The Diffusion of Support in an Online Social Movement: Evidence from the Adoption of Equal-Sign Profile Pictures

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ABSTRACT

In March of 2013, 3 million Facebook users changed their profile picture to one of an equals sign to express support of same-sex marriage. We demonstrate that this action shows complex diffusion characteristics congruent with threshold models, with most users observing several of their friends changing their profile picture before taking the action themselves. While the number of friends played a role in the adoption dynamics, so did demographic characteristics and the general propensity of the individual to change their profile picture. We show via simulation that the adoption curve is consistent with a heterogeneous-threshold model, in which the probability of adoption depends on both the number of friends and the susceptibility of the individual.

Author Keywords

Online Social Movements; Diffusion Mechanisms;

ACM Classification Keywords

J.4 Social and Behavioral Sciences: Sociology

General Terms

Human Factors; Measurement

The online realm has emerged as a fertile domain for collective action. Online activism has played an important role in such diverse large-scale organizing efforts as Iran's Green Movement of 2009, the US-centered Occupy Movement or the "Arab Spring" uprisings [23]. Given that social movements – whether on- or offline – encounter the problem of collective action [29], it is widely believed that activism in social movements is governed by a process of *complex diffusion*, alternatively known as complex contagion. This is the process in which the likelihood to engage in activism increases with the observation of other individuals' activism – in contrast with the alternative *simple diffusion* process, in which the activism likelihood remains constant or decreases with multiple exposures.

CSCW 2015, March 14–18, 2015, Vancouver, BC, Canada.
ACM 978-1-4503-2922-4/15/03.
http://dx.doi.org/10.1145/2675133.2675290

It is easy to see why social proof obtained from multiple sources would be necessary for many individuals to show their support for a cause they believe in. Engaging in a behavior that challenges the status quo carries inherent risks, from the minute – a quarrel with one's otherwise-thinking friends – to the life-threatening, as experienced by activists in a political movement challenging a repressive regime. Additionally, action requires participants to bear the costs of mobilization [26], ranging from the time spent filling out a petition to the money spent on monetary donations to one's favorite campaigns to the lost wages due to strike activity.

We investigate here a case where both the risks and the costs associated with activism were low but nonetheless still discernible. In this paper we focus specifically on the demonstration of support for marriage equality by changing one's Facebook profile picture to an equal sign. The fact that we find support for the hypothesis of complex diffusion in social mobilization even in the case of lower-risk social movement activity bolsters the importance of this kind of diffusion process as a crucial avenue through which political behavior spreads.

The equal-sign movement on Facebook was precipitated by a post on March 25th by the Human Rights Campaign (HRC) Facebook page calling on its fans to change their profile picture in advance of the US Supreme Court's consideration of two cases involving marriage rights for gay and lesbian couples.

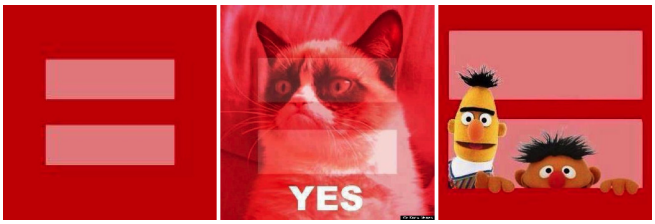

Figure 1: Example equal-sign profile pictures.

Within a week, an estimated 3 million Facebook users changed their profile picture to a form of the equals sign, making this the largest such single cascade on the site. In the months prior to the start of the diffusion, public opinion had shifted toward a majority support of marriage equality for gays and lesbians (58% vs 36%) [8], from roughly equal

amounts of support and opposition just 3 years prior. This attitudinal shift came after two decades of much slower, positive change in attitudes towards LGBT individuals and same-sex marriage in the U.S. [33].

Arguably showing support for same-sex marriage still carried a level of perceived risk. Even though an opinion in favor of same-sex marriage had recently experienced a dramatic increase in popularity, individuals may not have been aware of the shift due to its recency. Moreover, it was also likely that at least some friends and acquaintances of potential supporters of same-sex marriage held the opposing view. Although in this case a political statement may be more effective – there is the potential for changing others' opinions – displaying an opinion that is unpopular (or at least thought to be as such) creates the risk for conflict and contention. Given the uncertainty surrounding the extent of support for same-sex marriage and the potential risks resulting from adoption, we expect that most individuals would only change their profile picture after observing several others doing so, a situation that gives a real-world, observational illustration of the afore-mentioned complex diffusion dynamics in online social movements.

LITERATURE REVIEW

Social activism is currently evolving in multitudinous and complex forms in the online environment, which presents a rich medium for understanding the micro-level dynamics of political mobilization [25, 16]. However, the analysis of online social movements is currently in its infancy. Several studies to date have examined political movements on Twitter [9, 10, 27]. They have examined different actor types, from mainstream media to the individual, from local to remote, and their roles in information diffusion. [9] find that the communication network of the Occupy Movement induced from Twitter was more localized than the general political communication network, likewise displaying a hierarchical, hub-and-spoke structure. Similar processes were observed in episodes of online mobilization in Spain in May 2011 [15], and Tunisia and Egypt in 2011 [23, 34]. Despite the continued role of social media in social movements, the impact of online mobilization has been questioned: [10] revealed the temporal dynamics of Occupy, finding no substantial long-term changes in the level of engagement of individuals who took part in Occupy activism during the movement's early days.

Although these studies have yielded interesting insights, Twitter dynamics are driven in large part by accounts representing public figures, journalists, or celebrities. It is unclear whether the movements would have spread purely from individual to individual. In contrast, in this paper, by studying mobilization on Facebook, we examine diffusion that occurs largely between individuals. The current paper focuses on a particular episode – the diffusion of equal sign profile pictures – in the larger political movement aimed at gaining equal recognition for same-sex marriage as compared to opposite-sex marriage. A prior example of a behavior that has spread from individual to individual on Facebook is that of voting. [4] showed that someone who is informed that their friends clicked the 'I voted' button is more likely to do the same, especially if the friend is a close tie. However, voting is a desirable and uncontroversial behavior in contrast to expressing a potentially-contentious opinion.

