Concerns for others increase the likelihood of vaccination against influenza and COVID-19 more in sparsely rather than densely populated areas

Haesung Jung[a,1] and **Dolores Albarracín**[a,b]

[a]Department of Psychology, University of Illinois at Urbana–Champaign, Champaign, IL 61820; and [b]The Annenberg Public Policy Center, University of Pennsylvania, Philadelphia, PA 19104

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Vaccination yields the direct individual benefit of protecting recipients from infectious diseases and also the indirect social benefit of reducing the transmission of infections to others, often referred to as *herd immunity*. This research examines how prosocial concern for vaccination, defined as people's preoccupation with infecting others if they do not vaccinate themselves, motivates vaccination in more and less populated regions of the United States. A nationally representative, longitudinal survey of 2,490 Americans showed that prosocial concern had a larger positive influence on vaccination against influenza in sparser regions, as judged by a region's nonmetropolitan status, lesser population density, and lower proportion of urban land area. Two experiments (total $n = 800$), one preregistered, provide causal evidence that drawing attention to prosocial (vs. individual) concerns interacted with social density to affect vaccination intentions. Specifically, prosocial concern led to stronger intentions to vaccinate against influenza and COVID-19 but only when social density was low (vs. high). Moderated mediation analyses show that, in low-density conditions, the benefits of inducing prosocial concern were due to greater perceived impact of one's vaccination on others. In this light, public health communications may reap more benefits from emphasizing the prosocial aspects of vaccination in sparser environments.

vaccination | prosocial concern | herd immunity | social density | regional variation

Vaccination saves lives. If a sufficient number of individuals in a community vaccinate, the immune population will protect those who have medical reasons to avoid the vaccine and those who fail to develop an adequate immune response to the vaccine (1). Therefore, achieving high levels of vaccination at the population level is critical for the protection of not only an individual but also the community at large, a phenomenon referred to as *herd immunity* or *community protection*. Accordingly, encouraging people to consider the prosocial benefits of vaccination has been shown to increase vaccination. For example, promoting the notion of herd immunity strengthens people's intentions to vaccinate, especially in western (vs. eastern) populations which are less motivated to vaccinate out of concern for others (2). In addition, highlighting the benefit of herd immunity for other people (e.g., if you get vaccinated, then you would protect others who are not vaccinated) strengthens vaccination intentions more than highlighting how herd immunity allows individuals to free-ride on others' vaccination (e.g., the more people vaccinate in your environment, the more likely you would be protected without having to vaccinate) (3). Altruistic motives, however, have been shown to predict vaccination more strongly when the costs (e.g., the number of hurdles to get vaccination) of vaccination are low (3) and when people are less susceptible to an infectious disease themselves (4).

This research introduces a critical dimension that may modulate the influence of prosocial concern on vaccination: social density. Social density is an important factor to consider in understanding the ecology of infectious diseases because it directly affects the spread of infectious pathogens in both space and time (5, 6). For example, common infectious diseases spread more widely and more rapidly in socially denser (vs. sparser) environments given a higher average number of contacts per person during a time period (7). Socially dense environments such as large metropolitan areas also have higher social mobility involving frequent human exchange with adjacent regions, which further increases the risk of infections (8). Despite the close connection between social density and the spread of infectious disease, no past research has yet examined whether people living in denser or sparser environments are more or less motivated to vaccinate for the benefit of others.

On the one hand, people may be more motivated to vaccinate for others in denser (vs. sparser) environments. Specifically, perceived impact is an important driver of prosocial behavior (9) such that people help others more when they believe that their actions will generate more benefits and therefore make more impact on others (10). For example, people donate more to charity when they believe that another person or institution will match their gift, allowing their original gift to feel more substantial (11). In this context, consider people in denser (vs. sparser) environments, which objectively involve a higher (vs. lower) probability of disease transmission due to more social contacts. When considering the prosocial outcomes of vaccination, people in denser environments may perceive a larger impact, as they will save more lives if they receive a vaccine. In contrast, people in sparser environments may perceive a lesser

Significance

Vaccination yields the prosocial benefits of preventing the spread of infectious diseases and protecting communities from major disease outbreaks. This research examines how focusing on prosocial concerns motivates vaccination across environments with varying levels of social density. Contrary to the common intuition that prosocial concern should motivate vaccination more in denser areas with more social contacts and disease transmission risk, our results show that prosocial concern yields higher vaccination rates in sparser areas where people believe that their behavior will have more impact. This research identifies emphasizing prosocial aspects of vaccination as one means by which public health interventions can reduce the rural–urban disparity in vaccination.

