# Experimental evidence for tipping points in social convention

Article *in* Science · June 2018

DOI: 10.1126/science.aas8827



4 authors:

Damon Centola
Massachusetts Institute of Technology


Joshua Becker
Northwestern University


Devon Brackbill
University of Pennsylvania


Andrea Baronchelli
City, University of London

SOCIAL SCIENCE

# Experimental evidence for tipping points in social convention

**Damon Centola[1,2]*, Joshua Becker[1], Devon Brackbill[1], Andrea Baronchelli[3]**

**Theoretical models of critical mass have shown how minority groups can initiate social change dynamics in the emergence of new social conventions. Here, we study an artificial system of social conventions in which human subjects interact to establish a new coordination equilibrium. The findings provide direct empirical demonstration of the existence of a tipping point in the dynamics of changing social conventions. When minority groups reached the critical mass—that is, the critical group size for initiating social change—they were consistently able to overturn the established behavior. The size of the required critical mass is expected to vary based on theoretically identifiable features of a social setting. Our results show that the theoretically predicted dynamics of critical mass do in fact emerge as expected within an empirical system of social coordination.**

Observational accounts of rapid changes in social conventions have suggested that apparently stable societal norms can be effectively overturned by the efforts of small but committed minorities (*1*–*3*). From social expectations about gender roles in the workplace (*4*) to the popular acceptance of (or intolerance toward) tobacco use and marijuana use (*5*), accounts of changing social conventions have hypothesized that minority groups can trigger a shift in the conventions held by the majority of the population (*1*–*3*, *5*, *6*). Although this hypothesis presents a striking contrast to the expectations of classical equilibrium stability analysis from economic theory (*7*, *8*), it can nevertheless be well explained by the theory of critical mass as posited by evolutionary game theory (*9*–*11*). This theory argues that when a committed minority reaches a critical group size—commonly referred to as a "critical mass"—the social system crosses a tipping point. Once the tipping point is reached, the actions of a minority group trigger a cascade of behavior change that rapidly increases the acceptance of a minority view (*12*–*14*).

The simplest formulation of critical mass theory maintains that small groups of regular individuals—that is, with the same amount of social power and resources as everyone else—can successfully initiate a change in social conventions. According to this view, the power of small groups comes not from their authority or wealth but from their commitment to the cause (*14*, *15*).

Thus far, evidence for critical mass dynamics in changing social conventions has been limited to formal theoretical models and observations from qualitative studies. These studies have proposed a wide range of possible thresholds for the size of an effective critical mass, ranging from 10% of the population up to 40%. For instance, theoretical simulations of linguistic conventions have argued that a critical mass composed of 10% of the population is sufficient to overturn an established social equilibrium (*14*). By contrast, qualitative studies of gender conventions in corporate leadership roles have hypothesized that tipping points are only likely to emerge when a critical mass of 30% of the population is reached (*3*, *16*). Related observational work on gender conventions (*17*) has built on this line of research, speculating that effective critical mass sizes are likely to be even higher, approaching 40% of the population. Despite the broad practical (*18*, *19*) and scientific (*1*, *12*) importance of understanding the dynamics of critical mass in collective behavior, it has not been possible to identify whether there are in fact tipping points in empirical systems because such a test requires the ability to independently vary the size of minority groups within an evolving system of social coordination.

We addressed this problem by adopting an experimental approach to studying tipping-point dynamics within an artificially created system of evolving social conventions. Following the literature on social conventions (*9*, *20*, *21*), we study a system of coordination in which a minority group of actors attempt to disrupt an established equilibrium behavior. In both our theoretical framework and the empirical setting, we adopt the canonical approach of using coordination on a naming convention as a general model for conventional behavior (*21*–*24*). Our experimental approach is designed to test a broad range of theoretical predictions derived from the existing literature on critical mass dynamics in social conventions.