This study presents the opportunity of examining a large-scale and well-defined behavior – the adoption of an equal sign as one's profile picture – that has real meaning and involves real, though low-level risks. Prior work has considered how network structure and other factors may influence diffusion when there is some cost to adoption. Theoretical models have investigated how network topology [7] and a small committed minority [12] influence whether a behavior can spread through the network. There is increasing evidence that multiple exposures are most effective in determining the adoption of certain types of behaviors in the social realm, for instance in the adoption of health-related behavior [5, 6], use of political hashtags [31], product purchases [21], and joining groups [2]. Most of the above behaviors incur some cost, whether in terms of money (the purchase of a book), coordination (using the same hashtags as others), or time (reading a book or using a new health application).

In contrast to this complex model of diffusion, *simple contagion* – in which repeated exposures are progressively less effective in determining the adoption of a behavior – is the apparent driver of most online information diffusion [13], although the spread of a scientific rumor can be modeled as depending on the number of adopting friends [35, 11] and the community structure [36] in a non-trivial manner [11]. In this paper we present a novel model that accounts for both the increasing influence of multiple friends and variable susceptibility at the individual level, to produce adoption curves similar to those observed for the equal sign diffusion.

Furthermore, using an anonymized dataset that records both the timing of exposures and the demographics of the individuals exposed, we are able to formulate empirically the relationship between demographic attributes, exposure, and adoption probability.

DATASET DESCRIPTION

All analysis was performed on a de-identified version of already existing data, in accordance with Facebook's Statement of Rights and Responsibilities and Data Use Policy.

This de-identified dataset represented 3,232,827 profile pictures adopted by 3,054,327 users, 67.5% of whom were women, and 90.71% of whom were in the United States. Additionally, 106m users were exposed to equal-sign profile pictures, 104m of whom were in the United States.

Equal-Sign Picture Classifier

The first task is to identify profile photo changes that are related to the Equal Sign Movement. Using an internal classifier we pre-filtered 10 million pictures uploaded during the period 03/25 to 03/31 2013. The pre-filtering selected pictures rating highly on metrics for synthetic images and overlaid text. A separate audit was conducted on 500 randomly-selected images uploaded during the same period but which

were not included in the candidate set. The audit revealed no picture related to LGBT rights in the random sample we extracted. For each image in the candidate set we generated a number of features using the ImageMagick software [19]. The features included the (log-transformed) file size, the minimum, maximum, mean and standard deviation of the image-level distribution for red, green and blue values, the aspect ratio and area of the image, the relative ratio between the mean RGB colors, as well as a number of internal image-classification metrics. Using a hand-labeled dataset of 10,000 randomly-selected images we trained a Random Forest [22] classifier to distinguish images related to LGBT rights or marriage equality (whether for or against) from images which were unrelated to the topic. We evaluated the classifier using ten-fold cross-validation. In this setting, the classifier achieved mean precision of 0.986 (range between 0.974 and 0.995) and mean recall of 0.956 (range between 0.928 and 0.976).[1]

Although our classifier was built to distinguish pictures related to same-sex marriage from those unrelated to the topic, the overwhelming majority of these pictures was in favor of same-sex marriage. An audit of over 4,000 randomly-selected, hand-coded pictures revealed 97.7% to be in favor of same-sex marriage and only 2.3% being opposed. As a result, we focus here on the main process of diffusion as indicative of displays of support for same-sex marriage, leaving the modelling of the dynamics of opposition to future research.

Adopter Characteristics.

We investigate the relationship between demographic and socio-economic characteristics and adoption patterns for U.S. Facebook users who were exposed to Facebook friends' adoption of the equal sign as a profile picture during the observation window.[2]

Age and Gender.

Table 1 shows the probability that a U.S. user with at least one adopting friend will themselves adopt varies with age and gender. As the results reveal, women were substantially more likely than men to change their profile picture (2.3% of women and 1.3% of men adopted the equal-sign picture), the likelihood of adoption peaking in the age group 25-34 for both genders. Women also received slightly more overall exposures than men (median of 4 for women and 3 for men). On balance, female adopters displayed an equal-sign picture after *fewer* exposures than male ones, with a median of 8 for women and 10 for men.

Education

Individuals who listed higher education were also more likely to display the equal sign picture than those individuals not listing education. Whereas .8% of individuals who did not list any education level adopted, 1.0% of high school graduates did so, the proportion increasing to 2.4% for users with college degrees and to 4.6% for users with graduate educations.

Age Group	Overall	Women	Men
13-17	0.009	0.012	0.008
18-24	0.016	0.020	0.011
25-34	0.026	0.035	0.017
35-44	0.023	0.029	0.017
45-54	0.016	0.019	0.014
55-64	0.010	0.012	0.008
65+	0.007	0.008	0.006

Table 1: Adoption Probability for Exposed Users, by Age and Gender

Same-Sex Interest

Individuals listing themselves as "Interested in" persons of the same gender as themselves were 8 times more likely (11.0%) to adopt the equal sign than individuals whose "Interested in" field indicated persons of the opposite gender (1.4%). Individuals reporting same-sex interest were exposed to a median of 6 equal-sign pictures, whereas those reporting opposite-sex interest received a median of 4 exposures. Furthermore, adopters reporting (exclusive) same-sex interest were exposed, at the median, to 12 equal sign pictures before adopting, compared to a median of 8 exposures for those adopters reporting (exclusive) opposite-sex interest.

