Pandemics and Psychological Game Theory*

Martin Dufwenberg & Kathryn L. Reed

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Abstract: We use the mathematical framework called psychological game theory to explore how emotions, reciprocity, and social image concerns affect behavior, public health, and economic outcomes in pandemics.

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1 Introduction

Pandemics affect feelings and priorities. This, in turn, shapes behavior, impacting personal and public health as well as economic wealth. For example, a variety of emotions (e.g., frustration, anger, fear, anxiety, guilt, and regret) may influence not only how people adopt non-pharmaceutical interventions (NPIs) (e.g., social distancing, self-quarantining, and mask wearing) but also how they invest, vote, protest, look to the welfare of others, and evaluate and react to leadership. Other psychological considerations induce complex goals, e.g., the desire to reciprocate (being kind/unkind in return) or to maintain an attractive social image, which may also affect behavior and well-being. It is important to try to understand how these things interact.

*MD: Department of Economics, University of Arizona and University of Gothenburg, CESifo; martind@eller.arizona.edu. KLR: University of Arizona College of Medicine; kreed@obgyn.arizona.edu.

Economics has a strong history developing formal models of society, but relatively little attention has been devoted to incorporating emotions, reciprocity, and image concerns. One important exception, increasingly popular, is work based on a mathematical framework called psychological game theory (PGT). See Battigalli & Dufwenberg (B&D) (2021) for a systematic review.[1] PGT has not previously been used to understand pandemics, although Huang (2021) calls for such work.[2] Our goal is to conduct such an investigation.

The defining characteristic of PGT, essential for modeling emotions, reciprocity, and image concerns, is to allow decision makers' (or "players'") motivation (or "utility") to depend on beliefs (about beliefs, types, and actions) in ways that are not addressed in traditional models. We elaborate and explain below. Moreover, for our purposes, a key additional feature takes center stage. Whereas in (most) existing work involving PGT, emotions and other sentiments are derived with reference to merely a single valuable resource such as *money*, in pandemic settings a second valuable resource of *health* plays a key role. For example, the source of a decision maker's frustration or fear could be a precipitous drop in expected health (e.g., a perceived increased risk of dying from COVID-19), which may in turn drive behavior. Interesting and potentially complex effects may obtain because health as well as money is involved.[3]

PGT-based analysis is by its nature mathematical. If one develops all arguments in depth the text (or mathematics) may appear challenging. However, if one is careful when describing key ideas, specific examples can often be clearly described using words. The examples we develop are mostly both

[1] As B&D (2021) explain, the roots of PGT go back to pioneering work by Geanakoplos, Pearce & Stacchetti (1989) and is further developed in B&D (2009).

[2] See Huang pp. 127-9. Van Bavel et al. (2021) call for using "social and behavioural science to support COVID-19 pandemic response" more broadly. See also Caplin & Eliaz (2003) Caplin & Leahy (2004), Pope (2004), and Ferrer et al. (2015) all of whom argue that emotions may be important in various health contexts.

[3] For example, when spread of COVID-19 ignites, people may panic for health reasons and liqudate stock or stop producing babies. The resulting firesale or drop in birth-rate may have dramatic effects for a society's distribution of wealth and demography.

intuitive and intriguing. In order deny no category of readers access, for the most part we proceed relatively informally. Readers who want a deeper understanding of the models we describe, beyond how they apply in the specific applications that we discuss, are advised to consult the general models of belief-dependent preferences that we reference along the way.

Secton 2 explains what PGT is, and highlights how the framework needs to be expanded to allow for considerations of health. Sections 3-5 form the core of our analysis. We consider how three major categories of human motivation – emotions, reciprocity, and image concerns – may matter in a pandemic. Section 6 concludes.

2 Preliminaries

Game-forms & games A game-form describes the interaction between several players: the order in which they move, what their choices are, and the consequences of their actions. Game-forms can be depicted as "trees," or, if there are only two players who make their choices simultaneously rather than sequentionally, using a "bi-matrix." Here are two examples:

F_1 **&** F_2

F_1 is a "trust game-form" where two players move in sequence. Ann can choose to either *not trust* (N) Bob, in which case the game-form ends, each player getting a \$0 payoff, or to *trust* (T) Bob. Following T, Bob must choose to either *steal* (S), in which case he gets \$2 while Ann gets \$$-1$, or *reward* ($R$), in which case each player gets \$1. Ann's \$-payoff is written above Bob's.

F_2 is a a so-called "prisoners' dilemma" game-form, involving two players who move simultaneously. Either player chooses whether to *cooperate* (C) or to *defect* (D), and the outcome is indicated in the matrix, with Ann's \$-payoff written to the left, and Bob's to the right.

Game-theoretic analysis proceeds via three steps:

STEP 1: Specify a game-form. F_1 and F_2 exemplify.

STEP 2: Rewrite these game-forms to reflect how the players are motivated, using "utility functions." To exemplify using F_1 and F_2, if the players are motivated to make as much money as possible then the resulting games G_1 and G_2 will look *exactly* as the game-forms F_1 and F_2. However, if, for example, each player is "inequity averse," such that the goal is to maximize own monetary payoff minus the difference between the two players' monetary payoffs,[4] we get the following games:

$$G_1' \;\&\; G_2'$$

STEP 3: Apply a so-called "solution concept" to get predictions. In G_1 it is natural to apply backward induction: Bob would choose S (since $2 > 1$); anticipating that Ann chooses N (since $0 > -1$). Also in G_1' it is natural to apply backward induction, but the conclusion is different: Bob would choose R (since $-1 < 1$); anticipating that Ann chooses T (since $1 > 0$). In simultaneous-move games, like G_2 and G_2', it is commonplace to look for (Nash) equilibria: specifications of choices for each player such that each is maximizing utility given co-players' choices. In G_2, (D,D) is the sole equilibrium. In G_2', there are two equilibria,[5] (C,C) and (D,D).

To sum up, a game-form should be thought of as an objective description of a strategic situation: who is involved?, what can they choose?, what would be the consequences? A game-form does not describe the players' attitudes and evaluations of these consequences. By moving from a game-form to a game, such matters are, however, incorporated as well. The difference between a game-form and a game is human feelings, one could say, and these feelings are modeled using players' utility functions. In G_1, G_1', G_2, and G_2', each player's utility function converts overall distributions of monetary

[4]Our example here is closely related to the models of Bolton & Ockenfels (2000) and (especially) Fehr & Schmidt (1999). These approaches do *not* require PGT.

[5]The presence of multiple equilibria invites reflection on circumstances that favor a particular one. One might, e.g., argue, that if Ann & Bob had an opportunity to talk to each other, or if a policy-maker could make a recommendation, before they play G_2', they might agree to play (C,C) rather than (D,D), as each player is better off that way.

payoffs into modified utility numbers, according to the indicated formulae. Solution concepts are applied to games, not game-forms.

PGT & p-games For our purposes, it is essential to go deeper in STEP 2. G_1, G_1', G_2, and G_2' exhibit "traditional" games, meaning that players' utilities depend on choices only. PGT, by contrast, allows for utilities to depend on choices *and* beliefs (about choices or beliefs). The possibilities are multifold, as we'll show later. For now, to illustrate the key issue, assume that Bob experiences a pang of guilt if he causes Ann to get a lower payoff than she initially expected.[6] Consider STEP 1 with game-form F_1. Let p be the probability that Ann assigns to Bob choosing R. For STEP 2, consider G_1'', where $\theta_B \geq 0$ is a parameter to be interpreted as Bob's guilt sensitivity:

$$G_1''$$

If $p > 0$ and Ann chooses T and Bob chooses S then Bob causes Ann to get a lower payoff $(= -1)$ than she initially expected $(= p \cdot 1 + (1-p) \cdot (-1) = 2p - 1)$. The difference equals $(2p-1) - (-1) = 2p$, and G_1'' reflects that Bob experiences guilt in proportion to $2p$; the pang equals $\theta_B \cdot 2p$. The higher is θ_B, the more Bob suffers if he gives Ann less than she expected. The key thing to note: G_1'' is *not* a traditional game, because Bob's utility following choices T-then-S is not a number but rather an expression that depends on belief p. G_1'' is a psychological game (or "p-game").

