,focal}(e_1\&e_2) + (l_{e_1}-1)*\frac{(1-f_{i,focal}(e_1\&e_2))}{k_r-1}} > \frac{\sum_0^d w_d[e_1]*P(w_d)}{\sum_0^d w_d[e_2]*P(w_d)} \text{ , when } e_1 \rightarrow e_2 \quad (18a)$$

$$\frac{f_{i,focal}(e_2\&e_y) + (l_{e_2}-1)*\frac{(1-f_{i,focal}(e_2\&e_y))}{k_r-1}}{(l_{e_1})*\frac{(1-f_{i,focal}(e_2\&e_y))}{k_r-1}} > \frac{\sum_0^d w_d[e_1]*P(w_d)}{\sum_0^d w_d[e_2]*P(w_d)} \text{ , when } e_1 \rightarrow e_2 \quad (18b)$$

What equation 18a and 18b show is that when $e_1 \rightarrow e_2$, but an employee focuses sufficiently on an event pair that contains event 2 (e_2) and not event 1 (e_1) as in equation 18b, if $l_{e_2} > l_{e_1}$ this employee is likely to form an incorrect understanding. However what 18a shows is that even in a world where $l_{e_2} > l_{e_1}$, if an employee focuses sufficiently on event pairs that contain event (e_1) and event (e_2), this employee is likely to form correct causal understandings. Thus in an edge root cause world as outlined in equation 14 (such that $l_{e_1} = 0$ and $l_{e_2} > l_{e_1}$), equation 18a and 18b show that employees are likely to form divergent causal understandings.

A note for the example below, that if events e_1 and e_2 are in the focal pair, but $e_2 \rightarrow e_1$, then equation 18c below represents when an incorrect understanding would be formed.

$$\frac{f_{i,focal}(e_1\&e_2) + (l_{e_2}-1)*\frac{(1-f_{i,focal}(e_1\&e_2))}{k_r-1}}{f_{i,focal}(e_1\&e_2) + (l_{e_1}-1)*\frac{(1-f_{i,focal}(e_1\&e_2))}{k_r-1}} < \frac{\sum_0^d w_d[e_1]*P(w_d)}{\sum_0^d w_d[e_2]*P(w_d)} \text{ , when } e_2 \rightarrow e_1 \quad (18c)$$

And then equation 18d where event 2 (e_2) is not a part of the focus pair of events, but event 1 (e_1) is, and $e_2 \rightarrow e_1$.

$$\frac{f_{i,focal}(e_2\&e_y) + (l_{e_1}-1)*\frac{(1-f_{i,focal}(e_2\&e_y))}{k_r-1}}{(l_{e_2})*\frac{(1-f_{i,focal}(e_2\&e_y))}{k_r-1}} < \frac{\sum_0^d w_d[e_1]*P(w_d)}{\sum_0^d w_d[e_2]*P(w_d)} \text{ , when } e_2 \rightarrow e_1 \quad (18d)$$

This calculation supports the intuition of hypothesis 2, which is that when the true causal reality is an edge root cause reality and employee see unequal observation of the causal reality, divergence in causal understandings is likely. Thus, the mathematical model, built on the same assumptions as our theory section, supports both hypothesis 1 and hypothesis 2.

A Three Event Example: Causal Understandings as a Function of the Division of Experience, the True Causal Reality, and Causal Strength

In my motivating example, the Kodak engineering and management teams diverge on causal understandings about digital photography, coming to following conclusions in Figure 2 and 3 (reproduced below).

FIGURE 2: Kodak Engineering's Causal Understanding of Digital Photography
Consumer Demand for Digital → Develop Digital Technology → Cannibalize Film Business

FIGURE 3: Kodak Management's Causal Understanding of Digital Photography
Consumer Demand for Digital ← Develop Digital Technology → Cannibalize Film Business

My theoretical development suggests that if the true causal reality generating events contains an edge root cause, then because middle events are observed occurring more than edge events due to the division of experience in organizations, the divergence of causal understandings in Figure 2 is likely. My mathematical equations can be solved to show this is the case, which I generated above.