Friends with Same-Sex Interest

Consistent with both the "contact hypothesis" [18] and with homophily based on attitudes [20], we expect individuals who have many friends indicating same-sex interest to be more likely to display the equal sign picture. This is indeed the case: as Figure 2 shows, the probability of adoption increases dramatically with the number of friends listing themselves as "interested in" individuals of the same sex.

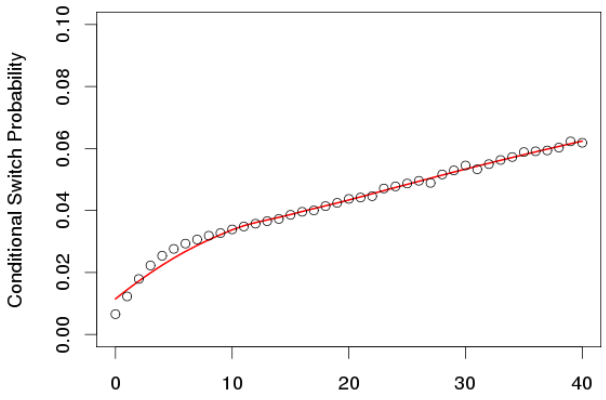

Figure 2: Adoption risk, by number of friends with same-sex interest.

[1] The lowest precision of 97.43% was achieved in a cross-validation run with 95.71% recall, whereas the lowest recall of 92.79% was achieved in a cross-validation run with 98.18% precision.

[2] We limit our analysis only to U.S. users given that the movement was overwhelmingly focused on the United States, and also due to the fact that the meaning of certain individual characteristics, such as religion, politics and education is highly dependent on national context.

Politics

Users who identified themselves as "very liberal" appear to be the most likely to adopt, 12.5% of those exposed having done so by the end of the observation window. The similar figure is 7.5% for liberal users, 5.1% for users identifying themselves as libertarian, 4.0% for moderates, 1.1% for "very conservative" users and 0.8% for conservative users. A potential explanation for the reversal seen between these last two categories has to do with the development of memes against same-sex marriage in response to the HRC campaign. While these memes are not prevalent in the overall population of Facebook users, it is plausible that very conservative individuals were more likely to be exposed to such counter-memes than individuals who listed themselves as conservative.

Religion

Religion has been recognized as a major factor in determining the support for same-sex marriage [28], and our results confirm its influence in shaping the probability of adoption of equal-sign profile pictures. Out of exposed U.S.-based users, 7.8% of persons identifying themselves as atheists and agnostics adopted the equal sign profile picture. The comparable figure is 2.3% for individuals indicating a religious affiliation, and 1.6% for individuals who listed no such affiliation.

HRC Followers

Because the Human Rights Campaign launched the equal-sign initiative, we expect individuals who were followers of the HRC Facebook page at the beginning of the observation window to have a higher probability of adoption. 32.5% of the 980 thousand US-based users who were followers of the HRC page at the start of the observation window came to display the equal sign, compared to 1.6% of non-followers. We also note 23.4% of U.S. users who adopted with no prior friends having adopted were followers of the HRC Facebook page, compared to 11.4% for individuals who adopted after their Facebook friends adopted.

Friends' Religion

Because individuals with similar political and religious affiliations tend to cluster together, we expect the counts of friends by affiliation to communicate more information about individuals with missing attributes. Additionally we expect that individuals who have more friends from a higher-adoption group would also be more likely to be exposed to the equal-sign meme, and to hold pro-same-sex marriage attitudes, both of which should make them more likely to adopt. Indeed, this is the case, as we see that the adoption probability increases sharply with the first few agnostic or atheist friends. the equal-sign picture (Figure 3). In contrast, we see a slower, linear increase with the number of religious friends – this may be a reflection of individuals with many friends (and thus more likely to use Facebook and participate in the campaign, see subsequent discussion) also having many religious friends.

Friends' Politics

The adoption probability increases dramatically with the number of very liberal friends, from around 0.8% for individuals who have no such friends to just under 12.2% for individuals with twenty Facebook friends who identify themselves as very liberal. The probability increases in a similar manner with the number of liberal and moderate friends and decreases slightly with the number of very conservative friends, as is apparent in Figure 4.

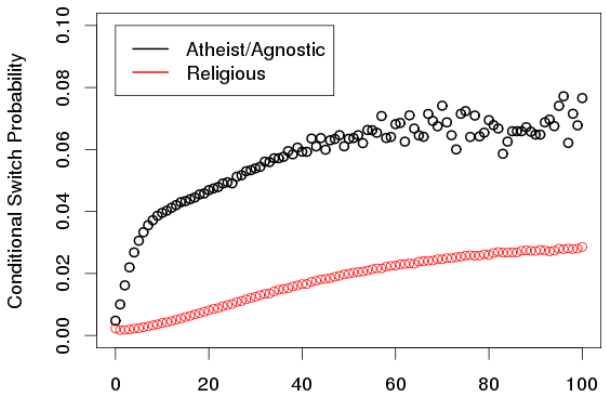

Figure 3: Adoption risk, by number of religious and atheist/agnostic friends.

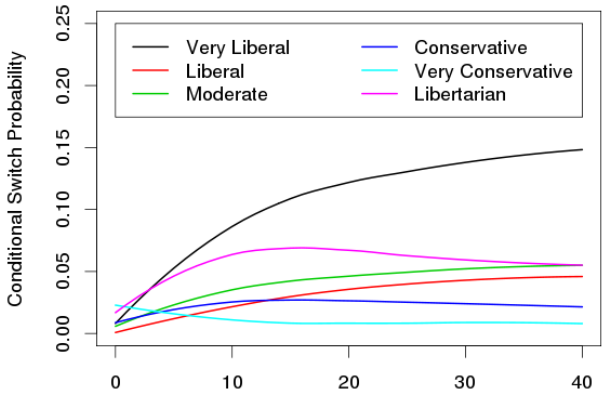

Figure 4: Adoption risk, by proportion of friends with political affiliation (LOESS regressions).