Health To address what happens in a pandemic, we also need to go deeper in STEP 1. As we said, game-forms describe "consequences" of players' actions, and this traditionally involves only monetary payoffs. However, for our purposes it is essential to also describe health outcomes. The emotional concerns, and the utilities, we describe may depend on, or affect, health.

[6]The example we give is a special case of Battigalli & Dufwenberg's (2007) theory. These authors cite work by psychologists Baumeister, Stillwell & Heatherton (1994) and Tangney (1995) to motivate their assumptions. See also Cartwright (2019).

Of course, health outcomes may themselves be multi-dimensional, involving, e.g, life expectancy, BMI, fever, olfactory loss, etc. However, in the name of simplicity, we collapse health into a single number. For example, 0 could be a bad outcome (e.g., painful death) while 1 could be perfect health. All in all, consequences, as described by STEP 1 in our approach, specify *two* numbers for each player: the monetary payoff *and* the health outcome.

Our focus We explore how in pandemics there will be interesting themes that PGT can be used to formulate. We believe the phenomena are important, and we give many examples. Before we start, however, we wish to clarify that there are also interesting phenomena the modeling of which would not require PGT. For example, consider how people were hoarding toilet paper at the start of the pandemic, and how this lead to a shortage in stores. It is possible to explain this without reference to PGT. If others hoard, then any individual who wants to secure access to toilet paper may need to do so as well. This can be explained using a traditional game, where players' payoffs and goals depend only on choices and not directly on beliefs. The example is interesting (we think); nevertheless, in this paper, our focus is different, and requires PGT.

3 Emotions

During the past quarter-century, increasing numbers of economists and psychologists argued that emotions can shape behavior in important ways.[7] We now use PGT to develop several applications that concern pandemics.

Guilt & self-isolation Chloë works at a library, in close contact with co-worker Doug as well as customers whom she offers advice on what to read,

[7]See, e.g., Elster (1996, 1998), Keltner & Lerner (2010), Lerner & Keltner (2000, 2001), Loewenstein et al. (2001), Lerner, Li, Valdesolo & Kassam (2014), and B&D (2021, Section 3) who also discuss the content of these papers and comment on the history of research on emotions.

etc. A couple of weeks after the onset of a pandemic, Chloë develops a slight fever and suspects she might have COVID-19. Should she go to work? Consider the following game-form (STEP 1), and subsequent assumptions:

F_3

Chloë has no health insurance. If she stays at home (H) she gets a money-and-health payoff of $(0, h)$, meaning zero-income and (expected) health h, where $0 < h < 1$. If Chloë goes to work (W) her payoff is $(1, h)$: income $= 1 > 0$ and health h (i.e., same as if she stayed at home). Doug's payoffs are $(1, 1)$ if Chloë chooses H: normal income and perfect health. Doug's payoffs are (y, h) if Chloë chooses W: some expected loss of income (since COVID-19 implies a positive probability of eventual hospitalization) as well as health (assume that if Chloë is infected with COVID-19 then she will pass the disease on to Doug, so Doug's health outcome is the same as Chloë's).[8]

Let's now add utilities (STEP 2). If Chloë cared only about her own monetary and health outcome, she would choose W. That way she has higher income ($1 > 0$), while her health ($= h$) is not affected. For example, let G_3 be the game where each player's utility is calculated as income+health. Chloë's utility of W equals $1 + h$ which exceeds her utility of H ($= 0 + h < 1 + h$).

G_3

Now consider p-game G_3', which is similar to G_3 except that Chloë is now sensitive to guilt (as modeled by B&D 2007; compare the previous section):

G_3'

In G_3', $\theta_C \geq 0$ is Chloë's guilt sensitivity, p is the probability that Doug assigns to Chloë choosing H, and $p(2-y-h)$ reflects Doug's loss relative to his expectations (in terms of income+health) when Chloë chooses W rather than

[8] We don't include the advised clients' payoff in the game; we could, but they would be similar to Doug's and the inclusion wouldn't change what we are about to say much.

H.[9] If θ_C is large enough, this p-game has multiple equilibria, distinguished by different values of p:

- First, we have an equilibrium with contagion (for any θ_C): Chloë goes to work and Doug anticipates that so $p = 0$. Note that Chloë is optimizing: Her utility from choice W equals $1+h-\theta_C \cdot 0 \cdot (2-y-h) = 1+h$, while her utility from choice H would equals $y + h < 1 + h$.

- Second, for large enough θ_C, we have a stay-at-home equilibrium: Chloë chooses H and Doug anticipates that so $p = 1$. Chloë's utility from H equals $y + h$, while her utility from choice W would equal $1 + h - \theta_C \cdot 1 \cdot (2 - y - h)$, which is lower than $y + h$ for large enough θ_C.

- Third, there is a "mixed" equilibrium where $0 < p < 1$ and Chloë is indifferent between W and H.[10]

Several implications are noteworthy. First, the existence of multiple and belief-dependent (via p) equilibria suggest a way that public policy based on recommendations, or even moral suasion, may be useful.[11] A public health authority could say "please play the second rather than the first equilibrium," or "we expect everyone with fever to stay at home." If the public (including Chloë & Doug) take such messages to heart, people would play accordingly. Second, if the analysis had neglected health, Doug's loss $p(2 - y - h)$ would have been miscalculated as $p(1 - y)$, since h would not have made it into the expression of his loss. This would affect the conclusions regarding what constitues a "large enough θ_C, " with implications as regards the viability and nature of the latter two equilibria. Third, people may have misconceptions about parameters like y and h. Suppose that y and h are, in fact, low numbers (as health records may reveal), but that Chloë, somehow (and after all this

[9] $[p(1 + 1) + (1 - p)(y + h)] - (y + h) = p(2 - y - h)$

[10] $y + h = 1 + h - \theta_C \cdot p(2 - y - h)$ implies $p = \frac{1-y}{\theta_C(2-y-h)}$.

[11] This issue ties in with discussions about how pre-play communication more broadly affects play. See , e.g., Charness & Dufwenberg (2006), Dufwenberg, Gaechter & Hennig-Schmidt (2011), and Crawford (2016).

is a new disease that most people know almost nothing about), believes that y and h are fairly high. In that case, even if p is high, Chloë might choose W rather than S, since $p(2 - y - h)$ would appear to Chloë to be lower than is true. Again, there is room for public policy, this time announcements regarding the size of y and h, to change behavior and expectations (in this case, p).

Guilt & masks or vaccinations The logic of the Chloë & Doug example extends to many settings where the issue would be whether Chloë should wear a mask, or get vaccinated, rather than self-isolate. However, the typical setting where masks or vaccinations are chosen tends to be symmetric, with many decision makers acting simultaneously. While guilt can still be relevant, another form of belief-dependent motivation called "reciprocity" is perhaps even more plausible in such settings. We therefore postpone our main focus on masks or vaccination till section 4, our section of reciprocity.

Fears & bears In early 2020, as COVID-19 started to spread, people eventually came to realize that a major pandemic was developing. Many became fearful; in the US, the scare spread more broadly around the end of February. Starting then, and throughout the next month, the stock market crashed. We use PGT to shed light on why this short but extreme bear market developed.

Psychologists and others document (i) that people become fearful when, unexpectedly, they perceive increased "danger," and (ii) that an important consequence is that people become extremely averse to risk.[12] Andersson (2021) presents a formal approach to modeling (i) and (ii), which is PGT-based. We apply/extend her ideas to shed light on the crash of March 2020.