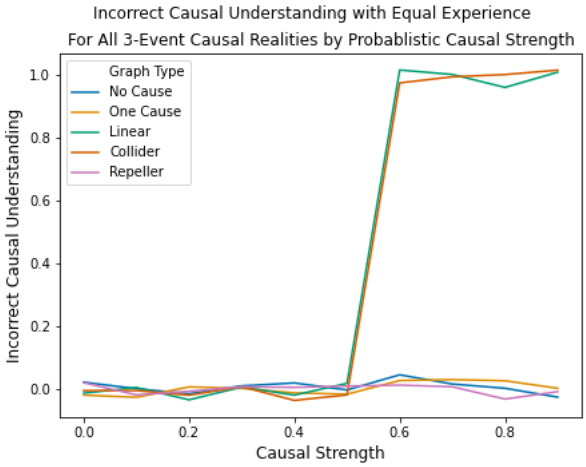
But how does this development matter for how causal understandings are formed in organizations? Calculating the values for the equations above, I show what levels of causal strength and how much division of experience will generate incorrect or divergent causal understandings between the Kodak managers and engineers given a true causal reality. In the results, only causal realities with an edge root cause generate divergent or incorrect understandings. In Table 7 I show all possible event-generating processes between the three events: consumer demand for digital (A), develop digital technology (B) and cannibalize film business (C), identifying which graphs contain edge root causes.

Table 7: All Possible Causal Realities Between Events A, B, and C

	Example Graph	**Number of Graphs in Type**	**Number of Arrows in Graph**	**Edge Root Cause**	**Equations Used**
No Cause	A B C	1	0	No	NA
One Cause	A->B C	6	1	No	13a, 18a, 18b
Repeller	A<-B->C	3	2	No	13b, 18c, 18d
Collider	A->B<-C	3	2	Yes	13a, 18a, 18b
Linear	A->B->C	6	2	Yes	13a, 18a, 18b

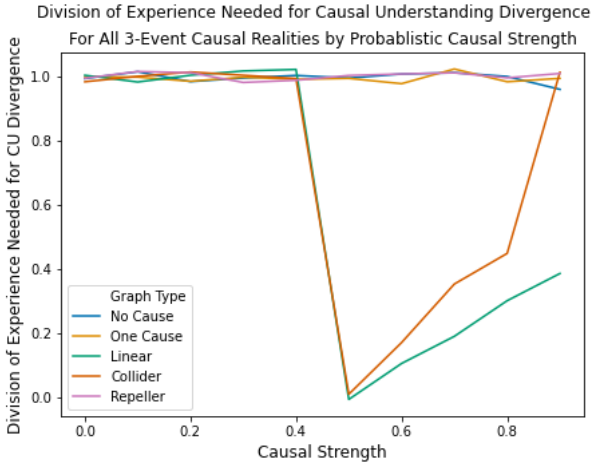
Then, for each possible causal reality listed in Table 7, I first calculate equation 13 for each causal reality under equal observation of slices of reality (assumption 7a), which tells us when employees will generate incorrect causal understandings. I visualize this in Figure 6, where on the x-axis is the causal strength of relationships between events (S). On the y-axis, if the value is 0, employees converge to the correct causal understanding of the true causal reality, if the value is 1, employees converge to the incorrect causal understanding of the true causal reality. To calculate the 0 and 1 values of the y-axis for each true causal reality, I use either equation 13a or 13b (specified in column 6 of Table 7) depending on whether the true relationship is either A→B or B→A. If equation 13 is satisfied, employees reach an incorrect causal understanding for the true causal reality at that causal strength, meaning a value of 1 on the y-axis.

FIGURE 6



Next, I consider the results of equation 18 for each possible causal reality listed in Table 7, which tells us under the unequal observation of slices of causal reality (assumption 7b), when employees will generate incorrect causal understandings. However, recall from hypothesis 2 and my mathematical development above that what is most likely expected for employees who differ in focus of events it that these employees will diverge in causal understandings. Thus, in Figure 7, I visualize employee divergence in causal understandings as a function of causal strength (S) and structure of true causal reality. On the x-axis is the causal strength of relationships between events (S). On the y-axis is the difference between focus on a pair of events that includes the root cause $f_{i,focal}(e_{rootcause}\&e_x)$ vs. focus on a pair of events that does not include the root cause $f_i(e_y\&e_x)$ necessary to generate a divergence in causal understandings for employees, i.e. to satisfy either equation 18a or 18b (or for repeller, 18c or 18d) (see Table 7, column 6).