Profile Photo Change Frequency.

An important observation concerns the fact that, regardless of values and attitudes, some individuals will only change their profile picture seldom, or they will not change their profile picture to display a meme, no matter the cause. Figure 5 bolsters this hypothesis, showing a steep increase in the adoption probability with the number of profile picture changes during the six months prior to the observation window.

Number of Facebook Friends

Another metric for site usage concerns the number of Facebook friends that a person had in the beginning of the observation window, graphed against the adoption probability in the lower panel of Figure 5. The adoption probability peaks around 400 friends, and then decreases slowly with an increase in friends. It seems likely that two countervailing processes are captured by this variable. On the one hand, site usage is likely to increase as the number of Facebook friends

increases. At the same time, as one accumulates friends, the salience of any friends' posting is reduced due to the increasing volume of information which the social networking platform delivers to the user.

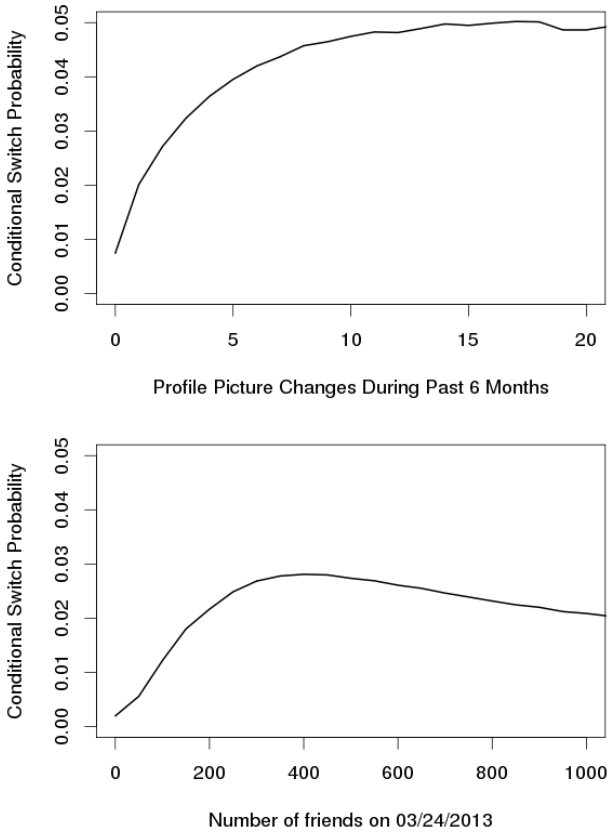

Figure 5: Adoption probability, by profile photo changes in the six months prior to March 24, 2013 and the number of friends on that date.

LOGISTIC MODEL FOR ADOPTION

As the prior statistics suggest, there are many variables that factor into the adoption of equal sign profile pictures. Many factors may be correlated however – religion and politics or education and age. To distinguish between the myriad variables at our disposal we use a logistic regression that predicts the probability of adopting the equal sign (Table 2). To avoid making any parametric assumptions about the function linking exposure to adoption, we used splines to measure the effect of each additional exposure starting from the first.

The complex diffusion hypothesis would have us expect a pattern of increased likelihood of adoption with each additional exposure. The model shows precisely this pattern, but only for the first six exposures (understood as the number of Facebook friends who adopted before ego). *Ceteris paribus,* the model estimates an increase in the odds ratio of adoption by a factor of $e^{.81} = 2.24$ for individuals who have received their first exposure, and of $e^{.5} = 1.64$ for individuals who have received their second exposure, the effect attributable to each exposure decreasing progressively to around the sixth exposure, where it becomes virtually flat. We also included a linear term for each additional exposure past the tenth – consistent with our prior findings the likelihood to adopt appears to decrease slightly with each additional exposure.

The results also reveal that the identified factors maintain their influence on the adoption probability, with a few exceptions. When factors such as politics and education are taken into account, both below-18 and 35-44 age groups appear more likely to adopt the equal sign. We also see that individuals who do not report a religious or political affiliation are rather unlikely to adopt the equal sign, even when a behavioral measure as direct as their previous profile photo change frequency is taken into account.

DIFFUSION AS COMPLEX CONTAGION

Measuring the contagion profile

A potentially confounding factor in measuring the influence of one's friends is the role of broadcast media in popularizing a certain action, in this case the change of one's profile picture to an equal sign. Unlike most memes spreading online, the equal-sign meme received ample coverage while it was diffusing. As such, it is perhaps not surprising that 58,111 individuals displayed the equal sign before any of their friends did. As Figure 6 shows, most of these "independent" adoptions occurred during March 26th, the first full day after the Equal Rights Campaign launched the original equal-sign picture.

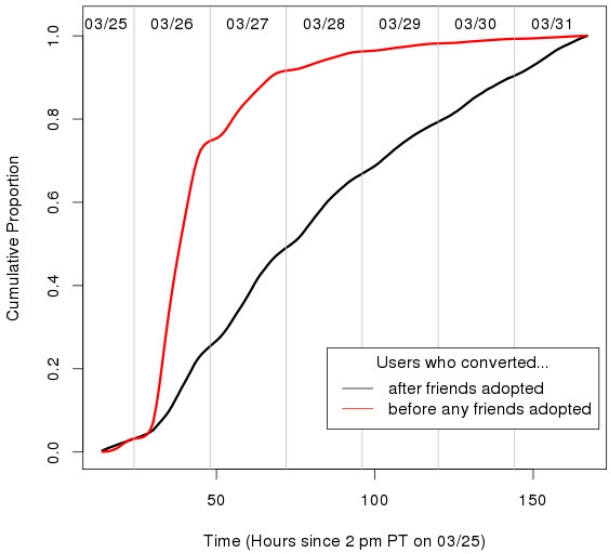

Figure 6: Cumulative Distribution Functions of users who first adopted equal sign with or without any friends having previously adopted.