Consider Emma, who has considerable funds in a 401K account, most of it in equity mutual funds. Each day she has a choice to either remain invested (R) in the market, or to liquidate (L) to get cash. A highly stylized way to

[12]See, e.g., Lerner & Keltner (2001) and Wang & Young (2020).

describe her daily choice problem would be via the following game-form and (identical) game, where we normalize Emma's income to be 1 if she liquidates and where $w \geq 0$ is determined at random.

$$F_4 = G_4$$

So far, Emma always chose R. We can rationalize this if her beliefs across values of w give sufficient weights to high values that she is willing to take the risk.[13] However, the payoffs in game G_4 reflect monetary payoffs only, which would be an adequate representation if Emma were always healthy and never stopped to worry about her health. However, come late February 2020, that all changed. Emma read an article about shortage of ventilators in Lombardy, and the journalist argued that the US would soon be in similar trouble. Emma panicked, thought she might die! Her mindset changed, and the game-form is now better modeled via $F_4^{'}$ than F_4:

$$F_4^{'}$$

Before the pandemic. Emma acted as if her health was perfect (say, $h = 1$); we simply left that constant out of the picture in F_4.[14] Ponder Emma's outlook following chance's initial choice of P (=pandemic). Her choice problem in $F_4^{'}$ differs from that in F_4 in several ways. First, she is now aware that the contingency represented by choice P was possible. We interpret ε as the probability with which pandemics occur, as perceived by

[13] This sentence informally involves STEP 2 from section 2. More formally, let $u_E(w)$ be Emma's utility of wealth w, while Emma's beliefs are given by the density $p_E(w)$. In the past, apparently, $\int_0^\infty p_E(w) \cdot u_E(w) \cdot dw \geq 1$.

[14] Brandt & Gardner (2000, p.712) explain that in "the early 20th century, infectious diseases predominated as the principal causes of death" but "by midcentury, the relative contribution of infections to the burden of disease in the United States had declined precipitously," and Emma's pre-COVID mindset is consistent with the latter record. Post-COVID, a focus on the effects of infectious diseases and contagion has emerged again, exacerbated by the extent of international contact and the effects of methods of decreasing viral transmission on economies, such as changes in work, educational and public activities. Thus a new concern about health risks has been introduced to the public awareness.

Emma, and assume that this is a small but strictly positive number, which, however, the pre-pandemic incarnation of Emma didn't dwell on. Second, post-pandemic, Emma has become aware of her health, and her payoffs are now recorded as money-and-health pairs, with $h < 1$, lower than perfect health, since Emma suddenly thought she might die. Third, Emma started thinking about how the pandemic might affect the value of stocks, either because the profitability of firms might change in a pandemic, or because of how stock market participants might choose to trade. This changed the distribution over w's that is relevant to her choice.

The move from F_4 to $F_4^{'}$, and the three modifications described in the previous paragraph, are, as regards the methodology described in section 2, concerned with Step 1. A fourth modification occurs as we consider Step 2. Namely, following observations (i) and (ii) above, Emma's utility function changes. First, following (i), if h is low enough, then the pandemic has made Emma fearful. Anderson assumes that a big enough increase in perceived "danger," which is the probability-weighted evaluation of really bad outcomes, causes fear. Andersson does not focus on health outcomes but rather just monetary payoffs, but her key idea can be easily extended and we do so here. Formally, Emma's initially expected health was equal to 1 (she took "perfect health" for granted), but once she is pandemic-aware (as seen via $F_4^{'}$) her expected health dropped to $h < 1$. If h is low enough, the difference, i.e. $1 - h$, may be large enough to trigger fear.[15] Second, following (ii), Emma becomes very risk averse. We follow Anderson and model extreme risk aversion in an extreme way; she will evaluate lotteries by their worst possible outcomes, regardless of probabilities. If we take our previous assumption that $w \geq 0$ to mean that $w = 0$ is the worst possible outcome, then we get p-game $G_4^{'}$, where payoffs are written as $w + h$.[16] and

[15] Emma may be fearful even if she is initially aware that a pandemic may occur. In that case, here initially expected health equals $(1 - \varepsilon) \cdot 1 + \varepsilon \cdot h$, while her expected health once the pandemic occurred is h. If the difference – $[(1 - \varepsilon) \cdot 1 + \varepsilon \cdot h] - h$ is large enough, which it may be if h and ε are small enough, fear will be triggered.

[16] $G_4^{'}$ is a p-game in the sense that the described payoff depend on ε (which is a belief

Emma will liquidate her portfolio of assets (since $1 + h > 0 + h$).

$$G_4'$$

If many people are like Emma, we get an economy-wide panic sale of shares in mutual funds, a firesale of stock, and a crash on Wall Street.

Baby maybe? Fear may impact other decisions than pension savings. For example, consider the decision to have a child. Parents are altruistic and care for the well-being of their offspring, and they worry about the future since the overall life-outcome of a child is uncertain. In the midst of a pandemic, that outlook may be affected in two ways. First, the probability distribution over life-outcome may shift in negative direction (e.g., infants may be more likely to get the disease and suffer). Second, parents may be in the grip of fear, for the reasons discussed in the previous section. Each effect suggests that birthrates will drop.[17] As regards modeling, the spirit of the analysis in the previous part, surrounding G_4', carries over, if one reinterprets $w \geq 0$ to concern a child's well-being rather than a pension savers' wealth. We leave details for the reader.

Frustration, anger, blame & aggression The "frustration-aggression hypothesis" is an established notion in psychology, since Dollard et al. (1939).[18] It says that people get frustrated when they are unexpectedly denied things they care about, whereupon they tend to get aggressive, possibly in particular toward persons whom they blame. Battigalli, Dufwenberg & Smith

of Emma's) in the sense that the utilities will be as given iff ε is low enough.

[17] This prediction is actually reflected in U.S. data: In December of 2020 there were 7.66% fewer births than in December of 2000. January 2021 births were down 9.41% compared with January 2020. The US Census Bureau (accessed Dec. 19, 2021) reports that the "winter decrease in births may have been prompted by couples who consciously chose to delay having children amid the uncertainty of the pandemic. It may also have been influences by stress of limited physical interaction with a sexual partner."

[18] See also, e.g., Averill (1982), Berkowitz (1989), and Potegal, Spielberger & Stemmler (2010).

(2019) (BDS) develop a formal approach, which is PGT-based due to frustration being anchored in beliefs that determine what is unexpected. BDS discuss various ways that aggression gets manifest, depending on a variety of potentially relevant notions of blame.

To illustrate the spirit of the issues involved, imagine for a moment that Fred and his wife Gwen were customers in a bar and that a waiter drops a large glass of Irish coffee in Fred's lap. With whom might Fred get angry? Could it be Gwen, who is innocent (except that maybe Fred would shout at her that she has lousy taste in bar selection)? Or would it be the waiter? If so, would it matter whether that waiter dropped the cup by mistake, or whether he did in on purpose (or knowingly to some degree, say by running around in the bar too quickly, trying to keep guests happy, in order to secure good tips, but then also accepting some risk of dropping things)? BDS present models that reflect these possibilities.[19] They focus on the case where frustration is anchored in unexpected losses of money, but it makes sense to expand that idea to clean pants, or, as will be our next example, health.

Consider the following scenario with two "periods." In period 1, COVID-19 starts to spread in Wuhan and Lombardy. People start to worry about global spread and many decision makers (politicians, epidemiologists, business owners, ordinary folks, etc) do stuff (order lockdowns, recommend social distancing, ignore mask mandates, space tables, cancel vacations). Now imagine (as a guy called Ian does) that as a result of all of this, the spread of COVID-19 in the U.S. could be either "limited" or "extensive." Assume that, at the end of period 1, there is extensive spread. In period 2, Ian observes this, although he cannot observe the specific choices of all those decision makers we mentioned. Assume that Ian is frustrated, because he didn't expect the spread of disease and he is denied something he cares about. Namely, Ian's expected health suddenly dropped. He is afraid he might die.[20] According

[19]BDS avoid taking a stand which possibility is most empirically relevant, partly deferring such inquiry to future research but partly also suggesting that the answer may depend on circimstances (e.g., how many Irish coffees Fred already had drunk).