FIGURE 7



To show the mechanism for why the results in Figure 6 occur (with a similar mechanism in Figure 7), for each of the causal realities I generate the observation of events A and B for employees vs. the actual occurrence for event A and B for employees across causal strengths (S) and report them in Figure 8a-e. When the observation and occurrence line remain on the same

side of zero to each other, this means that employee observation in the organization is consistent with event occurrence. However, for the edge root cause realities ‘Linear’ and ‘Collider’, above causal strength of 0.5, employee observation and occurrence are no longer consistent, breaking assumption 3, and generating incorrect causal understandings.

FIGURE 8

FIGURE 8A: No Cause Reality

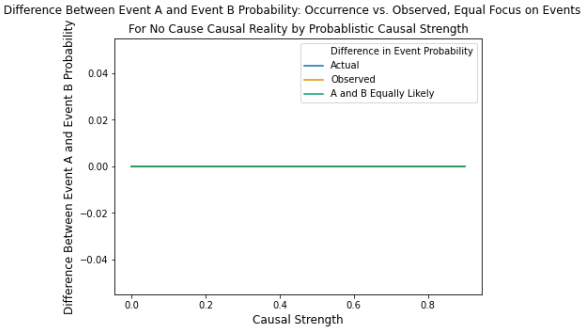


FIGURE 8B: One Cause Reality

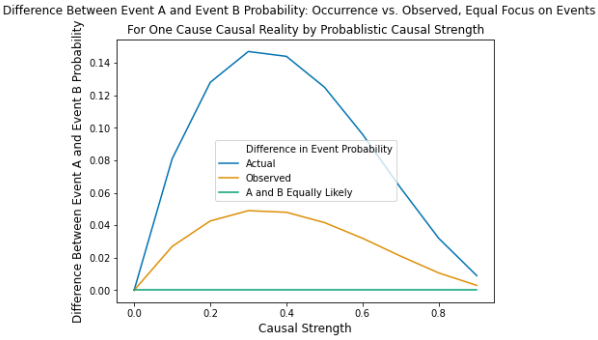


FIGURE 8C: Linear Reality

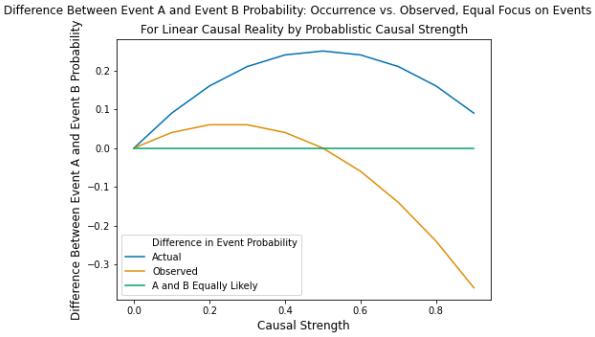


FIGURE 8D: Collider Reality

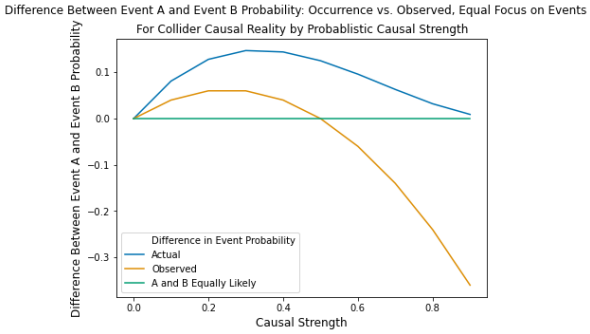
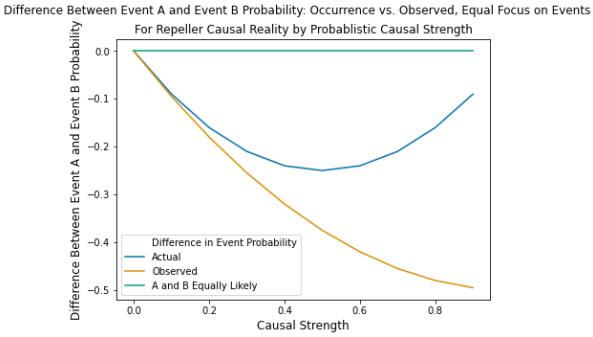


FIGURE 8E: Repeller Reality



Now that I’ve outlined what the model results are, I turn to how these results speak to my hypotheses, and more generally suggest when organizations are likely to experience a trade-off between correct and convergent causal understandings and division of labor. I used the intuition of causal modeling to develop the hypotheses that edge root cause realities are likely to generate incorrect or divergent causal understandings under the divided experience of organizations. My model shows that this is the case. In considering what this finding means for organizations, I return to the motivating example.