Next we examine the marginal likelihood of adoption, given exposure to adoption by one's friends. Figure 8 (a) plots the

Table 2: Determinants of Adoption (Logistic Regression)

Independent Variable	Coef.	(S.E.)	Z-stat.
Prior Exposures			
Intercept	4.278***	(0.062)	68.821
. . . 1st exposure	0.811***	(0.025)	32.542
. . . 2nd exposure	0.500***	(0.028)	17.772
. . . 3rd exposure	0.317***	(0.029)	11.107
. . . 4th exposure	0.161***	(0.030)	5.439
. . . 5th exposure	0.097**	(0.031)	3.118
. . . 6th exposure	0.037	(0.033)	1.122
. . . 7th exposure	0.081*	(0.035)	2.324
. . . 9th exposure	-0.020	(0.037)	-0.552
. . . 10th exposure	0.012	(0.039)	0.312
. . . > 10 exposures	-0.018	(0.030)	-0.598
each exp. > 10	-0.007***	(0.000)	-25.680
Site Usage			
Profile pic. changes	0.407***	(0.006)	66.774
Number of friends†	-1.681***	(0.022)	-77.982
Age (ref.: 25-34 years old)			
. . . below 18	0.134***	(0.037)	3.664
. . . 18-24	-0.347***	(0.016)	-21.682
. . . 35-44	0.129***	(0.015)	8.357
. . . 45-54	-0.034	(0.019)	-1.758
. . . 55-64	-0.354***	(0.027)	-13.345
. . . above 65	-0.629***	(0.037)	-17.009
Female	0.575***	(0.012)	49.143
Education (ref.: none reported)			
High School	0.212***	(0.025)	8.604
College	0.360***	(0.022)	16.499
Graduate School	0.559***	(0.025)	22.190
Same-/Opposite-Sex Interest			
Same-Sex Interest (SSI)	0.515***	(0.033)	15.483
Opposite-Sex Interest	-1.380***	(0.066)	-20.947
No. Friends w/ SSI†	0.353***	(0.008)	45.472
Religious Affiliation (ref.: none reported)			
Atheism/Agnosticism	0.539***	(0.031)	17.217
Religious	0.033**	(0.012)	2.786
Friends' Religious Affiliation†			
No. Atheist/Agnostic†	0.295***	(0.009)	32.390
No. Religious†	0.100***	(0.023)	4.333
Political Affiliation (ref.: none reported)			
Very Conservative	-0.048	(0.153)	-0.310
Conservative	-0.641***	(0.034)	-18.964
Moderate	0.261***	(0.032)	8.140
Liberal	0.684***	(0.019)	35.853
Very Liberal	0.690***	(0.048)	14.518
Libertarian	0.320***	(0.064)	4.968
HRC fan	1.111***	(0.027)	40.820
Friends' Political Affiliation†			
Very Conservative	-0.150***	(0.012)	-12.515
Conservative	0.126***	(0.010)	12.712
Moderate	0.074***	(0.011)	6.692
Liberal	0.317***	(0.012)	25.615
Very Liberal	0.078***	(0.010)	7.848
Libertarian	0.045***	(0.010)	4.435

$***: p < .001; **: p < .01; *: p < .05$. Two-sided tests. N=200,000. Sample balanced on DV. † transformed using $f(x) = \ln(x+1)$.

empirically-observed adoption rate for each additional "re-exposure," defined there as the adoption of the equal sign picture by another friend. [3] The figure shows an increasing trend in the effectiveness of each additional re-exposure up to the eighth event, after which the trend reverses. The decline in effectiveness for individuals re-exposed to multiple equal sign pictures hints at an "immunity" some users had to the equal-sign campaign. We can imagine that some individuals are highly unlikely to display an equal-sign picture, either due to disagreement with the campaign's goals, or because they do not post any memes at all, or even due to inexperience with the Facebook interface.

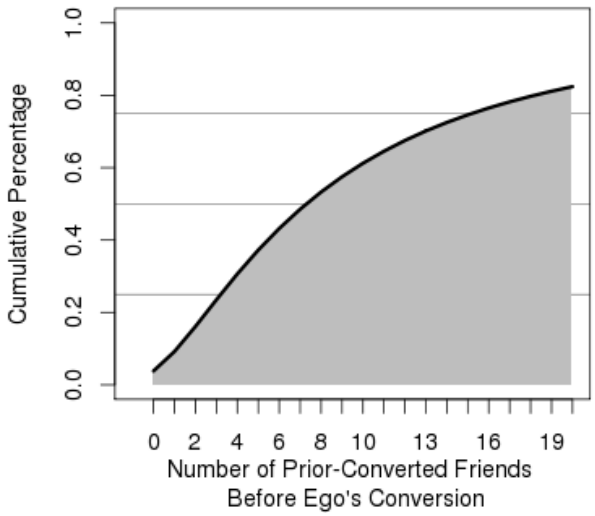

Figure 7: Probability of Conversion by number of friends previously adopting equal-sign (Cumulative Distribution Function).