[20]The source of Ian's frustration could also be loss of income, if he were laid off because

to the frustration-aggression hypothesis, this may trigger aggression.

What will Ian do in period 2? To approach that question we need to specify Ian's options. Assume that Ian will decide on two issues: First, he will vote for one of two presidential candidates, A the incumbent, or B, the challenger. Second, he will decide whether or not to engage in domestic violence towards his wife Jen. The structure of the situation can be sketched as follows (with Ian choosing both row and column in the subgame following the arrow):

$$F_5$$

Despite the assumptions we made about period 2, F_5 is an incompletely specified game tree because we haven't pinpointed the structure of period 1. In F_5 we merely wrote "period 1," and, as indicated, what goes on in period 1 is something so complicated that it defies comprehensive exact modeling. One way to nevertheless engage in economic analysis would be to simplify period 1, and describe it in some simpler way. For example, one might assume that each of three players – the incumbent A, a chief epidemiologist called C, and a president of another country called D – simultaneously choose R or W ("right" or "wrong"). Assume that if all three were to choose R, then the spread of COVID-19 in the U.S. would be limited while if at least one of them choose W the spread would be extensive. One could then go on and analyze what choice that Ian would make. Recall, he is frustrated facing an unexpected drop of expected health. What he will do depends on how he deals with blame, in a fashion analogous to what we said about Fred in the spilling-of-Irish-coffee example. If Ian just wants to vent his anger, perhaps his wife, Jen, makes for an easy and convenient target? This seems senseless – unlike A, C, or D – Jen had no direct impact on Ian's frustration. However, maybe Ian doesn't care. In fact, there is evidence that domestic violence has risen during the pandemic; Ian beating Jen could be consistent with that

his employer went bankrupt when the pandemic hit.

pattern.[21] But is also possible that Fred has a more nuanced approach to aggression, that he only goes after others whom he deem responsible. He would then make guesses about the behavior of A, C, and D. Ian may not have been told who chose W, but he may form beliefs, and then go after someone accordingly. For example, if he believed that A chose W then he might vote for B. If he believed that C chose W then he might vote for A if he believed that C is a member of the same party as B. If he believed that D chose W, then he might vote for whatever presidential candidate is taken to be most likely to impose sanctions on D's country. There are many possibilites. However, Jen would not be the target.

BDS' model could be used to conduct an analysis along the lines just hinted at, and this analysis would convert game form F_5 into some psychological game G_5 (with formulas replacing α, β, γ, and δ). We would like to point out a limitation. While BDS have a fairly nuanced discussion of blame, they do not explicitly consider scapegoating, i.e., biased or factually incorrect attribution of responsibility for some bad outcome. As exemplified by the specific assumptions described in the previous paragraph, BDS' analysis involves given p-games. The players' attribution of blame is based on a correct interpretation of the structure of those p-games. In that sense, players cannot be "too wrong" in regards to whom they blame. This is a good thing in the sense that the conclusions will be consistent with the specific modeling assumptions that have been made, but it may be restrictive in the sense that those assumptions may not be the right ones to capture the mindset of all decision makers. We do not say this as something critical about explicit modeling, but rather as a reflection on how hard it may be to distill something as complicated as "period 1" down to a specific part of a mathematical structure.

[21] The pattern would be reminiscent of Card & Dahl's (2011) finding that the police get more reports of domestic abuse when when local football teams favored to win lose.

Scapegoating Take that thought (regarding F_5 and G_5) one step further, such that we can give a comment on the issue of scapegoating. Think of F_5 not as the starting point of describing the world, but rather as an attempt to structure the thought processes and interaction between a smaller set of decision makers. In fact, let's limit attention to the thought processes and actions on the one individual Ian! Think of F_5 as describing his mindset. This now would allow for the consideration that he may think of "period 1" differently than would some other person (like Knut or Leah). For example, Ian may be prone to some extreme conspiracy theory which makes some person X the culprit who caused the pandemic, and then, in period 2, go after X, even if most folks would say that the mindset was crazy.

Comparison with Wang et al. Our outlook in this section has been to take emotions for granted, and to then explore how this affects behavior, health, and economic outcomes. We have not taken a stand on whether emotions are good or bad in and of themselves, unlike a recent study by Wang et al. (2021). These authors (389 of them!) argue that the COVID-19 pandemic has lead to "heightened levels of negative emotion, which ... contribute to a number of negative psychological, behavioral and health consequences." They then present evidence from a multi-country study that a policy of "reappraisal interventions" intended to change "how one thinks about a situation with the goal of influencing one's emotional response" may "increase psychological resilience" (see p. 1089).[22] From our PGT-based perspective we may add that such reappraisal techniques may have behavioral consequences that extend beyond emotion-regulation. For example, consider our above example with "fears and bears," and suppose that fear is largely avoided by use of an intervention. As a consequence, the raison-d'etre of a fire sale of stock that

[22] For example, one form of reappraisal is "repurposing," or "focusing on a potentially positive outcome that could come from the current situation in a way that changes the emotional response to it." Wang et al. give the example of saying that the COVID-19 "situation is helping us realize the importance of meaningful social connections" (p. 1090).

we described will evaporate, so there is no reason to predict that there will be a crash on Wall Street.[23]

4 Reciprocity

A player who is motivated by reciprocity wants to be kind to a person who is kind to her or him, and unkind to whoever is unkind. Scholars in many fields have argued that related forms of motivation are commonplace.[24] In a seminal contribution, Rabin (1993) showed that formal modeling plausibly requires tools of PGT, and Dufwenberg & Kirchsteiger (D&K) (2004) further develop the approach and we will work with D&K's model here.[25] Let us jump right in and examine how reciprocity may shape behavior in a pandemic. We postpone general broader remarks about the nature of reciprocity until later in the section.

Face masks Wearing a mask involves personal costs (e.g., making it harder to breathe or communicate) as well as personal benefits (e.g., a reduced risk of catching COVID-19). Masks also conveys benefits to *others*, who are

[23]While this example illustrates, and Wang et al.'s main outlook presumes, that negative emotions harm individuals, one may be wise to not take that for granted in all situations. See, e.g., Haidt (2012, pp. 52-56) for s discussion of how "beginning in the 1980s" psychologists have increasingy recognized that emotion often help cognition. It seems conceivable that reappraisal interventions in some setting may steer individuals away from modes of information processing that may be helpful.

[24]For early discussions in anthropology, sociology, social psychology, biology, and economics, see (respectively) Mauss (1954), Gouldner (1960), Goranson & Berkowitz (1966), Trivers (1971), and Akerlof (1982). Fehr & Gächter (2000, p. 159) reproduce a 13th century quote from the Edda that shows how people thought about reciprocity much earlier than that: "A man ought to be a friend to his friend and repay gift with gift. People should meet smiles with smiles and lies with treachery." Dufwenberg, Smith & Van Essen (2013, Section III) give examples from popular culture, business, and experiments. Sobel (2005) offers a broad critical discussion.