We first synthesized these diverse theoretical and observational accounts of tipping-point dynamics to derive theoretical predictions for the size of an effective critical mass (*25*). Based on earlier theoretical (*9*, *26*) and qualitative studies of social convention (*20*, *23*), we propose a simple model of strategic choice in which actors decide which social conventions to follow by choosing the option that yields the greatest expected individual reward given their history of social interactions (*9*). In this individual learning model, people coordinate with their peers so long as they benefit individually from coordinating. The

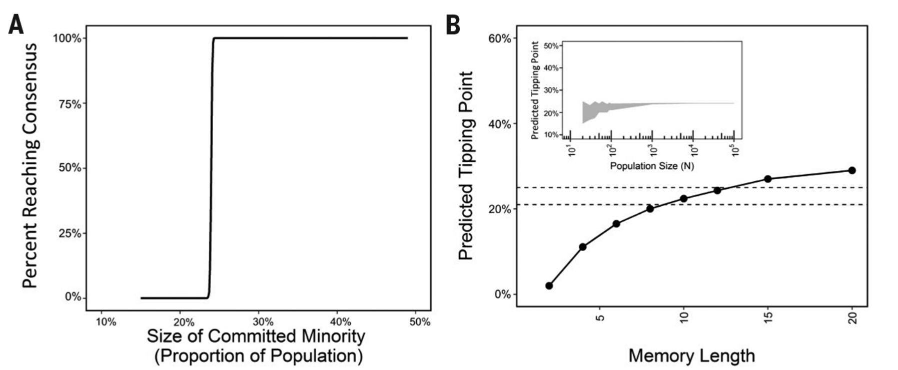


**Fig. 1. Predicted tipping points in social stability.** (**A**) Theoretical modeling of the proportion of outcomes in which the alternative behavior is adopted by 100% of the population. In this system, the number of agents ($N$) = 1000, the number of interactions ($T$) = 1000, the number of past interactions used in agent decisions ($M$) = 12. (**B**) The size of the predicted critical mass point is shown as a function of individuals' average memory length, $M$, where ($N$ = 1000, $T$ = 1000). The dashed lines indicate the range enclosed by our experimental trials, showing the largest unsuccessful minority (21%) and the smallest successful minority (25%). Although the expected size of the critical mass point increases with $M$, this relationship is concave, allowing the predicted tipping point to remain well below 50% as $M$ gets large (>100). (Inset) Effect of increasing population size on the precision of the size of the committed minority ($C$) prediction ($M$ = 12, $T$ = 1000). For $N$ < 1000, small variations in the predicted tipping point emerge due to stochastic variations in individual behavior. Shaded region indicates $C$ sizes where success was observed frequently but without certainty. Above this region, for larger $C$ sizes, the probability of success reaches 1; for $C$ sizes below this region, the likelihood of success goes to 0.

[1]Annenberg School for Communication, University of Pennsylvania, Philadelphia, PA, USA. [2]School of Engineering, University of Pennsylvania, Philadelphia, PA, USA. [3]Department of Mathematics, City, University of London, London, UK.
*Corresponding author. Email: dcentola@asc.upenn.edu

model predicts a sharp transition in the collective dynamics of social convention as the size of the committed minority reaches a critical fraction of the population (Fig. 1). When the size of the committed minority is below this predicted tipping point, the dominant social convention is expected to remain stable, whereas above this size it is expected to change (*25*).

Our theoretical predictions for the size of the critical mass were determined by two parameters: individual memory length ($M$) and population size ($N$). Explorations of these parameters (Fig. 1) show that the predicted size of the tipping point changes with individuals' expected memory length ($M$). When participants have shorter memories ($M$ < 5 interactions), the size of the critical mass is smaller. Even under the assumption that people have very long memories ($M$ > 100 interactions), the predicted critical mass size remains well below 50% of the population (*25*), indicating that critical mass dynamics may be possible even in systems with long histories. Variations in population size were explored computationally in the range 20 < $N$ < 100,000 and were not found to significantly affect the predicted critical mass size (*25*). Figure 1 shows that for populations in the range 20 < $N$ < 1000, stochastic fluctuations introduce a small uncertainty into the estimate of the critical mass size. However, for population sizes $N$ > 1000, the predicted tipping point for social change is constant and independent of $N$ [complete details in (*25*)].