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[1]To whom correspondence may be addressed. Email: haesung.annie.jung@gmail.com.

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impact, as they will save fewer lives if they receive a vaccine. Hence, the influence of prosocial concern on vaccination may be stronger in more densely populated settings, through a heightened sense of personal impact.

On the other hand, people may be more motivated to vaccinate out of prosocial concerns in sparser (vs. denser) environments because they perceive their own contribution to be more important and therefore more impactful (12). Specifically, people are more likely help others when they are uniquely positioned to do so compared to when they perceive that many other people could also help. For example, people contribute more to public goods in smaller (vs. larger) groups (13, 14) and attend more to calls for help in the presence of few (vs. many) bystanders (15). In the case of sparser (vs. denser) environments, the absence (vs. presence) of other potential helpers may increase people's perception of their personal impact on the community. Hence, the influence of prosocial concern on vaccination may be stronger in more sparsely populated settings, through a heightened sense of personal impact.

Our hypotheses about the influence of prosocial concern on vaccination thus hinged on competing predictions about perceived impact. Whereas denser areas may lead to greater perceived impact because vaccinating may prevent more infections, sparser areas may also lead to greater perceived impact because individuals feel that their own contribution is more unique. We tested the predictions in one longitudinal survey and two controlled experiments, one of them preregistered and conducted with a representative sample of Americans. The survey (study 1) measured vaccination behavior throughout the 2018–2019 flu season. We measured individual differences in prosocial concern for vaccination and examined the extent to which prosocial concern influenced vaccination across varying levels of social density, which was judged by the metropolitan status, population density, and proportion of urban land area of participants' residence. We specifically examined whether prosocial concern interacted with social density, having more or less influence in denser or sparser areas.

Two follow-up experiments established causality by manipulating social density and prosocial concern and by testing their interactive effects on intentions to vaccinate against influenza (study 2) and COVID-19 (study 3, preregistered). These experiments further tested whether, across dense and sparse conditions, prosocial concern influences vaccination intentions through corresponding influences on perceived impact. Over our three studies, we also controlled for well-known correlates of vaccination and vaccination intentions [i.e., demographic variables, perceived risk of infection (16–21), perceived vaccine efficacy (19, 20, 22), perceived knowledge about vaccines (23, 24), perceived ease of vaccination (25, 26), and perceived vaccination norm (24, 27, 28)] and correlates of social density [ethnic diversity (29), social intimacy (30, 31), and negative affect (32)].

Results

Study 1. Study 1 recruited a nationally representative sample of American adults (n = 2,490) to participate in a longitudinal survey at six different time points across the 2018–2019 flu season. Our key dependent variable was whether participants received the vaccine at any point during the flu season, which they reported from time point 2 through time point 6. Because participants also reported their zip code, social density was gauged by calculating county-level metropolitan status, state-level population density, and state-level proportion of urban land area in accordance with participants' zip code. At time point 1, participants completed questions about how worried they would be about infecting their family members, neighbors, coworkers, and strangers, respectively, if they did not get the flu vaccine. These four items demonstrated a high internal consistency (alpha = 0.88) and were thus averaged to create a single index of prosocial concern. In addition, at time point 1, participants also answered demographic questions including gender, age, race/ethnicity, political orientation, religiosity, level of education, household income, employment status, and whether they had health insurance (*SI Appendix*), as well as questions about perceived risk of infection with the flu, perceived vaccine efficacy, perceived vaccine knowledge, perceived ease of getting vaccinated, and perceived norm for vaccination (*Materials and Methods*).