[25]Reciprocity theory represents the first systematic application of PGT to a general class of games. Rabin restricted attention to two-player simultaneous-move games. D&K (2004) extended the ideas to a larger class of games, allowing for arbitrary number of players and sequential moves. D&K (2019) compare the approaches in detail, and give further related references.

protected as well. Consider two individuals – Max & Nora – who meet, say, in a grocery store. Just before entering the store, each of them makes a choice whether or not to mask up. Assume that, for each of them, the own cost of masking up is $c > 0$, the own benefit is $b > 0$, and the benefit to the other party is $x > 0$ ("x" for externality). Game form F_6 describes the situation:

$$F_6 = G_6$$

If the players were "selfish," meaning that they care only about their own personal costs and benefits, then we would get a game G_6 that looks just like F_6. In this case, a selfish player would voluntarily wear a mask; "mask up" is a dominant strategy. To make the problem more interesting, and in many settings perhaps more realistic, assume for now instead that $b > c$. In this case, a selfish individual would choose "no mask." Let us also assume that $b + x > c$, so that the total benefit generated if a player masks up exceeds the cost. The situation we hav**e c**reated resembles the picture emerging from much public debate, where it is argued that everyone would be better off if they were vaccinated and it is taken as a problem that many individuals do not want to do so. Given the assumptions made, G_6 has the structure of a prisoners' dilemma. For example, if $c = 3 > 2 = b = x$, then we get a game-form with the same payoff structure as F_2 and a game with the same utility structure as G_2.

It is helpful to focus on a specific example, so let's keep the assumption that $c = 3 > 2 = b = x$. Rather than assume that the players are selfish, however, let us assume that they are motivated by reciprocity. Let G_6' be the resulting p-game. Rather than try to draw a figure of G_6', because the payoff expressions tend to get convoluted, we will explain what calculations that go into this p-game. Player i's utility can be written as a sum $\pi_i + \theta_i \cdot \kappa_{ij} \cdot \lambda_{iji}$, where π_i is the convenience+health payoff (reflected via $c = 3 > 2 = b = x$, and matching F_2), λ_{iji} is i's belief regarding how kind j is to i; κ_{ij} is how kind i is to j; and $\theta_i \geq 0$ is a parameter reflecting how much i cares for reciprocity (if $\theta_i = 0$ we have the special case where the answer is "not at all;" the utility structure would then be like in G_2). Let us first talk about κ_{ij} and λ_{iji} in the abstract, then calculate these numbers. κ_{ij} and λ_{iji} can be positive or negative, and the essence of reciprocity is captured, mathematically, via sign-matching incentives. If $\lambda_{iji} > 0$ then the reciprocity-part of i's payoff (i.e., $\theta_i \cdot \kappa_{ij} \cdot \lambda_{iji}$) is positive iff $\kappa_{ij} > 0$. If $\lambda_{iji} < 0$ then $\theta_i \cdot \kappa_{ij} \cdot \lambda_{iji}$ is positive iff $\kappa_{ij} < 0$. When i maximizes utility, i will trade off his concern for recirocity (i.e., $\theta_i \cdot \kappa_{ij} \cdot \lambda_{iji}$) with his convenience+health (i.e., π_i).

Specifically, in G_6', if i chooses "mask up" instead of "no mask" then he increases the other player j's health payoff by two units: j's payoff changes from -1 to 1 if j chooses "mask up," and j's payoff changes from 0 to 2 if j chooses "mask up. κ_{ij} is calculated as the difference between the health payoff that i believes that j gets, and the average between the maximum and the minimum that i believes that j could get that. It follows that $\kappa_{ij} = 1$ if i chooses "mask up" while i $\kappa_{ij} = -1$ if i chooses "no mask."[26]

We can now look for symmetric equilibria – a standard of behavior for player i and j, i.e., Max & Nora – such that each of them optimizes while holding correct beliefs about the behavior of the other. If the players care enough for reciprocity, i.e. if θ_i is high enough, then there are two such equilibria. First, it could be that they both "mask up." Each player's utility, using the calculations above, would be $\pi_i + \theta_i \cdot \kappa_{ij} \cdot \lambda_{iji} = 1 + \theta_i \cdot 1 \cdot 1 = 1 + \theta_i$, as opposed to what player would get if he deviated to choose "no mask" namely $\pi_i + \theta_i \cdot \kappa_{ij} \cdot \lambda_{iji} = 2 + \theta_i \cdot (-1 \cdot)1 = 2 - \theta_i$. This will be an equilbrium if there is no incentive to deviate, i.e. if $1 + \theta_i \geq 2 - \theta_i$, or $\theta_i \geq \frac{1}{2}$. Second, it could be that they both choose "no mask." Each player's utility would be $\pi_i + \theta_i \cdot \kappa_{ij} \cdot \lambda_{iji} = 0 + \theta_i \cdot (-1) \cdot (-1) = \theta_i$, as opposed to what player would get if he deviated to choose "mask up" namely $\pi_i + \theta_i \cdot \kappa_{ij} \cdot \lambda_{iji}$ $= -1 + \theta_i \cdot 1 \cdot (-1) = -1 - \theta_i$. Since $\theta_i > -1 - \theta_i$ for any $\theta_i \geq 0$, this second equilibrium is possible regardless of how much players care for reciprocity.

[26] The answer does not depend on i's belief in G_6': If i believes that j chooses "mask up" and i chooses "mask up" then $\kappa_{ij} = 1 - \frac{1}{2}(1 + (-1)) = 1$; if i believes that j chooses "no mask" and i chooses "mask up" then $\kappa_{ij} = 2 - \frac{1}{2}(2 + 0) = 1$; etc. As we discuss below, kindness would *not* be belief-deendent for other values of b, c, and x.

Reflect on these two patterns of equilibrium behavior. In the first case the two players are kind to each other, and they are happy that way because each of them thinks of the other as kind. The second case is one where the two players are unkind to each other, and each does their best because (i) they want to be unkind to their unkind co-player and (ii) they thereby also maximize the π_i-part of their utility (since $0 > -1$).

Which of the these equilibria is most relevant? We suggest that the answer may in part depend on *policy*! Equilibria do not emerge in a vacuum. Public debate and statements made by, e.g., public health officials or politicians, may shape citizens beliefs and behavior. There may be room for a policy that explains that people are likely to meet and that those encounters will look like G_6'. This may happen often, so G_6' will be played by many pairs of individuals. It may be explained and argued that the overall outcome is best for all if the first rather than the second equilibrium is played! Good policy may involve that people in public office carefully recommend to the public that they behave a certain way. If the public believes that many will follow the recommendations then all individuals will want to follow suit.

The policy insight of the previous paragraph is intuitive and it matches what many public officials do. We elucidate an underlying rationale, namely that people may be motivated by reciprocity.

Finally, we promised to return to the topic of why reciprocity theory is PGT-based. The reason is that kindness in general is a belief-dependent notion. G_6' actually did not illustrate that – see the related comment in footnote ... – and we chose the example that way to keep things simple. Small changes to the parameters b, c, and x would change that, e.g. if we replaced the x's in the top-left box with y's, and then assumed that $c = 3 > 2 = b \geq x \geq y > 1$ (interpretation: i's own mask protects an un-masked j more than a masked j). The resulting game form, call it F_6^*, still has the structure of a prisoners' dilemma. How kind i is choosing "mask up" depends on i's beliefs about j.[27] For more (richer) examples and more

[27]If i believes that j chooses "mask up" and i chooses "mask up" then $\kappa_{ij} = -1 + y -$

discussion, see D&K (2004) (e.g., their opening example).

Vaccinations Getting vaccinated involves personal costs (e.g., side effects) as well as personal benefits (reduced risk of catching disease). A vaccination also conveys benefits to *others*, to whom one is less likely to pass on a disease. To a large degree, the story now goes on analogously as for the above case of masks. All of the arguments we made above have counterparts. Reciprocity might have analogous relevance, substituting vaccinations for masks. However, we wish to point out that a few features may make the logic with vaccines differ from that with masks, depending on details of the situation one explores. Let us hint at some examples, and then develop one theme more fully:

First, the counterparts to parameters b, c, and x may differ, affecting how high the reciprocity sensitivity θ_i needs to be for an all-vax-up equilibrium (where players would be kind to another, per analogy with the previously described all-mask-up equilibrium).