We recruited 194 subjects from the World Wide Web and placed them into online communities where they participated in a social coordination process (*27*, *28*). Upon arrival to the study, participants were randomly assigned to participate in one of 10 independent online groups, which varied in size from 20 to 30 people. In a given round of the study, the members of each group were matched at random into pairs to interact with one another. Within each pair, both subjects simultaneously assigned names to a pictured object (i.e., a face), attempting to coordinate in the real-time exchange of linguistic alternatives (*20*, *25*). If the players entered the same name (i.e., coordinated), they were rewarded with a successful payment; if they entered different names (i.e., failed to coordinate), they were penalized. In each community, individuals interacted with each other over repeated rounds of randomly assigned pairings, with the goal of coordinating with one another (*25*). Participants were not incentivized to reach a "global" consensus but only to coordinate in a pairwise manner with their partner on each round. Participants were financially rewarded for coordinating and financially punished each time they failed to coordinate with each other (*25*). Once a convention was established for the entire population, the incentives strongly favored coordinating on the equilibrium behavior.

After each round, the participants could see only the choices that they and their partner had made, and their cumulative pay was updated

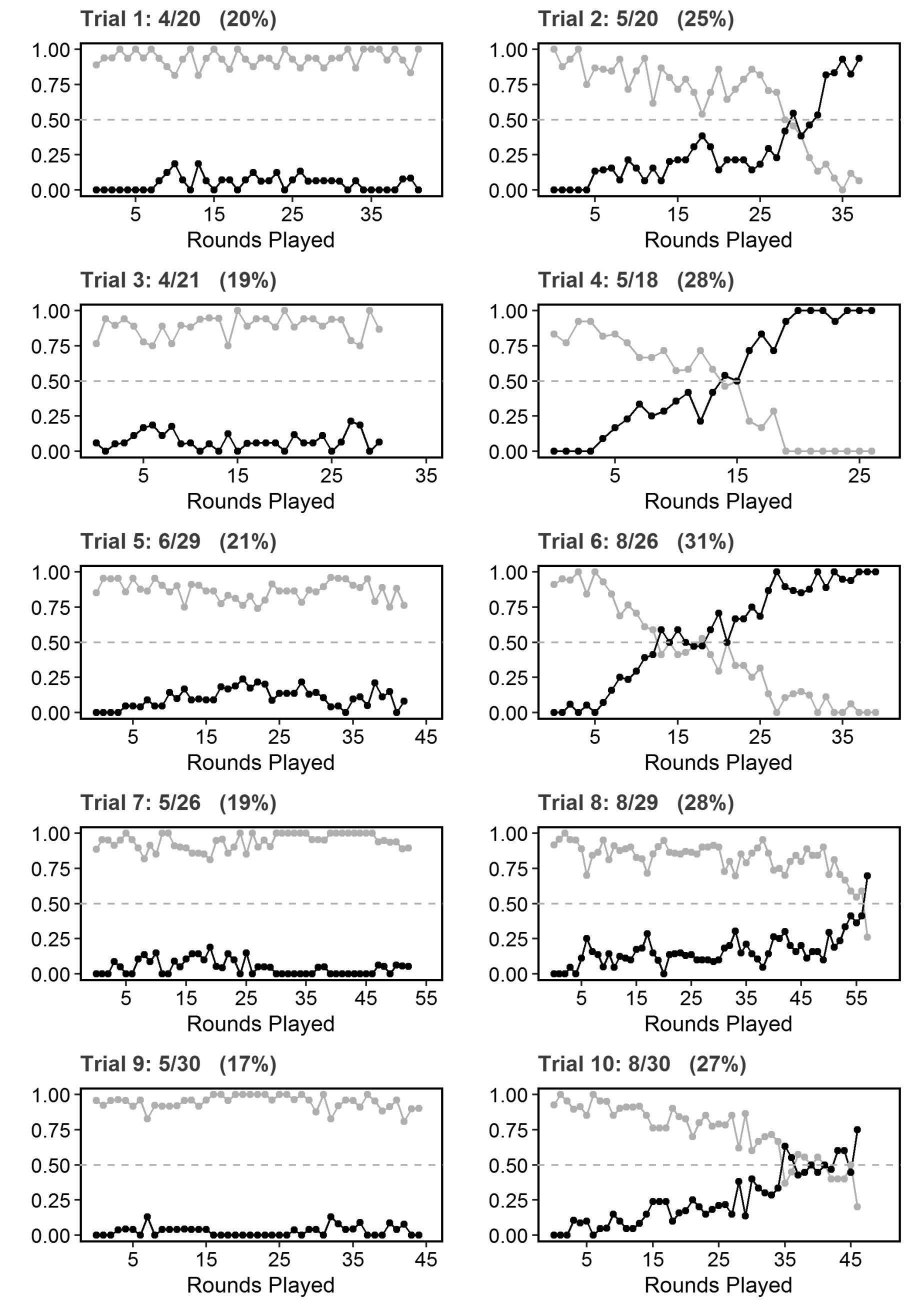


**Fig. 2. Time series showing adoption of the alternative convention by noncommitted subjects (i.e., experimental subjects).** Gray lines indicate the popularity of the established convention; black lines show the adoption of the alternative convention. Success was achieved when more than 50% of the noncommitted population adopted the new social convention. Trials in the left column show failed mobilization, whereas trials in the right column show successful mobilization. A transition in the collective dynamics happens when $C$ reaches ~25% of the population. Each round is measured as $N/2$ pairwise interactions, such that each player has one interaction per round on average.