We conducted three separate regressions to test the influence of prosocial concern on vaccination rates across different levels of metropolitan status, population density, and urban land area proportion, respectively. All continuous predictors were z standardized before the analyses. As presented in Table 1, logistic regressions consistently showed a higher likelihood of vaccination when prosocial concern was higher (model 1: $z = 6.64$, $P < 0.001$, 95% CI: 0.75, 1.37; model 2: $z = 15.58$, $P < 0.001$, 95% CI: 0.63, 0.81; model 3: $z = 15.79$, $P < 0.001$, 95% CI: 0.64, 0.82), and no main effects of social density (Table 1). More relevant to our hypotheses, however, prosocial concern had a larger positive effect on vaccination when participants resided in nonmetropolitan areas ($z = -2.18$, $P = 0.03$, 95% CI: −0.70, −0.05), regions with lower population density ($z = -2.29$, $P = 0.02$, 95% CI: −0.45, −0.08), and regions with lower proportion of urban land area ($z = -3.35$, $P < 0.001$, 95% CI: −0.23, −0.06). Thus, prosocial concern correlated with vaccination more positively in areas that were more sparsely rather than more densely populated (Fig. 1).

We next tested the robustness of the findings in Table 1 by also controlling for demographic variables, as well as perceived risk of infection with the flu, perceived vaccine efficacy, perceived vaccine knowledge, perceived ease of getting vaccinated, and perceived norm for vaccination. Based on participant's zip code, we also included an index of state-level ethnic diversity, as this factor could covary with social density and prosocial concern, thus acting as a confound. Among the covariates, ethnic diversity was significantly correlated with all indices of social density (metropolitan status: $r = 0.25$, $P < 0.001$; population density: $r = 0.13$, $P < 0.001$; urban land proportion: $r = 0.10$, $P < 0.001$), and perceived vaccine efficacy weakly correlated with two indices of social density (population density: $r = 0.04$, $P = 0.08$; urban land proportion: $r = 0.04$, $P = 0.06$). Importantly, however, the interaction between prosocial concern and social density did not change due to the introduction of the covariates (*SI Appendix*, Table S1).

In addition to analyzing the combined effects of prosocial concern and density indices on vaccination, we examined how these variables affected the timing of vaccination. As presented in Table 2, Cox proportional hazard survival analyses consistently showed that prosocial concern encouraged earlier vaccination (model 1: $z = 7.35$, $P < 0.001$, 95% CI:0.47, 0.82; model 2: $z = 17.75$, $P < 0.001$, 95% CI: 0.48, 0.60; model 3: $z = 17.76$, $P < 0.001$, 95% CI:0.49, 0.61), whereas social density was unrelated to vaccination timing (Table 2). More importantly, prosocial concern encouraged earlier vaccination to a greater extent in regions with lower population density ($z = -2.89$, $P = 0.004$, 95% CI: −0.15, −0.03) and lower proportion of urban land area ($z = -3.87$, $P < 0.001$, 95% CI: −0.17, −0.06). These effects held after controlling for demographic variables and all of our covariates (*SI Appendix*, Table S1). However, as indicated by a nonsignificant interaction, the effect of prosocial concern on the timing of vaccination did not significantly differ across metropolitan and nonmetropolitan regions ($z = -1.27$, $P = 0.20$, 95% CI: −0.30, 0.06). Overall, the results supported the hypothesis that prosocial concern motivates vaccination to a greater extent in socially sparser environments, rather than the hypothesis that prosocial concern motivates vaccination more in the epidemiologically riskier, socially denser environments. Nevertheless, the effect of prosocial concern on the timing of vaccination was weaker as judged by less consistent effects across the indices of social density.

Table 1. Effects of prosocial concern and density on vaccination

	β (SE)	z	p	95% CI
Model 1: Density index: Metropolitan status				
Prosocial concern	1.05 (0.16)	6.64	<0.001	(0.75, 1.37)
Metropolitan status	−0.25 (0.15)	−1.68	0.09	(−0.53, 0.04)
Prosocial concern × metropolitan status	−0.36 (0.16)	−2.18	0.03	(−0.70, −0.05)
Model 2: Density index: Population density				
Prosocial concern	0.72 (0.05)	15.58	<0.001	(0.63, 0.81)
Population density	0.07 (0.07)	1.02	0.31	(−0.05, 0.23)
Prosocial concern × population density	−0.24 (0.11)	−2.29	0.02	(−0.45, −0.08)
Model 3: Density index: Proportion of urban land area				
Prosocial concern	0.73 (0.05)	15.79	<0.001	(0.64, 0.82)
Urban land proportion	0.03 (0.04)	0.69	0.49	(−0.05, 0.11)
Prosocial concern × proportion of urban land area	−0.14 (0.04)	−3.35	<0.001	(−0.23, −0.06)

β are standardized estimates. SE are standard errors. CI are confidence intervals.