Second, vaccination decisions are irreversible (to some degree). If a person is vaccinated (hence kind) on a Monday he or she will also be vaccinated (and still kind) also on Tuesday, and perhaps even several months out. This is unlike the case with masks, which may or may not be worn tomorrow; players' options remain open. This may have consequences for behavior by persons motivated by reciprocity, as well as the impact of regulations.[28]

Third, unlike with masks, one player can not so easily tell what strategy another player adopts. While one can (usually) tell if someone else wears a mask, it is harder to know if someone else is vaccinated. If one asks them, they may lie. If one interacts with them, one may not know whether of not

$\frac{1}{2}((-1+y)+(-1)) = \frac{y}{2}$; if i believes that j chooses "no mask" and i chooses "mask up" then $\kappa_{ij} = x - \frac{1}{2}(x+0) = \frac{x}{2}$; etc. Note that $\frac{y}{2} = \frac{x}{2}$ iff $y = x$.

[28]In 2021 the Arizona legislature passed a law making mask and vaccine mandates illegal. The law was to go in effect in September that year. Some Tucson schools,unhappy with the ruling, imposes vaccine mandate rules as of August, thereby forcing students who comply to be vaccinated also come September. Note that the same gambit would not be available as regards masks.

they are vaccinated (and thus kind), which will matter to (and potentially affect the behavior of) someone motivated by reciprocity. This is the theme that we will now expand on further, and we do this under a new title:

Face masks, vaccinations, and a super-spreader Dr. Ola, the likable Dean of the College of Eco-Health (CoEH) was approached and recruited away by another far-away college (CoFA). In July 2021, amidst the COVID pandemic, colleagues at CoEH threw a farewell cocktail party. People were generally sad to see Dr. Ola go, and grateful for his good work over the years, so many showed up. Most were vaccinated, although no one could know for sure about anyone else in particular (compare the "third" item above). Every partygoer had a mask in their pocket. Most everyone had anticipated putting it on. Many had mostly hunkered down during the pandemic. Some had hardly been outside their home for a year-and-a-half. All of them were worried about the recent spread of "the delta variant."

The party started. In the beginning only few had come. They kept their distance and no one took the initiative to put on a mask. The gathering kept growing, everyone was happy, but many were also getting uneasy. People looked at others to see if they put on their masks, but no one did. The party grew larger and boisterous. Everyone loved the atmosphere but many got increasingly worried. Drinks were served and people were hugging and giving speeches. *No one put on their mask*!

What happened and why? Here is a reciprocity-based theory which we suggest can provide a plausible explanation. A crucial feature concerns the non-observability of vaccination-status – the "third" item above:

Let's ask ourselves: *Is it an equilibrium that no one wears a mask at the party?* The answer would likely be no if people were only concerned about their health. The event, as we have described it, has all the characteristics of a potential super-spreader. Hence, this would seem like a situation where $b > c$. Anyone who cares enough to have a mask in their pocket would have to believe that it makes sense to remove the mask from that pocket and put it on the face.

Suppose instead that people are motivated by reciprocity. Will the answer change? At first glance, one may be inclined to say no. If a person puts on a mask then he or she would be reducing their risk of others contracting the disease – clearly this is kind, and it might seem that people would want to be kind to their friends at the party. However, and now it gets subtle, recall that people motivated by reciprocity react to the *perception of how kind others are*, i.e., player j wishes to tailor κ_{ji} – i's kindness to j – to λ_{jij} which is j's belief of how kind i is to j. Now look at the situation from i's point of view, and consider that there is a future and that j and others may do stuff to i (e.g., agree to have lunch with i, or not recommend i for a raise or promotion).[29] It is clear that i needs to consider how *others* (including j) will interpret i's behavior should i put on a mask.

We propose that there are two possible such interpretations, which depend not only on i's decision to wear a mask but also on j's guess regarding whether or not i is vaccinated: First, j may reason as follows: "i is surely vaccinated and by now also masking-up i is clearly kind to me." Second, j may reason as follows: "Oops, i is the only one masking-up here; I guess that this must mean that i is *not* vaccinated. What a terrible thing to do, to attend this party despite not being vaccinated; that's very *unkind* of i."

Both of these modes of reasoning seems possible, and reciprocity theory would not by itself pin down which form of reasoning would apply. If everyone (and not only j) would reason in analogy with the second interpretation, then everyone (and not only i) would have a strong incentive *not* to put on the mask. Everyone would hate to be regarded as the surely unvaccinated person who crashed the party, because everyone would worry that others wouldn't

[29] Formally, according to D&K's original theory, for reciprocity to kick in this way, with resepect to a future (with lunches and raises), on would have to explicitly model that future within the game. However, it is very natural to accept the idea that a player would not want to be kind to folks bound to judge him as unkind, because of such future consideration. See Dufwenberg et al. (2021) for theoretical and experimental work developing such an angle in a different setting.

treat them well in the future. That is, if people are motivated by reciprocity, and if the way that they come to evaluate behavior is as we describes, then *it can be an equilibrium that no one wears a mask at the party.*

We hasten to add that it is not the only equilibrium. If everyone wore a mask, and if everyone believed most everyone were vaccinated, then everyone would believe that the others were on balance kind, and this would also be an equilibrium. This illustrates a theme we touched on before, namely that policy may influence which equilibrium will be played. For example, if the group that organized the party would have said, in their invitation, that "we expect everyone to mask up," then it may seem likely that the all-mask-up equilibrium would be played.[30]

5 Image concerns

This form of motivation involves caring about others' opinions about oneself. Following B&D (2021), one may discern two varieties, depending on whether the opinions of others concern one's actions or one's traits. We develop one application of each sort.

The super-spreader, revisited Refer back to our superspreader example above. The *no-one-wears-a-mask* equilibrium that we described invoked reciprocity, and we referred to a strategic future (with lunches & raises affected by the mask-wearing decision). We may modify that story such that a similar outcome is supported by an alternative image-concern story, as follows:

Drop the assumption that players are motivated by reciprocity. Assume instead that players are motivated such that they like it when others believe that they are kind (a possibility suggested by D&K 2019, p. 228). Since kindness depends on a player's action (as well as that player's belief), this is a case where decision makers care about others' opinions regarding their

[30] Alternatively, an entrepreneurial party-goer may try to flip things as follows: Grab the mic and say: "Welcome to this super-spreader event. Our Dean, Dr. Ola, is leaving us for the CoFA. Dear Dr. Ola, we have a present for you: the delta variant!"

actions. It is now straightforward to check that the *no-one-wears-a-mask* pattern remains an equilibrium under these new assumptions. The only difference to the previous example is that what stops a player from putting on a mask is no longer a player's anticipation that others will treat him badly in the future, but rather that he simply likes being viewed as kind.

So, we have now told two, similar yet different, stories of why *no-one-wears-a-mask* may constitute equilibrium behavior at superspreader events. Both make sense. Arguably, the more ways that a particular pattern of behavior can be explained, the more likely the pattern could be empirically relevant. We conclude that there are good public health reasons to worry that cocktail parties may turn into superspreaders.

Polarization & vaccines During the COVID pandemic some people have chosen to not get vaccinated for reasons that others would call crazy. For example, some claim that they will not get vaccinated because they believe that the vaccines contain microchips that are used to track people down. We offer a potential explanation for this phenomenon, using a PGT-based utility that captures that players care about others' opinions of their traits.

Specifically, suppose that the world is full of two different "types" of people; call them *red* and *blue*. Assume that red and blue folks support different political ideologies, but physically *they look the same*. Unless a player can somehow reveal her or his type, others could not be sure whether the player is red or blue.

Now suppose that people, red as well as blue, care about two things: (i) their health and (ii) how strongly folks of their own type to believe that they are that type.[31] Specifically, assume that a red [blue] player i's utility equals $h + p$, where h is i's health and p is the probability that other red

[31] Assumption (ii) is reminiscent of ideas considered by Bernheim (1994); see in particular p. 863 where he discusses how individuals may "place more weight on the opinions of those more like themselves." Of course, people would plausibly also care about how much money they make, but since such material payoff are held constant and play no role in our example we do not specify them at all.