accordingly. They were then randomly assigned to interact with a new member of their group, and a new round would begin. These dynamics reflect common types of online exchanges, in which community members directly interact with the other members of a large, often anonymous population—using, for instance, chat interfaces or messaging technologies—leading them to adopt linguistic and behavioral conventions that allow them to effectively coordinate their actions with other participants' expectations (*20*, *29 30*). Consistent with these types of settings, participants in the study did not have any information about the size of the population that was attempting to coordinate nor about the number of individuals to whom they were connected

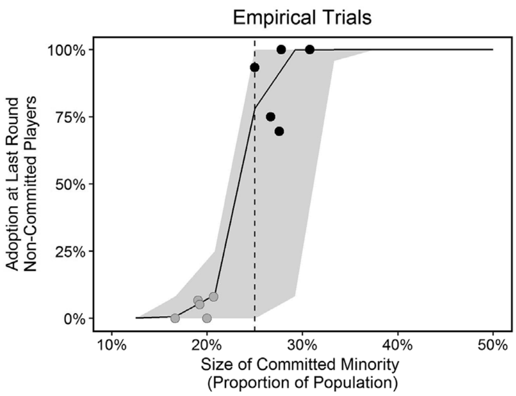


**Fig. 3. Final success levels from all trials (gray points indicate trials with *C* < 25%; black points indicate trials with *C* ≥ 25%.** Also shown is the theoretically predicted critical mass point (solid line) with 95% confidence intervals ($N$ = 24, $T$ = 45, $M$ = 12; gray area indicates 95% confidence intervals from 1000 replications). The dotted line indicates $C$ = 25%. The theoretical model of critical mass provides a good approximation of the empirical findings. For short time periods ($T$ < 100 interactions), the critical mass prediction is not exact (ranging from 20% < $C$ < 30% of the population); however, over longer time periods ($T$ > 1000) the transition dynamics become more precise (solid line, *25*).

(*9*, *20*, *23*). In every group, this interaction process quickly led to the establishment of a groupwide social convention, in which all players in the network consistently coordinated on the same naming behavior (*20*, *25*). Once a convention was established among all experimental participants, we introduced a small number of confederates (that is, a "committed minority") into each group, who attempted to overturn the established convention by advancing a novel alternative (*25*).