Study 2. We next conducted an experiment to better establish the causal influence of prosocial concern on vaccination across different levels of social density and to determine the role of perceived impact in relation to the effects observed in study 1. Specifically, study 2 examined whether the greater influence of prosocial concern on vaccination in sparser environments is mediated by perceived impact, the extent which one's vaccination will positively impact others in the community. Study 2 further tested alternative explanations that were not addressed in study 1. In particular, social density (e.g., crowdedness) may elicit feelings of discomfort and negative affect, which may, in turn, decrease people's motivation to protect others (32). Likewise, urban dwellers tend to be more alienated and less socially connected with others than rural dwellers (30, 31), which could also result in lower motivation to vaccinate for the benefit of others. Therefore, we examined the moderating effect of social density while controlling for differences in feelings of negative affect and social intimacy.

Study 2 recruited Mechanical Turk workers in the United States ($n = 240$) to participate in an online survey on consumer health. The design was a 2 (social density: low vs. high) × 2 (prosocial concern: prosocial vs. individual) factorial. Social density was manipulated by presenting participants with an image of a less or more crowded store and asking participants to spend a few minutes describing their thoughts and feelings in the store. Participants answered several dummy questions about the store and proceeded to read an article about the flu vaccine. The article explained several outcomes of flu vaccination, including both individual and prosocial benefits. We manipulated prosocial concern by having some participants write about how they

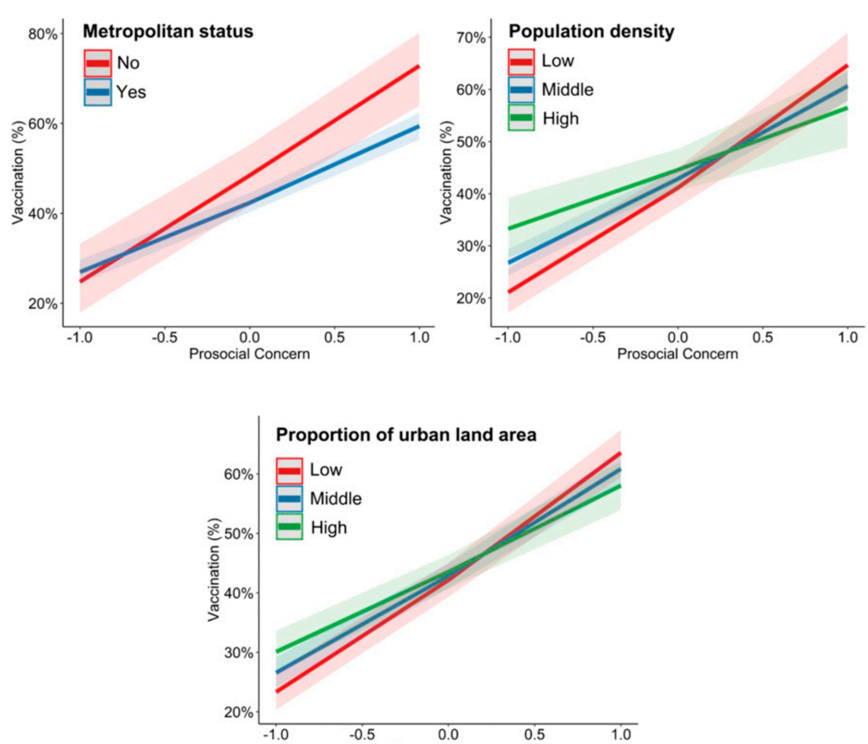

Fig. 1. Interactions between prosocial concern and indices of density on vaccination. All continuous variables (prosocial concern, population density, proportion of urban land area) were standardized prior to analyses. Prosocial concern had significant and steeper positive slopes when density was lower (i.e., 0 for metropolitan status, at 1 SD below the standardized mean of population density and proportion of urban land area) than when it was higher (i.e., 1 for metropolitan status, at 1 SD above the standardized mean of population density and proportion of urban land area).