An important nuance in our study concerns the definition of "exposure." Whereas the theoretical case presents exposure as easy to quantify, this concept's manifestation in the real world is considerably more complicated. A user may become only vaguely aware of a friend's adoption of the equal sign when the friend's new profile picture appears in the chat side bar. The impression's salience will arguably increase if the profile picture change generates a story in the user's Newsfeed. Furthermore, the user will become even more aware of their friend's decision if they click on such a story, and even more so if they engage with the story by "liking" it. In Figure 8 (b) we consider all these alternative measures of exposure, all of which show the same concave pattern with respect to the probability of adoption.[4]

[3] We only count re-exposures as valid at the first time when a user was known to have logged in to the Facebook platform. For instance, if at t_0 user u logged into Facebook and had $k = 3$ friends who had changed profile pictures, while at the time of u's next login (t_1) $k = 7$ friends had changed profile pictures, we will only count u as having "received" exposures with $k = 3$ and $k = 7$, since it was only at these values that u *could* have changed their profile picture.

[4] The choice of "liking" as a measure of exposure may seem bizarre, as liking seems to be more a measure of pre-existing ideological support for the campaign's goals than a "pure" measure of exposure. A

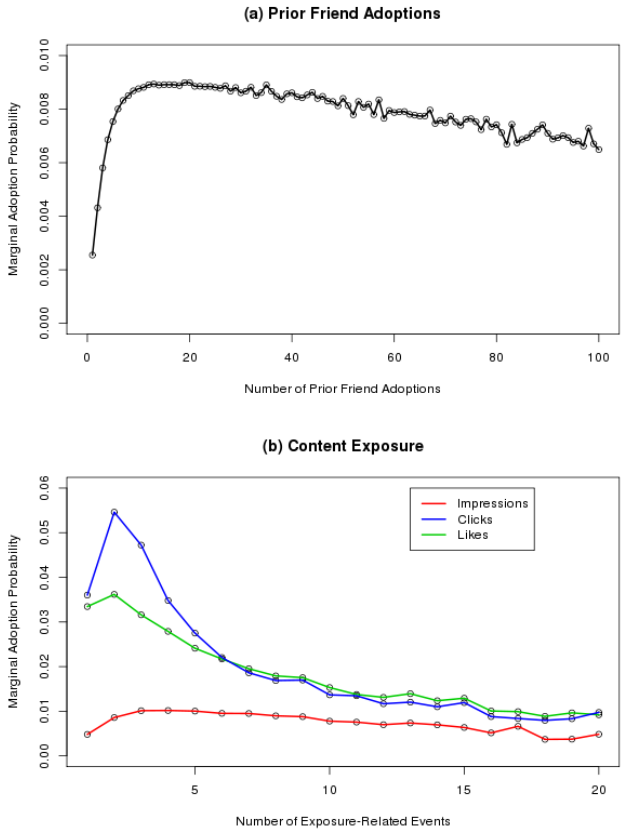

Figure 8: Marginal Adoption Probability as function of friends' adoption and of exposure to profile picture changes.

Distinguishing degrees of complexity in diffusion

The observed, complex diffusion curves for the equals sign stand in contrast to the simple contagion model, where contact with any one adopter carries a constant probability of spreading the diffusion to the susceptible individual. We expect diffusion processes on Facebook to vary between simple and complex according to the cost and benefit of adoption. The simplest contagion ought to occur when the individual has to expend very little time and effort to share content, e.g. simply replicating information. On Facebook, such simple diffusion occurs when a compelling image or message, appearing in a person's Newsfeed, is reshared by that person to her friends at the click of a button.[5] The effort expended is low and also the benefit of sharing the information does not depend on the number of friends who have shared it before. If anything, the image might be less appealing to share if everyone else has shared it already [24]. We therefore expect photo reshare cascades to be well-modeled by a process of simple contagion and include the three such photo cascades in July of 2013 which were the most reshared instances corresponding to known rumors [14]. Other items we might expect to diffuse through a more "complex" or threshold-like mechanism [17]. This may include expressing opinions for which one doesn't know that they are shared by a majority of one's social network, or taking risks such as making oneself vulnerable to ridicule or associating with a disease or condition [30]. In the case of the LGBT rights issue, we hypothesize social proof to be of paramount importance. Given the great level of contention in the same-sex marriage debate, taking a stance either for or against same-sex marriage potentially brings along important social risks to the actor.

We also expect complex diffusion to be more likely to occur when the effort of sharing information is greater than simply clicking a button. Prior to the existence of the reshare button, many ideas propagated when individuals copied others' status updates and pasted them into their own. This action required more effort than a click, and the message varied as well, allowing us to compare diffusion across different memes.

Figure 9 compares the average number of friends who have adopted before an individual does with the total size of the cascade for the three different kind of diffusion: the equal sign movement, three most reshared photo-reshares associated with rumors in July 2013, and 107 copy and paste memes active during 2009-2011. In general, in larger cascades it is more likely that many of one's friends posted first, simply because many people have posted. However, it is the deviations from this trend that reveal how the risk and effort in sharing correlate with seeing several friends post before taking action. As anticipated, the photo reshare cascades exhibit simple contagion – they are typically propagated as soon as 1.3 - 1.5 of one's friends have reshared, i.e. a single exposure is typically sufficient to pass on a rumor. In contrast, copy and paste memes are copied on average after several friends have first. Within these memes there are interesting differences in the extent of complex diffusion as shown in Table 3. High-threshold memes tend to expose the poster to potentially-negative social consequences: the actor risks embarrassment when promising to answer any question posed by their friends – as one such meme demands. By comparison, low-threshold memes deliver only benefits to the actor, as there is arguably little contention (at least comparatively) as to the desirability of appreciating teachers or family, or raising awareness of a security feature.

We observe that the equals sign diffusion is positioned among the higher threshold memes, some of which express political

division of online behavior into "passive" exposure and "active" engagement would be misguided however. A user's current friendship circle and, by extension, their current content stream is the result of prior decisions made by the user: the user decided whom to add as a friend and what kind of content to give feedback on. Thus we may think of liking an equal-sign profile picture change as a particularly strong exposure to the diffusion episode *and* as a manifestation of one's pre-existing ideological support for the movement. Similarly, one's friendship circle is not randomly-selected but its composition is influenced by homophily. Inasmuch as attitudes towards gay rights are one dimension of homophily, the fact that one has friends who support the marriage equality cause is likewise, partially, an indicator of active support for the cause. This entanglement between exposure and support is arguably nothing other than a ramification of the long-noticed confounding of homophily and social influence [1].