Trials varied according to the size of the committed minority ($C$) that attempted to overturn the established convention. In total, we studied the dynamics of critical mass in 10 independent groups, each with a committed minority of a fixed size. Across all 10 groups, the sizes of the committed minorities were in the range (15% < $C$ < 35%).

Figures 2 and 3 report tipping-point dynamics in the collective process of overturning an established equilibrium. Consistent with the expectations of our theoretical model (using empirically parameterized values of $N$ and $M$), when the size of the committed minority reached ~25% of the population, a tipping point was triggered, and the minority group succeeded in changing the established social convention.

Five trials were conducted. Each trial was composed of two communities—one with the committed minority below the expected critical size ($C$ < 25%) and one with it equal to or above ($C$ ≥ 25%). In every trial, the community with $C$ < 25% had only small numbers of converts to the minority view. Over the course of these trials, each of these converts eventually reverted to the dominant norm. Continuous interactions led to occasional switching by subjects throughout the study. However, over all the trials, in the condition where the minority group was smaller than 25% of the population, on average only 6% of the noncommitted population adopted the alternative behavior by the final round of the study.

For each of these unsuccessful trials, we conducted a corresponding trial using another population of the same size but with a larger committed minority (25% ≤ $C$ ≤ 31%). In all these groups, the alternative norm reached the majority of the population within the experimental window of observation (Figs. 2 and 3). Over all trials, populations with $C$ ≥ 25% were significantly more likely to overturn the dominant convention than populations with a committed minority below 25% ($P$ = .01, Wilcoxon rank sum). We found that in one case (Trial 1) this transition from failure to success was the result of increasing the size of the committed minority by only one person.

Figure 3 shows a summary of final adoption levels across all trials, along with expectations from our empirically parameterized theoretical model, with 95% confidence intervals. Populations with committed minorities ranging from 25% ≤ $C$ ≤ 27% achieved uptake levels between 72 and 100% within the empirical observation window. At $C$ = 31%, the committed minority achieved consensus within the window of empirical observation. Figure 3 compares these observations to numerical simulations of the theoretical model using population sizes and observation windows ($T$ rounds of interaction) comparable to the experimental study ($N$ = 24, $T$ = 100, $M$ = 12). Memory length for these simulations was calibrated using subjects' empirical memory lengths in this study based on their observed behavior over all 10 groups. A memory length in the range 9 ≤ $M$ ≤ 13 provides a good approximation of subjects' observed behavior, correctly predicting 80% of subjects' choices across all trials (*25*). The theoretically predicted critical mass size from this model fit the experimental findings well (Fig 3). Numerical analyses indicate that with larger population sizes, the critical mass point becomes more exact (See Figs. 1 and 3), approaching 24.3% of the population.

Our experimental results do not show agreement with theoretical predictions from models of social convention that predict low critical mass thresholds, at 10% of the population. However, our findings show good agreement with qualitative studies of gender conventions within organizational settings (*3*), which hypothesized that a critical mass of ~30% could be sufficient to overturn established norms (*16*). Our results may suggest that in organizational contexts—where population boundaries are relatively well defined and there are clear expectations and rewards for social coordination among peers—the process of normative changes in social conventions may be well described by the dynamics of critical mass.

The design choices that aided our control of the study also put constraints on the behaviors that we could test. Our experimental design provided subjects with social and financial incentives that strongly favored coordinating on an established social convention (*25*). However, in the real world, individuals' emotional and psychological commitments to established behaviors can create additional resistance to behavior change (*31*). To further explore these expectations, supplementary analyses of our theoretical model (fig. S7) (*25*) extend our basic predictions to consider how the critical mass size may differ under conditions of greater social entrenchment. When actors are more conservative—exhibiting an explicit bias in favor of the established convention (based on a skewed best-response calculation favoring the equilibrium behavior)—tipping-point dynamics were still predicted to be achievable by committed minorities with only marginally larger group sizes.