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Table 2. Effects of prosocial concern and density on vaccination timing

	β (SE)	z	p	95% CI
Model 1: Density index: Metropolitan status				
Prosocial concern	0.65 (0.09)	7.35	<0.001	(0.47, 0.82)
Metropolitan status	−0.13 (0.10)	−1.28	0.20	(−0.34, 0.07)
Prosocial concern × metropolitan status	−0.12 (0.09)	−1.27	0.20	(−0.30, 0.06)
Model 2: Density index: Population density				
Prosocial concern	0.54 (0.03)	17.75	<0.001	(0.48, 0.60)
Population density	0.02 (0.03)	0.52	0.61	(−0.05, 0.08)
Prosocial concern × population density	−0.09 (0.03)	−2.89	0.004	(−0.15, −0.03)
Model 3: Density index: Proportion of urban land area				
Prosocial concern	0.55 (0.03)	17.76	<0.001	(0.49, 0.61)
Urban land proportion	0.03 (0.03)	0.97	0.33	(−0.03, 0.09)
Prosocial concern × proportion of urban land area	−0.11 (0.03)	−3.87	<0.001	(−0.17, −0.06)

β are standardized estimates. SE are standard errors. CI are confidence intervals.

could protect others by getting the flu vaccine (i.e., prosocial concern condition) and other participants write about how they could protect themselves (i.e., individual concern condition) by getting the flu vaccine. After the writing task, participants indicated their intentions to vaccinate and the extent to which their decision to vaccinate would make a positive impact on others. Participants then responded to manipulation checks and items that addressed alternative explanations (i.e., affect and social intimacy; *Materials and Methods*).

As shown in Fig. 2, a factorial ANOVA yielded a significant interaction between social density and prosocial concern on vaccination intention (F [1,236] = 4.86, P = 0.03, 95% CI: 0.11, 1.95). In the low-density condition, participants in the prosocial concern condition reported stronger intentions to vaccinate (M = 5.61, SD = 1.46) than did participants in the individual concern condition (M = 4.89, SD = 2.02); t(118) = 2.25, P = 0.03. In the high-density condition, however, participants had similar intentions to vaccinate regardless of whether they were in the prosocial (M = 5.02, SD = 1.89) or the individual concern condition (M = 5.32, SD = 1.81); t(118) = −0.90, P = 0.37. Thus, these results conceptually replicated the findings from our longitudinal survey in an experimental context.

We next examined whether the varying effect of prosocial concern across low and high social density conditions was due to differences in the perceived impact of vaccination in each case. After all manipulations were checked and found to produce the expected results (*Materials and Methods*), we found a significant interaction between social density and prosocial concern on perceived impact (F[1,236] = 4.51, P = 0.03, 95% CI: 0.07, 1.76; Fig. 3). In the low-density condition, participants in the prosocial concern condition perceived that their vaccination would have a greater impact on others (M = 5.38, SD = 1.38) than did participants in the individual concern condition (M = 4.77, SD = 1.94); t(118) = 1.98, P = 0.05. In the high-density condition, participants in the prosocial concern condition reported perceptions of impact (M = 4.92, SD = 1.72) similar to those in the individual concern condition (M = 5.22, SD = 1.56); t(118) = −1.01, P = 0.32. A bias-corrected moderated mediation analysis based on a bootstrapping method (33) showed a significant moderated mediation (Index = −0.73, 95% CI: −1.41, −0.07). When social density was low, prosocial concern increased the perceived impact of vaccination, which, in turn, drove its positive effect on vaccination intentions (ab = 0.49, 95% CI: 0.02, 0.98). This indirect effect was not evident when social density was high (ab = −0.24, 95% CI: −0.70, 0.22). Importantly, the effects held after controlling for feelings of social intimacy and affect (Index = −0.74, 95% CI: −1.39, −0.11).