The Kodak managers and engineers are trying to understand digital photography in order to form a successful strategy to approach digital technology development for their organization. In order to generate this solution, employees at Kodak need to understand the space in a way that allows them to come to a correct and convergent strategy of what to do next. But Kodak has also divided the work of their employees, such that the Kodak managers and engineers are likely to have experienced digital photography in different ways. Given this structure of work and experience, when are the managers and the engineers likely to be able to form a correct and convergent causal understanding of what happened? If the true causal reality does not contain an edge root cause, the managers and the engineers are likely to agree on the correct causal understanding even under their differences in experience. However, if the causal reality does contain a middle root cause, either the managers and engineers will agree of the incorrect causal understanding or disagree on causal understandings, generating difficulty forming a successful strategy to address development of digital technology in the photography industry.

Overall, my model suggests the importance of the structure of true causal reality for when organizations are likely to face difficulty forming correct and convergent causal understandings under the division of labor.

DISCUSSION & CONCLUSION

Below I summarize the findings of my theoretical and mathematical model, suggest a wide set of contexts that this type of model can apply to, and suggest directions for future research on causal understandings in organizations.

What do we gain from considering causal reality in the formation of causal understandings in organizations?

Organizational research has previously ignored causal reality for reasons both theoretical and practical (i.e. Levitt & March, 1988; Weick et al., 2005; McIver & Lengnick-Hall, 2017). While there are arguments against the consideration of causal reality, my model nonetheless suggests that examining the interaction between an organization's division of work and causal reality provides a powerful way to predict when employees within an organization will reach incorrect or divergent causal understandings. Specifically, when true causal reality contains an edge root cause, employees will either converge on incorrect causal understandings or reach divergent causal understandings, depending on the division of work in the organization.

The application of this model to real world organizations, however, may be stymied by a particularly troublesome and necessary assumption of it, which is assumption 2, that individuals cannot observe the true causal reality. My model provides a proof of concept for how the true causal reality is important, but in order to identify situations where causal understandings are likely to be incorrect or divergent, knowing the structure of causal reality is essential. So how can a model showing that the structure of true causal reality be useful when it assumes that the structure of true causal reality is unobservable?

Practically, my model is likely to be most useful for organizations in three ways. First, in ex post analysis of organizational failures and success, my model suggests that considering the structure of causal reality might help distinguish why Kodak failed, but why a newer competitor in the digital film space who was not so entrenched in traditional film, may have succeeded. My model would provide the hypothesis that the reality that Kodak faced was not only uncertain, but also structured in such a way that converging on the correct assumptions in order to form the

right strategy may have been a difficult task due to Kodak management's focus on traditional film.

Consider how a non-incumbent in the traditional film market, such as Fujifilm, may have differently been able to approach the non-edge root cause reality faced by Kodak. Fujifilm, as the non-incumbent, may have been less concerned about the cannibalization of the film business, of which Kodak dominated, which may have freed them up to focus on the demand potential of digital film technology (Ho & Chen, 2018). Only an over-sampled focus on the root cause slice of this linear causal reality could help an organization avoid the "Caught in the Middle of Causality" inference errors that Kodak made. Organizations that did not dominate the traditional film business may have been more able to focus on this part of the causal reality, and thus generate correct understandings and effective strategies in digital photography. My model would suggest that given the reality faced in the digital photography market, and the structure of division of work in organizations, only organizations whose employees oversampled on the root cause of the digital photography space were likely to generate correct causal understandings.

Second, my model may be particularly useful to organizations when they are attempting to select the most successful strategy from a set of divergent causal understandings. While motivated reasoning and other factors may be at play in divergent causal understandings, another consistent reason employees in an organization reach divergent understandings of events is because of the division of work, and thus experience in organizations (Dearborn & Simon, 1958; Joseph & Gaba, 2020). However, only certain structures of causal reality are likely to generate divergent understandings from division of labor, edge root cause realities. In the case where the structure of causal reality is generating divergent understandings in organizations, my model provides a clear prediction for whose causal understanding will be correct, the employee who observes the root cause and its associated events more.

Because the true causal reality cannot be observed, it may be difficult to directly identify the root cause. However, my model suggests that having a theory for who is most likely to observe the root cause, may help organizations make more principled decisions in choosing a strategy from divergent causal understandings. For example, some work suggests that managers may be closer to the root cause of events, making manager's causal understanding of root cause events more likely to be correct, but potentially generating myopia to the trickle-down effects of higher-order decisions (Hannan et al., 2003). While in other instances, employees on the ground who are doing the work and are closer to the action, may observe the root causes of issues in the organization more saliently, and thus soliciting input, especially divergent input, from employees, may generate more successful strategy (Tegarden et al., 2005).