In delimiting the scope of our findings, we emphasize that the critical mass value of 25% is not expected to be a universal value for changing social conventions. Our results demonstrate that within an endogenous system of social coordination, tipping-point dynamics emerged consistent with theoretical expectations. Further work is required to determine the applicability of our findings to specific social settings. In particular, alternative empirical parameterizations of our model can result in alternative predictions for the expected size of the critical mass. We expect that the findings from our study can be considerably expanded by future empirical work studying the dynamics of tipping points within other empirical systems of social convention.

For instance, an important setting in which these results might be usefully applied concerns the growing ability of organizations and governments to use confederate actors within online spaces to influence conventional behaviors and beliefs. Recent work on the 50 Cent Party in China (*32*, *33*) has argued that the Chinese government has incentivized small groups of motivated individuals to anonymously infiltrate social media communities such as Weibo with the intention of subtly shifting the tone of the collective dialogue to focus on topics that celebrate national pride and distract from collective grievances (*32*). We anticipate that social media spaces of this kind will be an increasingly important setting for extending the findings of our study to understand the role of committed minorities in shifting social conventions. Similarly, the results from our study may also be usefully applied to the dynamics of critical mass in other online settings, such as changing social expectations regarding (i) the standards of civility on Facebook and other online discussion forums (*19*, *34*), (ii) the acceptability of bullying behavior in adolescent chat groups (*35*), and

(iii) the appropriate kinds of content to share with strangers over social media (*36*), all of which have been suggested to exhibit susceptibility to shifts in conventional behavior as a result of the activity of a small fraction of the population (*19*, *34*, *36*).

## REFERENCES AND NOTES

1. T. Kuran, *Am. J. Sociol.* **100**, 1528–1551 (1995).
2. K. D. Opp, C. Gern, *Am. Sociol. Rev.* **58**, 659–680 (1993).
3. R. M. Kanter, *Am. J. Sociol.* **82**, 965–990 (1977).
4. D. Dahlerup, L. Freidenvall, *Int. Fem. J. Polit.* **7**, 26–48 (2005).
5. S. Bikhchandani, D. Hirshleifer, I. Welch, *J. Polit. Econ.* **100**, 992–1026 (1992).
6. T. Kuran, *Private Truths, Public Lies: The Social Consequences of Preference Falsification* (Harvard Univ. Press, 1997).
7. J. C. Harsanyi, R. Selten, *A General Theory of Equilibrium Selection in Games* (MIT Press, Cambridge, 1988).
8. J. F. Nash, *Proc. Natl. Acad. Sci. U.S.A.* **36**, 48–49 (1950).
9. H. P. Young, *Econometrica J. Econom. Soc.* **61**, 57–84 (1993).
10. M. Kandori, G. J. Mailath, R. Rob, *Econometrica J. Econom. Soc.* **61**, 29–56 (1993).
11. G. Ellison, *Econometrica J. Econom. Soc.* **61**, 1047–1071 (1993).
12. T. Schelling, *Micromotives and Macrobehavior* (Norton, New York, 1978).
13. M. Granovetter, *Am. J. Sociol.* **83**, 1420–1443 (1978).
14. J. Xie *et al.*, *Phys. Rev. E Stat. Nonlin. Soft Matter Phys.* **84**, 011130 (2011).
15. D. M. Centola, *Ration. Soc.* **25**, 3–40 (2013).
16. D. Dahlerup, *Scand. Polit. Stud.* **11**, 275–298 (1988).
17. S. Grey, *Polit. Gend.* **2**, 492–502 (2006).
18. G. Marwell, P. Oliver, *The Critical Mass in Collective Action* (Cambridge Univ. Press, 1993).
19. K. Nyborg *et al.*, *Science* **354**, 42–43 (2016).
20. D. Centola, A. Baronchelli, *Proc. Natl. Acad. Sci. U.S.A.* **112**, 1989–1994 (2015).
21. D. Lewis, *Convention: A Philosophical Study* (Harvard Univ. Press, Cambridge, 1969).
22. C. Castellano, S. Fortunato, V. Loreto, *Rev. Mod. Phys.* **81**, 591 (2009).
23. S. Garrod, G. Doherty, *Cognition* **53**, 181–215 (1994).
24. L. Wittgenstein, *Philosophical Investigations* (John Wiley & Sons, 2009).
25. Materials and methods are available as supplementary materials.
26. A. Baronchelli, M. Felici, V. Loreto, E. Caglioti, L. Steels, *J. Stat. Mech. Theory Exp.* **2006**, P06014 (2006).
27. D. Centola, *Science* **334**, 1269–1272 (2011).
28. D. Centola, *Science* **329**, 1194–1197 (2010).
29. L. Backstrom, D. Huttenlocher, J. Kleinberg, X. Lan, Group formation in large social networks: membership, growth, and evolution. Proc. 12th ACM SIGKDD Int. Conf. Knowl. Discov. Data Min., 44–54 (2006).
30. F. Kooti, H. Yang, M. Cha, P. K. Gummadi, W. A. Mason, The Emergence of Conventions in Online Social Networks. Proc. Sixth Int. AAAI Conf. Weblogs Soc. Media ICWSM 2012 (2012).
31. C. Tilly, S. Tarrow, *Contentious Politics* (Oxford Univ. Press, New York, ed. 2, 2015).
32. G. King, J. Pan, M. E. Roberts, *Am. Polit. Sci. Rev.* **111**, 484–501 (2017).
33. G. King, J. Pan, M. E. Roberts, *Science* **345**, 1251722 (2014).
34. A. Antoci, A. Delfino, F. Paglieri, F. Panebianco, F. Sabatini, *PLOS ONE* **11**, e0164286 (2016).
35. E. L. Paluck, H. Shepherd, P. M. Aronow, *Proc. Natl. Acad. Sci. U.S.A.* **113**, 566–571 (2016).
36. C. Shih, *The Facebook Era: Tapping Online Social Networks to Market, Sell, and Innovate* (Pearson Education, 2010).