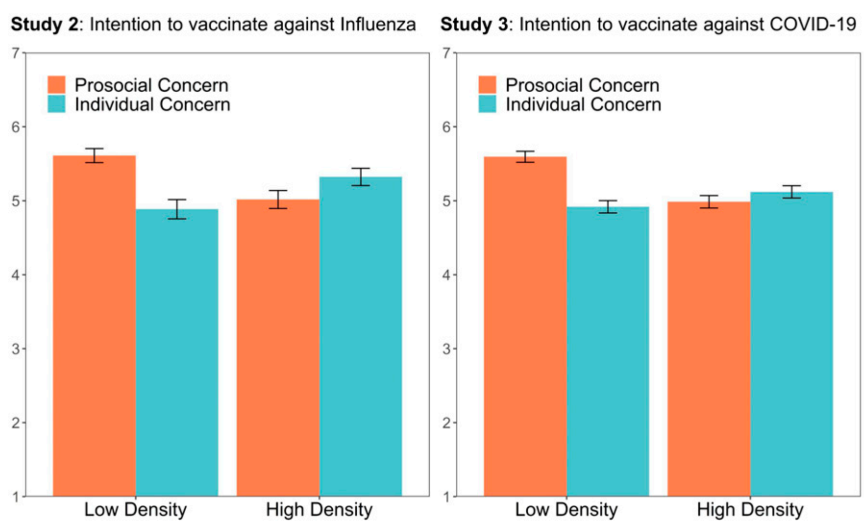

Fig. 2. Interaction between prosocial concern and density on intentions to vaccinate against influenza (study 2; n = 240) and COVID-19 (study 3; n = 560). Error bars represent ±1 SE of the mean. When social density was low, prosocial concern led to stronger intentions to vaccinate than individual concern. When social density was high, prosocial concern led to similar intentions to vaccinate as individual concern.

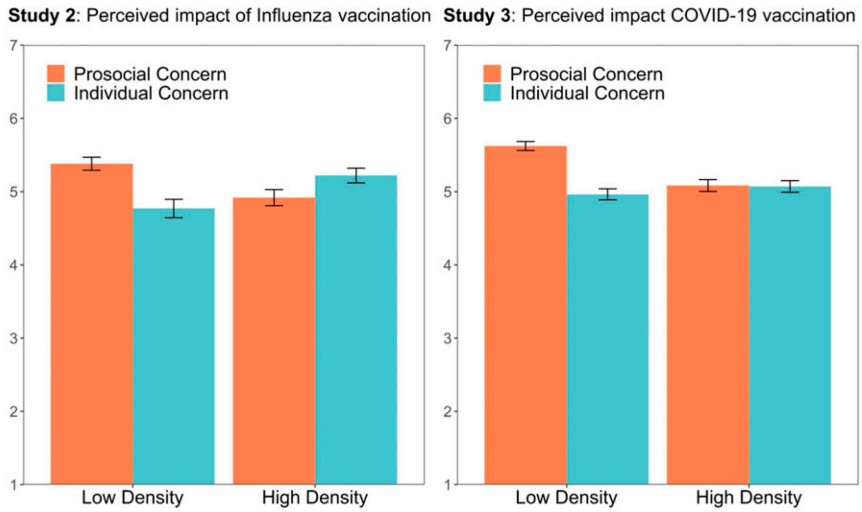

Fig. 3. Interaction between prosocial concern and density on perceived impact of vaccination against influenza (study 2; $n = 240$) and COVID-19 (study 3; $n = 560$). Error bars represent ±1 SE of the mean. When social density was low, prosocial concern led participants to perceive a greater impact than individual concern. When social density was high, prosocial concern led to similar perceptions of impact as individual concern.

In conclusion, the results from the first two studies supported the prediction that prosocial concern influences prosocial action more when fewer people are in the vicinity. Study 2 also showed that this effect is driven by greater perceptions of the impact of one's vaccination. Nevertheless, one may argue that a potential limitation of studies 1 and 2 is that the studies examined vaccination against the flu, which may be perceived as relatively lower risk than, for example, the novel coronavirus. One could further argue that our effects may not hold for higher-risk diseases with more significant health and social consequences. When stakes are high, people may be motivated to vaccinate regardless of where they live or regardless of whether they are concerned with the prosocial or individual benefits of vaccination. To conceptually replicate and test the robustness of the effects observed in our previous studies, we conducted a preregistered experiment (https://aspredicted.org/q7mb7.pdf) that examined the effects of social density and prosocial concern on the intention to vaccinate against COVID-19.

Study 3. Study 3 involved a nationally representative sample of American adults ($n = 560$) who participated in an online survey on consumer health. Like in study 2, participants were randomly assigned to one of the conditions of a 2 (social density: low vs. high) × 2 (prosocial concern: prosocial vs. individual) factorial design. We successfully manipulated social density (low or high) using the same protocol as study 2. After the manipulation, participants read an article about a COVID-19 vaccine. The article described an interview with Anthony Fauci, the director of the National Institute of Allergy and Infectious Diseases (NIAID), during which he discussed the possibility of a COVID-19 vaccine becoming available in the foreseeable future (34). We successfully manipulated prosocial concern by having some participants read about how they could protect others in their community by getting the COVID-19 vaccine (i.e., prosocial concern condition), and other participants read about how they could protect themselves (i.e., individual concern condition) by getting the COVID-19 vaccine (*Materials and Methods*). Participants indicated their intentions to vaccinate and the extent to which they expected their decision to vaccinate to have a positive impact on others in their community. As in study 2, participants then responded to manipulation checks and items that addressed alternative explanations (*Materials and Methods*).