[5] It should be emphasized that in the case of profile picture there is no button allowing one to copy another's profile picture on Facebook. The other's profile picture must be downloaded and then re-uploaded to the site.

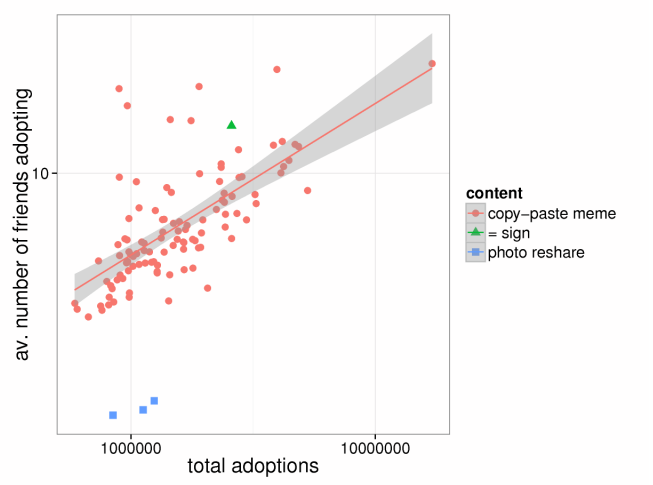

Figure 9: Comparison of the average number of friends previously adopting for three kinds of diffusion actions: changing one's profile to the equals sign, copying and pasting a status update meme, and resharing a photo embodying a rumor.

or religious opinions. With a mean of 14.4 and a median of 8 friends having switched before a given user (Figure 7)[6], the equal-sign movement appears to have required more social proof than most copy-and-paste memes, showing that most individuals need to observe several of their friends taking the action before social proof is sufficient to justify deciding to engage in the action themselves. This could be the result of effort (downloading the photo, and then re-uploading it takes several steps relative to a single click reshare), but also uncertainty about the meaning, importance and popularity of the initiative.

Simulation

We next present a simple model that can account for a range of complex diffusion curves. Prior complex contagion models typically assume that individuals have varying adoption thresholds [17], with the threshold expressed either in terms of the absolute number of friends who have adopted a behavior, or the proportion of friends who have. If such models were to hold, then observing more friends adopting a certain behavior should correspond to a higher likelihood of adoption. Instead, what we saw in Figure 8 and what has surfaced in prior studies [21], is that people who have many exposures, e.g. 40, are less likely to adopt than those who have had a moderate number. How is that possible? One workaround has been to specify the probability of adopting after k friends, $P(k)$, explicitly [31], but this fails to expose the fundamental ingredients of the diffusion process.

Here we propose a model with two separate, essential ingredients, which together produce adoption curves consistent with the complex diffusion model. First, each additional exposure presents an opportunity to adopt, but the marginal increase in adoption probability diminishes. That is, I will be more likely to adopt if a 5th friend adopts than when the 4th friend adopted, but the increase won't be as great as when two friends adopt vs. one., as we saw in the preceeding sections. Second, individuals' susceptibility is heterogeneous: some are more prone to the behavior or cause then others, regardless of the number of adopting friends. A model multiplying the two factors together can produce both the initial increase in probability with increasing numbers of exposures, as well as decreasing probabilities at high numbers of exposures – individuals who have not adopted by this point are very likely to have very low susceptibility and additional exposures are less likely to sway them. We simulate such a spreading process on the network of a small country with 810,923 Facebook users and 76,447,288 undirected edges. There are three main ingredients: (a) the overall infectiousness (virality) of the behavior v, (b) the susceptibility of the individual s_i, and (c) how the likelihood of adoption varies with the number of adopting friends k.

[6]Here we consider only the case of users who have switched after at least one of their friends, see discussion below for the role of broadcasting in getting users to display the picture.

Table 3: Examples of low- and high-threshold textual memes on Facebook.

Friends	Resid.	Normalized Meme Text
20.1	14.2	copy this as your status and see what people want from you 1 phone number 2 second chance 3 hangout 4 friendship ...
23.5	13.3	copy this into your status and see what people rate you 1 crazy 2 I'd marry you 3 talkative 4 sarcastic ...
15.4	8.3	i will be completely honest for 24 hours you can ask me one question only in my inbox any question no matter how crazy sinister or wrong it is i will answer ...
10.8	2.9	in america the homeless go without eating ... yet we donate billions to other countries before helping our own first ...
10.5	2.6	... easter is not about bunnies and chocolate eggs let s lift up god s name and make a statement
9.4	1.5	i am a handful unfortunately most women won t re post this i m strong willed independent a bit outspoken and i tell it like it is
8.3	-0.7	do any of us really know everybody on our friend list here is a task for you i want all my fb friends to comment on this status about how you met me
3.4	-2.3	it s national book week the rules grab the closest book to you go to page 56 copy the 5th sentence as your status ...
3.3	-2.4	a teacher somewhere in your neighborhood tonight is grading iand preparing lessons to teach your children while you are ...
3.5	-3.1	your brother is your first friend in life no one will ever understand your crazy family like your brother even if you ...
3.9	-3.6	attention while on fb look at your url address the very top box on on screen if u see http instead of https ...

Note: Friends: mean number of friends adopting prior to ego's adoption. Resid.: residual of Friends in linear regression (see Figure 9).

