Supplementary materials for “The policy consequences of cascade blindness”

Detailed methods and results

**Study 1**

*Participants*. 46 participants were recruited through Amazon.com's Mechanical Turk platform (for a discussion on the validity of results from this platform, see Paolacci, Chandler, & Ipeirotis, 2010) and participated in the study for monetary compensation.

*Design and procedure.* Participants were placed in the role of a power company CEO and were tasked with determining how much power to produce in each of 10 cities with the aim of maximizing profits. Participants were informed of the cost of producing power, the price at which power would be sold, and the consequences of undersupplying a given city with power. Participants were told:

It costs $5 to generate a Megawatt Hour of power, and your customers pay you $7 per Megawatt Hour of power. That means that for every Megawatt Hour that is used, you make a $2 profit! However, any power that you generate that is NOT used still costs you $5, and since you didn’t sell it, you’ll take a $5 loss.[[1]](#footnote-1)

Unfortunately, if the demand in a given city exceeds the amount of power that the city’s power plant has generated for that day, then the power plant will not be able to handle the load, and the power distributor will crash. When this happens, you are still stuck with the costs of power generation, but no power will be distributed in that city, meaning you don’t make any income from that city! Moreover, it costs $5,000 to fix a broken power distributor.

Half of the participants were randomly assigned to be in an independent-plants condition, and were informed:

If you happen to underestimate demand in a particular city, and as a result the power distributor in that city crashes, your remaining functional power plants will be completely unaffected. Although you will not earn any income from cities where the power distributors have crashed, the remaining functional power plants will still provide power to their own cities, and you can potentially make enough profits in those other cities to offset some of the losses from failed power plants.

The remaining participants were assigned to a coupled-plants condition, and were informed:

If you happen to underestimate demand in a particular city, and as a result the power distributor in that city crashes, your remaining functioning power plants will pick up some of the unfilled demand. 20 percent of the demand from any crashed power plant will be reallocated to the functioning power plants from other cities (each of the functioning plants will take an equal share of that demand). This will increase the demand at all of your other plants, allowing you to sell power that would otherwise go unused – assuming those other plants have enough capacity to handle this increased demand. However if the functioning power plants do not have the capacity to handle the increased demand, they too will crash. In such a situation, the Coupling Distributor would then reallocate 20 percent of the demand from those (newly crashed) plants to the remaining functioning plants. This process will continue until no additional functioning plants crash from the added load.

Participants in both conditions were given a fictional back-story to increase their motivation and interest in the game:

There’s one more thing you should know. The President of Evil Inc., Johnny Evil, announced in his morning press release that he plans to engage in a hostile takeover our company! If he’s successful, he will fire all of your employees (including you!) and tear down your power plants for scrap metal.

You can’t let that happen! Evil Inc. has started raising money for the hostile takeover bid, and you need to have enough money on hand to fend him off when he tries to buy a controlling stake in the company. You don’t know exactly how many days from now Johnny Evil will try to enact his evil plan, nor exactly how much money you will need to prevent Evil Inc. from being successful, so it is best to make as much money as you can, as quickly as possible.

Participants were then given a comprehension quiz testing their understanding of the setup and the within-game compensation scheme consisting of questions such as: “If you create 1000 Megawatt hours of power, and the demand is 200 Megawatt hours, how much money will you gain or lose?” If participants missed a question, they were required to re-read the experimental directions until they achieved a perfect score on the quiz.

After passing the comprehension quiz, participants completed 15 trials, called "days" within the game. At the start of each trial, participants were shown their current cumulative cash balance (starting at $150,000), a reminder of the cost of producing power, and an array of pictures representing 10 power plants, each associated with a different city (see Figure 2 in main text). Cumulative cash balances were allowed to go negative in case participants were very unsuccessful in early trials of the game.