## ACKNOWLEDGMENTS

We gratefully acknowledge research assistance from S. Kim and N. Herbert, helpful suggestions from P. Starr and A. van de Rijt, and programming assistance from A. Wagner and R. Overbey. This research was approved by the Institutional Review Board at the University of Pennsylvania, where the study was conducted, and it included informed consent by all participants in the study. **Funding:** The authors received no external funding in support of this research. **Author contributions:** D.C. and A.B. designed the study. J.B. and D.B. collected the data. D.C., J.B., D.B., and A.B. analyzed the data. D.C. wrote the manuscript. All authors commented on and approved the final manuscript. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** The datasets are available upon request and upon publication will be publicly available for download from the university Web site: http://ndg.asc.upenn.edu/experiments/creating-critical-mass. Upon publication, the data will be available at Dataverse, doi:10.7910/DVN/11HUAG. The code in R is available on GitHub at https://github.com/NetworkDynamicsGroup/BestResponseNameGame.

## SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/360/6393/1116/suppl/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S7
References (*37*)

3 January 2018; accepted 20 April 2018
10.1126/science.aas8827

Science

# Experimental evidence for tipping points in social convention

Damon Centola, Joshua Becker, Devon Brackbill and Andrea Baronchelli

*Science* **360** (6393), 1116-1119.
DOI: 10.1126/science.aas8827

**Tipping points in social convention**

Once a population has converged on a consensus, how can a group with a minority viewpoint overturn it? Theoretical models have emphasized tipping points, whereby a sufficiently large minority can change the societal norm. Centola *et al.* devised a system to study this in controlled experiments. Groups of people who had achieved a consensus about the name of a person shown in a picture were individually exposed to a confederate who promoted a different name. The only incentive was to coordinate. When the number of confederates was roughly 25% of the group, the opinion of the majority could be tipped to that of the minority.

*Science*, this issue p. 1116