We assume that the susceptibility is distributed exponentially. A few people are quite susceptible but most are not. For most trends and fashions, this is likely a sensible assumption, where a few enthusiasts are readily converted, but most of the population is not eager to adopt.

$$p(s_i) = \lambda e^{-\lambda s_i} \quad (1)$$

Next, we model the influence of observing increasing numbers of friends. Seeing more friends should have more influence than seeing fewer, but there should be diminishing returns for each additional friend. We choose to model the probability of adoption as being proportional to the logarithm of k_i to capture this intuition. Finally, we combine all three factors to derive the probability of adoption $p(a_i)$ by individual i, with susceptibility s_i and k friends who have adopted so far:

$$p(a_i) = v s_i \log(k+1) \quad (2)$$

We run the simulation by increasing the virality v until occasional cascades occur starting from a randomly selected individual. Each individual who adopts has one chance to influence each of their friends. We then track k for each adoption and non-adoption after each exposure.

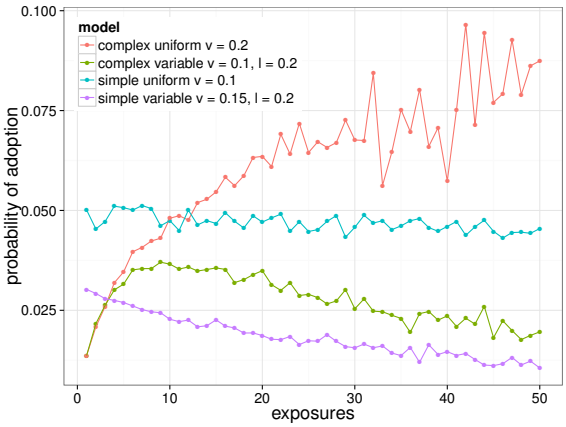

Figure 10: Infection rates of re-exposures (simulated).

In Figure 10 the simulation replicates the empirical diffusion trend from Figure 8 – a trend which is also consistent with the complex diffusion hypothesis. We note that both variable susceptibility and multiple exposures are key to obtaining the characteristic curve. For example, if everyone in the population is equally susceptible, and each exposure has equal likelihood of infection, then the curve is entirely flat. On the other hand, if susceptibility within the population is variable, but each additional exposure has the same probability of infection per individual, then the probability of adopting with each additional exposure drops, because the users who are left over after several exposures are the ones with a lower susceptibility.

Similarly, if the susceptibility is uniform, but observing more friends increases the probability of adoption, then greater k should correspond to strictly higher adoption probability, which is inconsistent with the empirical observation. Finally, if we incorporate both variable susceptibility, and increasing probability of adoption with more exposures, we replicate the empirically-observed pattern. There is an initial increase in adoption probability as more friends adopt and there are many relatively susceptible individuals who are becoming exposed. Those individuals who "survive" many exposures without adopting are likely to be quite resistant to adoption – an observation that serves to explain why the probability of adoption drops again after reaching a peak around a middling number of prior adopting friends.

The above simulation is overly simplistic and does not take into account the varying login rates of different users or the true distribution of susceptibilities. However, it does demonstrate that a few simple assumptions are sufficient to recreate the characteristics of adoption in this diffusion process.

CONCLUSION

In this paper we analyzed the behavior of a single, large social movement on Facebook. Millions of users changed their profile pictures in support of same-sex marriage. Although this was by no means the first large cascade on Facebook, it had a very distinct characteristic: most of these individuals changed their profile picture to a variant of the equal sign only after observing *several* of their friends doing so first. Relative to other types of diffusion on Facebook, the spread of memes in this context is consistent with the complex diffusion hypothesis.

In particular, our findings further bolster the observations made by Romero, Meeder and Kleinberg (2011), about the operation of complex contagion in activities perceived as higher-risk or requiring coordination on the Internet. However, our paper reveals a seemingly-peculiar adoption curve which climbs steeply to a peak level of the adoption probability as the number of adopting friends increases from zero, only to continue on a trajectory of slow decline beyond its maximum. This shape is markedly different from the concave, increasing graph often associated with theoretical understandings of complex diffusion (see the "complex uniform" graph in Figure 10 for an illustration). Our simulation results reveal that, indeed, a process of complex diffusion is very likely to be at work in the case of the equal-sign diffusion episode too. However, the important addendum is that actors in this case present a great degree of heterogeneity in their susceptibility to adoption, a situation which we expect to be the case in many cases involving political mobilization.

These findings are (unsurprisingly) consistent with the existence of different mean levels of susceptibility to adopting a politically-significant meme in various social groups, defined by age, gender, education, and political beliefs. These meso-level differences should not obscure the existence of large amounts of intra-group variation in each person's adoption probability as a function of number of friends adopting. Indeed, we see the same pattern of decline in the adoption probability persist even after accounting for a large number of factors related to social group membership (Table 2).

Hence, we not only provide additional evidence of this diffusion pattern in a different, broader setting, but also demonstrate how varying susceptibilities and multiple exposures can produce P(k) curves similar to those observed in this process. Rather than having to directly specify P(k) in the simulation [31], we make a more natural set of assumptions: susceptibility is highly skewed, and additional exposures have incremental but diminishing influence. Finally, by accounting for the timing and quantity of exposure doses, our work also highlights the robustness of the complex diffusion hypothesis to different measurements of exposure. Our analysis of the drivers of adoption revealed that, net of exposures and Facebook usage, there are important, socially-driven differences in the likelihood to adopt.

As always, there is an interesting confound because susceptibility is homophilous, so that someone who has many friends who have changed their profile picture is themselves likely to be the type of person who would change their profile picture. Previous work [3] has shown that additional exposures

will have higher influence with diminishing returns relative to the individual not observing any social signal from their friends. However the relative effect of seeing one's friends is only partly measured through our observational study [32]. We believe that separating the relative importance of influence and susceptibility in these types of diffusion processes would be a fruitful direction for future research.

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