An expected demand distribution was randomly generated for each city such that midpoint of each city's demand distribution was independently sampled from a normal distribution with a mean of 1600 Megawatt Hours and standard deviation of 100 Megawatt Hours. Each city was labeled with the expected demand range, which participants had been informed represented the width of a roughly bell-shaped distribution for power demand in that city:

The true demand for a city virtually always falls within the range that the analysts have identified. On average, the demand will fall right at the midpoint of the range that the analysts have identified; half of the time, the actual demand will be above that midpoint, and half of the time the actual demand will be below the midpoint. Two thirds of the time the demand will be within 200 Megawatt Hours of the midpoint, and 95 percent of the time the true demand will fall within 400 Megawatt Hours of the midpoint.

Participants entered into text boxes the amount of power that they wished to produce in each city. Actual demand was then determined based on the distributions that participants had been provided. In particular, initial demands for each city were sampled from normal distributions whose means matched the midpoint of each estimated demand range and whose standard deviations were 100 Megawatt Hours.

In the independent-plants condition, if a plant's power supply was at least as great as its city's demand, then the plant succeeded and supplied that amount of power. Otherwise the plant failed and supplied no power.

In the coupled-plants condition, plant failures were determined by the following algorithm:

1. Set each plant's available capacity to the amount selected by the participant.

2. Set each plant's load to equal the power demanded by its associated city.

3. Any plant whose load exceeds its available capacity fails and supplies no power.

4. 20 percent of the total unfilled demand from failed plants is divided equally among unfailed plants, adding to their load.

5. Steps 3 and 4 are repeated until no additional plants fail.

A results screen then showed overall income and expenses for that day, the actual demand for power in each city, and whether the power plant in each city could supply all the power that was asked of it. In the coupled-demand condition, power plant failures were animated, allowing participants to see when failures of some power plants caused further failures.

After trials 2, 5, 8, 11, and 13, participants were shown snippets of storyline text intended to increase their engagement in the game. (Example text: "News Flash: Protesters picketed outside of Evil Inc's headquarters yesterday chanting 'save our power plants' and 'don't take our power'. Despite the public pressure, Evil Inc. has not indicated that they will abandon their hostile takeover plans.")

*Results*. The data for five participants were not included in the analysis: one participant due to a computer recording error, two for providing invalid input, and two for failing to complete the study.

Participants in the independent condition earned an average total of $262,454, while participants in the coupled condition *lost* an average of $69,865 (t(40) = 2.241, p = .031)[[2]](#footnote-2). Part of the reason for this is that participants had fewer plants fail on average in the independent condition (x = .91) than in the coupled condition (x= 2.1) although this difference did not reach conventional levels of significance (t(40) = 1.9, p = .064). Importantly, total system failure happened 73 times in the coupled conditions, but only twice in the independent condition (chisquare(1, n = 75) = 67.21, p < . 001). In contrast, mid-range failures (i.e. 3 to 6 failures) happened 34 times in the independent condition, but never in the coupled condition.

**Study 2**

*Participants*. 307 participants were recruited through Amazon.com's Mechanical Turk platform and participated in the study for monetary compensation.

*Design and procedure.* Study 2 closely mimicked the design of Study 1, with two main differences: (1) some participants were provided with graphs showing how likely various levels of failure were for each choice of capacity (see Figure 4 in the main text for screenshots of the different conditions) and (2) to allow for real-time feedback, participants were asked to choose a single capacity level to be applied to all power plants on a given game day (trial). Each subject completed 10 trials. For simplicity, on each trial each city's power demand was drawn from the same normal distribution with standard deviation 1,000. To ensure that participants continued to respond to expected demand ranges, the mean of the distribution for power demand changed between trials as indicated in Table 1.

Table 1. Mean power demand for each game day (trial) of Study 2.

Trial Mean demand (kWh)

1 10000

2 9000

3 11000

4 11000

5 12000

6 10000

7 10000

8 8000

9 10000

10 11000

Capacity was set by moving an on-screen slider to positions that represented different levels of power generation. As participants in failure-graph conditions moved the slider, they were shown a histogram representing the probability distribution for the number of expected plant failures given the currently selected capacity. Participants in money-graph conditions were shown a histogram representing the probability distribution for expected net profits (or losses). Participants in no-graph conditions were not given any distributional information, and thus were forced to determine the likely outcome themselves (as in Study 1). Participants in graph conditions were given explanations in advance of how to read the graphs, such as the following:

To help you choose wisely, the company analysts will tell you in advance how likely each outcome is, given your choice of how much power to generate. For example, suppose that you have tentatively chosen to generate 3500 Mwh. A graph will be displayed that shows how likely various outcomes would be if you were to generate that amount of power:

In this case, you can read off the graph that it would be 60% likely that your net gain for the day would be about $40,000, 35% likely that your net gain for the day would be about $10,000, and so on.