[blue] players on average assign to i being red [blue]. Since p reflects other players' beliefs, the presence of p in i's utility is what makes the formulation PGT-based.

Assume that a vaccinated player gets health $h = 1 - \varepsilon$ whereas an unvaccinated player gets health $h = 1 - \delta$, where ε and δ are probabilities of death and $0 < \varepsilon < \delta < 1$.

Now consider the following pattern of behavior, which we will prove constitutes an equilibrium: All blue players choose to get vaccinated. All red players choose not to get vaccinated (and instead say silly things about the microchips theory). First note that, given the described pattern of behavior, the proportion of blue types among the vaccinated is 1. The proportion of red types among the unvaccinated is also 1. If players anticipate this, it follows that $p = 1$ for all players.

The utility of blue types is then $h + p = (1 - \varepsilon) + 1 = 2 - \varepsilon$. Note that blue types optimize, since were they to instead not get vaccinated they would get utility $h + p = (1 - \delta) + 0 = 1 - \delta < 2 - \varepsilon$. The utility of red types is $h + p = (1 - \delta) + 1 = 2 - \delta$. Note also that red types optimize, since were they to instead get vaccinated they would get utility $h + p = (1 - \varepsilon) + 0 < 2 - \delta$.[32] Since both red and blue types do the best they can, given the behavior of everyone and the correct corresponding beliefs, we have an equilibrium.

In this equilibrium red types get a lower utility than blue types. As regards the image part of the utility – i.e., p – both types score as well as they can, since each enjoys $p = 1$. However, the health part h of the utility is lower for red types, who get $h = 1 - \delta$ rather than $h = 1 - \varepsilon > 1 - \delta$. Red types sacrifice their health knowingly and willingly, accepting some loss of health because, in their eyes, this is amply compensated by the image gain of being able to signal to the other reds that they are ilk. Reds may say that there are microchips in the vaccine, but there is little reason to believe

[32] Note that $(1 - \varepsilon) + 0 < 2 - \delta \iff \delta - \varepsilon < 1$, and that this inequality is indeed true since we have assumed that $0 < \varepsilon < \delta < 1$.

that they actually believe this.[33] What they really care about is not any microchips but rather their image.

6 Concluding remarks

The mathematical framework of psychological game theory (PGT() can be used to assess decision makers' behavior during a pandemic. The dimension of health concerns adds to the considerations of motivations and utilities. Peoples' behaviors concerning the use of NPIs, vaccinations, and the contribution of group identities to health behavior may be better understood using PGT. Leaders and policy-makers may be able to change the games people play if the rules are better understood.

Emotions, reciprocity, and image concerns – the categories of motivations explored in the previous sections are those that most work based on PGT dealt with. These categories do not exhaust the forms of motivation that can be explored using PGT, and which may play a role in a pandemic. PGT-related themes that we have not covered include belief-dependent loss aversion, self-esteem, social norms, and motivated beliefs. We will not define these notions; refer to B&D's (2021, Section 5) for a discussion and relevant references. We propose that exploring related examples would be worthwhile, but leave such exercises for future work.

Michie & West (2021) suggest that "to address the continuing threat from COVID-19 and future pandemics ... will require collaboration among behavioral, social, biomedical, public-health and clinical scientists" (p. 749). Our team – a behavioral game-theorist and an obstetrician & gynecologist – have taken up the mantle. As regards methods, of course, many may be conceivable. Ours has been the mathematical framework of PGT. We hope that our readers have enjoyed the ride and that they will be inspired to do follow-up work.

[33] If this is true, then it would also suggest that they have an incentive to get vaccinated but not tell anyone about it (and also lie and claim that they did not).

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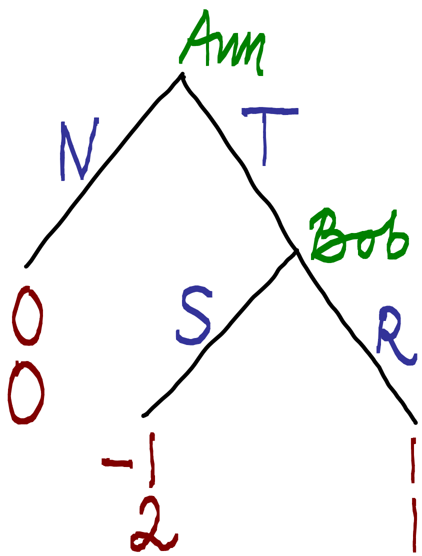
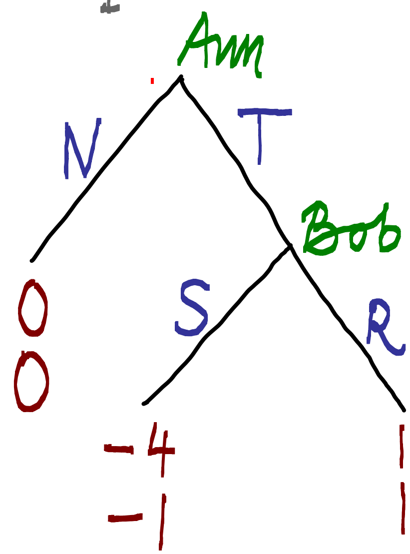
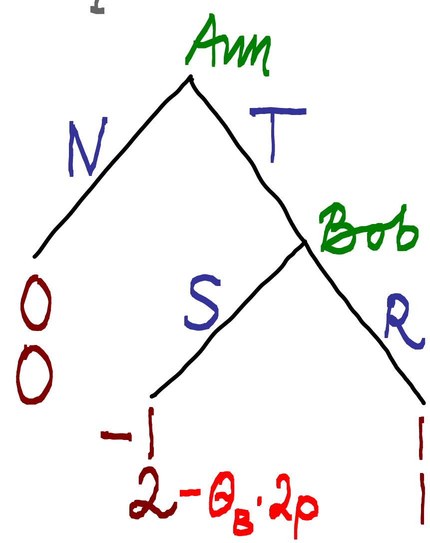
$F_1 = G_1$


Ann
N
T
Bob
S
R
0
0
-1
2
1
1

G_1'


Ann
N
T
Bob
S
R
0
0
-4
-1
1
1

G_1''