Finally, my model suggests a rather counterintuitive, but hopeful implication for the division of work and divergent causal understandings in organizations. Traditional accounts of modularity in organizations point to how the division of work drives divergence and disagreement, harming coordination and performance (i.e. Clement, 2023; Santos et al., 2021; Heath & Staudenmayer, 2000). This research has an often unified story that, when it comes to making collective decisions, divergence in understandings decreases collective outcomes. While it's likely that the processes to reach a convergent decision will be more difficult under the divergent causal understandings that are formed in my model, the results of division of experience for the likelihood of coming to the correct causal understanding in an organization are uniformly positive.

This is because in edge root cause realities, if employees were not differentially focused on different parts of this causal reality, employees would converge on causal understandings, but

they would agree on an incorrect understanding. In this light, divergence in causal understandings due to division of work can be seen as a positive outcome of organizational processes. When employees see different slices of reality, then even for edge root cause realities in which it is extremely difficult to infer correct understandings, there is a chance that organizations can reach the correct causal understanding, because some employees do hold this understanding.

Ultimately, while the true structure of causal reality is unobservable, my work suggests that having a theory about the structure of the true causal reality may help organizations consider how to better select which causal understanding to form strategy on when causal understandings diverge. In addition, in ex post analysis of organizational failure and success based on causal understandings, perhaps considering the structure of causal reality can provide a more tangible input to the uncertainty and causal ambiguity that can generate differences in outcomes for organizations (Raynor, 2007; King, 2007).

Where else do the results of the interaction of division of experience and causal reality apply?

While the work above uniformly focuses on the organizational context, my theory on causal reality applies to any context that consistently divides individual scope and frequency of experience. Societal structures, such as the sociodemographic features of race, gender, and income, may also be likely to systematically structure individuals' experience of event (Healey & Stepnik, 2009). Expanding my model to this wider set of social structures, my theory provides a potential explanation for why, for example, low-income and high-income parents may disagree on causal understandings of raising children (Lareau, 2018). Or even why democrats and republicans, whose experience is often stratified by many social features, may observe the same set of political events and come to different understandings on them (Cutler, 2003; Basta, 2017). Thus, while I believe that organizations are particularly likely to exhibit the particular division of experience outlined in my model above, future work might well consider how other societal groups whose experience of events is also structured, may also reach divergent causal understandings as a function of the division of experience and the structure of causal reality.

Where do we go from here?

The goal of the theory developed in the paper is to help future work in organizations and social science research better identify why incorrect and divergent causal understandings occur. I suggest an additional and often overlooked source of this variance in causal understandings, which is the structure of true causal reality. While the structure of true causal reality is not readily observable to researchers and practitioners alike, my work suggests that having a theory of what the structure of true causal reality is may help us better understand the antecedents of division and make principled selections of causal understandings when divergence exists. Several pathways for future work follow.

First, while the propositions above are developed by following the set of assumptions, the first test of my theory is, in a controlled experimental setting, to see whether under this assumption set, individuals form incorrect and divergent causal understandings. Work on causal narratives in economics has run models and sets of experiments that generally support the idea that the observation of co-occurrence of events generates the types of causal inference errors I identify in my theory above (i.e. Spiegler, 2016; Eliaz & Speigler, 2020). However, this work does not test the set of assumptions about how organizations divide work and event experience, thus future work should explore how the formation of causal understandings under the specific

set of divided work we expect to see in organizations is likely to generate the theoretical insights developed here.

Second, a major contribution of this work in organizational contexts is that it may help organizations make principled decisions about which causal understandings may generate successful strategy when there is divergence of causal understandings in the organizations. Future work should explore this theoretical insight by specifically examining organizational contexts where division in causal understandings arise, testing whether forming a model of the structure of causal reality and identifying which set of stakeholders are most likely to observe the root cause of events, may help organization select better strategies and ultimately perform better.

Finally, organizations' division of experience represent similar division of experience that occurs in many different parts of our society. For any social science scholar who studies populations that diverge on causal understandings, from work on polarization to work on class differences in parenting, considering the structure of causal reality and division of experience of individuals may help explain the divergence of individuals who may ostensibly observe the same reality.

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