As you move the slider to explore different choices of how much power to generate, the graph will update to display the chances of various outcomes given those choices.

Participants were randomly assigned to a condition in a 2 (independent vs. coupled) x 3 (no-graph, failure-graph, money graph) design.

The algorithm for determining plant failures was the same as Study 1 except that in coupled conditions, 12 percent rather than 20 percent of the total unfilled demand from failed plants was reallocated. This compensated for the fact that in a given trial, the expected demands between cities were more highly correlated in Study 2 than in Study 1, since in each Study 2 trial every city's demand was drawn from the same distribution.

No motivational snippets were displayed between rounds.

*Results*. Five participants were removed for failing to complete the experiment. An additional five participants were removed as outliers for having a rate of failure falling at least eight standard deviations from the mean[[3]](#footnote-3).

There were large differences in the amount of money earned across conditions. In the no-graph condition, participants in the coupled condition earned less over the course of the ten trials (x = $205,968) than participants in the independent condition (x = $628,962) and this difference was statistically significant (t(96) = 3.6, p < 01). Although participants across the board performed better in the failure graph condition, participants still earned less in the coupled condition (x = $563,323) than in the independent condition (x = $766,134) and this difference was also statistically reliable (t(97) = 2.1, p < .05). Participants performed even better in the money graph condition, and here the difference between the independent condition (x = $819,886) and the coupled condition (x = $802,155) had disappeared (t(97) = .21, p > .8). To make sense of this pattern, we ran a 2 (Coupling Level: Coupled vs. independent) x 3 (Graph Type: No graph vs. Failure Graph vs. Money Graph) ANOVA. There was a significant main effect for graph type (F(2,291) = 15.6, p < .001) a main effect of coupling level (F(1, 291) = 13.7, p < .001) and these main effects were qualified by a graph type x coupling level interaction (F(2, 291) = 4.1, p < .05).

This difference in performance by condition appeared to once again be driven by the number of plant failures. In the no graph condition, participants had more failures per trial in the coupled condition (x = 1.24) than in the independent condition (x = .81) and this difference was statistically significant (t(96) = 2.3, p < .05). In the failure graph condition, participants also had more failures in the coupled condition (x = .79 ) than in the independent condition (x = .51) which was marginally significant (t(96) = 1.7, p = .092). In the money graph condition participants had similar numbers of failures in the coupled (x = .45) and in the independent (.49) conditions (t(96) = .30, p > .7). Unsurprisingly given this pattern, when we ran a 2 (Coupling level: coupled vs. independent) x 3 (Graph type: no graph vs. failure graph vs. money graph) ANOVA[[4]](#footnote-4), we found a main effect for coupling (F(1,291) = 5.5, p < .05) , and a main effect for graph type (F(2,291) = 12.0, p < .001), although the interaction was not statistically reliable (F(2,291) = 2.1, p = .12).

**Study 3**

*Participants*. 118 participants were recruited through Amazon.com's Mechanical Turk platform and participated in the study for monetary compensation.

*Design and procedure.* Study 3 game play proceeded as in the independent no-graph and coupled no-graph conditions from Study 2, except that an incentive-compatible compensation scheme was introduced. The back story of the game was changed to make the "days" within the game independent, and no cumulative balances were reported. Participants were told:

Your real-world Mechanical Turk compensation depends on how you do within the game:

You start with a base compensation level of $10. You will be playing 10 rounds (called 'days' within the game). At the end of the game, we will randomly choose 1 of these ten 'days' from your game and increase or decrease your real-world compensation in proportion to your net within-the-game earnings on that day. 1000 game dollars translates into 1 cent in the real world.