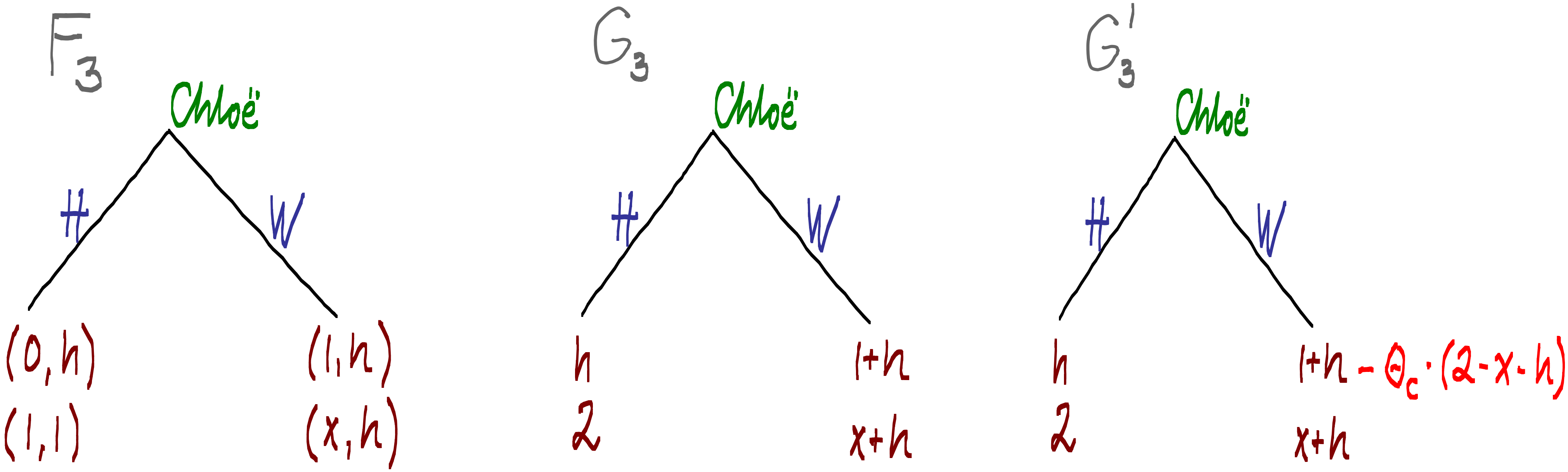

Ann
N
T
Bob
S
R
0
0
-1
2-θB·2p
1
1

$F_2 = G_2$

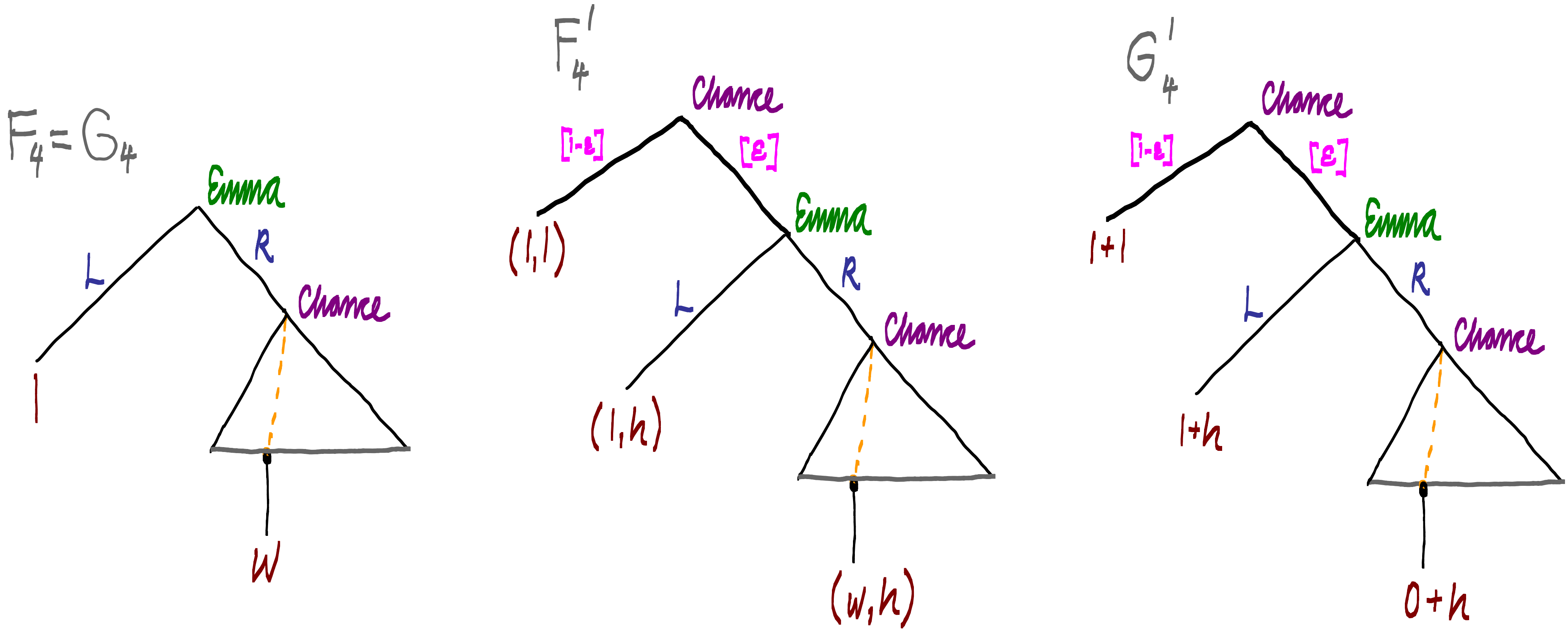
Ann \ Bob	C	D
C	1, 1	-1, 2
D	2, -1	0, 0

G_2'

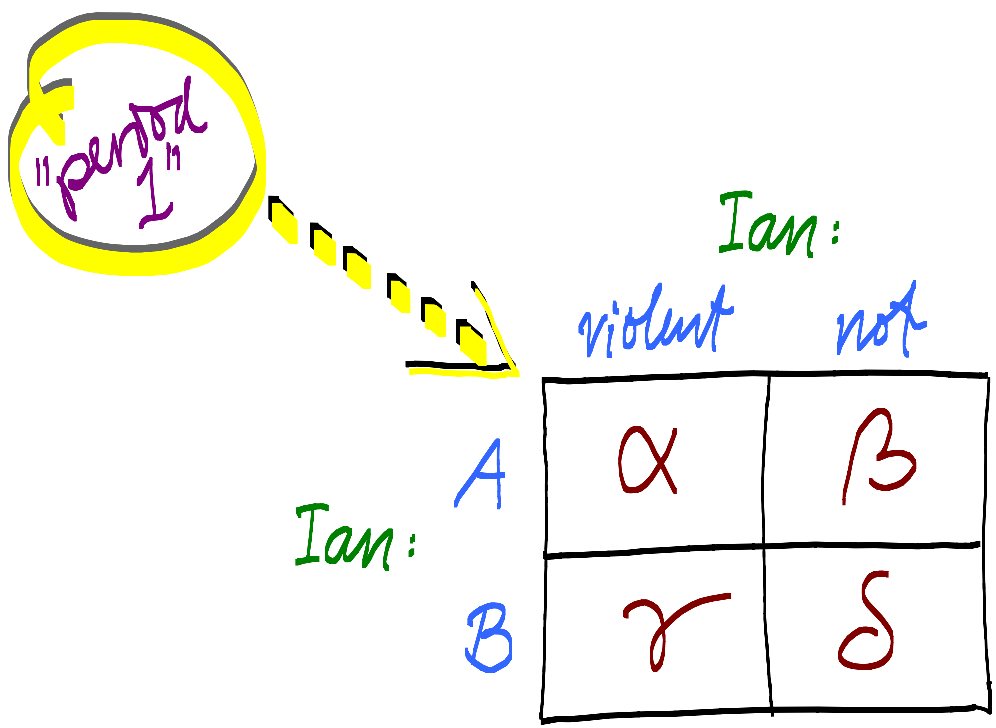
Ann \ Bob	C	D
C	1, 1	-4, -1
D	-1, -4	0, 0,



F_3
Chloë
H
W
(0, h)
(1, 1)
(1, h)
(x, h)
G_3
Chloë
H
W
h
2
1+h
x+h
G_3'
Chloë
H
W
h
2
1+h − $\Theta_c \cdot (2 - x - h)$
x+h


$F_4 = G_4$
Emma
L
R
Chance
1
w
F'_4
Chance
[1-ε]
[ε]
(1,1)
Emma
L
R
(1,h)
Chance
(w,h)
G'_4
Chance
[1-ε]
[ε]
1+1
Emma
L
R
1+h
Chance
0+h

F_5



$F_6 = G_6$

Nova:

Max:	mask up	no mask
mask up	$b-c+x$, $b-c+x$	$b-c$, x
no mask	x, $b-c$	0, 0

F_6'

Nova:

Max:	mask up	no mask
mask up	$-1+x$, $-1+x$	-1, x
no mask	x, -1	0, 0

F_6^*

Nova:

Max:	mask up	no mask
mask up	$-1+y$, $-1+y$	-1, x
no mask	x, -1	0, 0