For example, if on the randomly chosen game day you gained $70,000, your compensation will be increased by $0.70, so it would total $10.70.

Another example: If on the randomly chosen game day you lost $80,000, your compensation will be decreased to by $0.80, so it would total $9.20.

We will also impose a hard cap on the above formula, so that your overall compensation for participating in the whole experiment will never be greater than $17 or less than $3.

*Results*. The data from all participants was included in this analysis. Participants in the independent condition earned an average of $42,203 (in game money) per trial, while those in the coupled condition *lost* an average of $21,715 (in game money) per trial. A mixed model GLM with trial as a within-subject variable and condition as a between-subject variable showed this difference to be statistically reliable (F(1,1181) = 6.3, p < .05). This difference was driven by the number of plant failures, with participants in the coupled condition experiencing, on average, nearly twice as many failures (x = 1.7) as those in the independent condition (x = .83). As with earnings, a mixed model GLM with trial as a within subject variable and condition as a between subject variable revealed this difference to be statistically reliable (F(1,1181) = 274.7, p < .001)[[5]](#footnote-5).

Breaking down those failures, in the coupled condition there were 82 trials in which total system failure occurred (roughly 14% of trials) while in the independent condition total system failure never happened (chisquare (1, n = 82, p < .001)[[6]](#footnote-6). In contrast, mid-range failures (i.e. 3 to 6 failures) happened 65 times in the independent condition (roughly 11% of trials), but only 14 times in the coupled condition (roughly 2.5% of trials; chisquare(1, n = 79) = 32.9, p < .001).

There was also evidence that participants learned how to better manage coupled systems over the course of the experiment. While the correlation between trial number and earnings was not statistically reliable in the independent condition (r = .298, p > .05), that relationship in the coupled condition is significantly positive (r = .841, p < .01). These differences were driven by reductions in the number of plant failures over the course of the experiment. While the number of plant failures decreased for both participants in the independent (r = .615, p < .05) and coupled conditions (r = .842, p < .01), the magnitude of the reduction was much greater in the coupled condition such that by day 10 the difference in the number of failures was effectively non-existent.

To put this in perspective, on Trial 1, participants in the coupled condition suffered an average of 4.3 failures, and lost $184,748 (in game money) while those in the independent condition suffered an average of 1.3 failures and earned $15,235 (in game money; ttrial\_1\_failures(117) = 4.37, p < .001; ttrial\_1\_earnings(117) = 4.468, p < .001). However, by Trial 10, participants in the coupled condition suffered an average of only .569 failures, and earned an average of $73,467 (in game money) while those in the independent condition suffered an average of .567 failures and earned an average of $77,080 (in game money; ttrial\_10\_failures(116) = .008, p > .99; ttrial\_10\_earnings(116) = .18, p > .85).

1. Actual electricity prices are orders of magnitude higher; we kept the numbers small to avoid unnecessary cognitive load on participants. [↑](#footnote-ref-1)
2. Because the distributions are not always normal and violate the assumptions of some of the tests, we also ran Mann Whitney U tests to deal with possible violations of the assumptions of parametric tests. All the results were qualitatively the same. [↑](#footnote-ref-2)
3. These were three cases in which every power plant failed on every trial, because participants were not moving the slider to set capacity thus always setting minimum capacity, and two other cases where participants appeared to only figure out how to move the slider in the second half of the game. Importantly all five of these participants came from the coupled conditions and three came from the no-graph condition, which means that their removal only makes the reported tests conservative. Including these outliers only magnifies the trends reported herein. [↑](#footnote-ref-3)
4. This between-subject ANOVA was based on average number of failures per trial with participant as the level of analysis. [↑](#footnote-ref-4)
5. There were some participants who dropped out of the study midway through, but since each trial was an independent observation, we were able to include those participants’ partial data in the analyses, which is why the numbers don’t add up to 10 trials per participant times the number of participants. Removing those participants does not qualitatively affect the results. [↑](#footnote-ref-5)
6. Because there were zero observations the assumptions of chisquare test was violated but given the 82 to 0 split, inferential statistics aren’t necessary to infer reliability. [↑](#footnote-ref-6)