The findings from our preregistered study 3 supported the conclusions from the earlier studies. Reproducing the findings from study 2 (Fig. 2), a factorial ANOVA yielded a significant interaction between social density and prosocial concern on vaccination intention; $F(1{,}556) = 6.19$, $P = 0.01$, 95% CI: 0.17, 1.45. In the low-density condition, intentions to vaccinate were stronger among participants in the prosocial concern condition ($M = 5.59$, SD = 1.75) than participants in the individual concern condition ($M = 4.92$, SD = 1.96); $t(271) = 3.01$, $P = 0.003$. In the high-density condition, however, intentions were similar across the prosocial ($M = 4.99$, SD = 2.00) and individual concern conditions ($M = 5.12$, SD = 1.98); $t(285) = -0.57$, $P = 0.57$.

We next examined whether the different effects of the prosocial concern manipulation on vaccination in sparse and dense conditions were due to corresponding differences in perceived impact. As in study 2 (Fig. 3), we found a significant interaction between social density and prosocial concern on perceived impact ($F[1{,}556] = 4.69$, $P = 0.03$, 95% CI: 0.06, 1.23). In the low-density condition, participants in the prosocial concern condition indicated that their decision to vaccinate would have a greater impact on others ($M = 5.62$, SD = 1.45) than did participants in the individual concern condition ($M = 4.96$, SD = 1.78); $t(271) = 3.36$, $P = 0.001$. In contrast, in the high-density condition, perceptions of impact were similar across the prosocial ($M = 5.08$, SD = 1.91) and individual concern conditions ($M = 5.07$, SD = 1.87); $t(285) = 0.06$, $P = 0.95$. A bias-corrected moderated mediation analysis based on a bootstrapping method (33) showed a significant moderated mediation (Index = −0.58, 95% CI: −1.11, −0.06). When social density was low, prosocial concern increased the perceived impact of vaccination, which, in turn, led to stronger vaccination intentions ($ab = 0.60$, 95% CI: 0.25, 0.94). Finally, this indirect effect was not evident when social density was high ($ab = 0.01$, 95% CI: −0.39, 0.42), and all effects held after controlling for feelings of social intimacy and affect (Index = −0.62, 95% CI: −0.1.11, −0.14).

Discussion

Vaccination plays a pivotal role in protecting communities by interrupting the chain of human-to-human transmission and thus preventing major disease outbreaks. In this research, we examined how considering the prosocial consequences of vaccination affects vaccination, and whether this effect varies across levels of social density, a contextual factor that directly affects the spread of an infection in a given population. In doing so, we measured individual differences in prosocial concern for vaccination, and experimentally manipulated prosocial concern to observe its effects on vaccination against two different infectious diseases, namely, influenza and COVID-19. We also explored several indices of social density (i.e., metropolitan status, population density, and proportion of urban land area), and measured vaccination intention as well as actual behavior. The findings converged to show that, even though the level of prosocial concern is similar across levels of social density, this concern has more positive influence on vaccination when social density is lower.

Specifically, study 1 surveyed 2,490 Americans and found that prosocial concern, measured as respondents' concern for infecting others if they themselves do not vaccinate, had a greater positive influence on vaccination in regions that are nonmetropolitan, have lower population density, and have lower proportion of urban land area than regions that are metropolitan, have higher population density, and have higher proportion of urban land area. Studies 2 and 3 provided an experimental demonstration of the interactive effects of prosocial concern and social density and found that calling attention to the prosocial (vs. individual) benefits of vaccination had a larger positive effect on vaccination intentions when density was low (vs. high). These studies further showed that social density itself does not affect the level of prosocial concern (*Materials and Methods*). However, prosocial (vs. individual) concern influenced vaccination more among participants who imagined being in sparse (vs. dense) environments and thus having more impact on others.

Our findings have several theoretical and practical implications. They extend prior work on the importance of impact when encouraging prosocial actions to identify social density as one determinant of perceived impact. Theoretically, then, social density may influence other behaviors that are considered to affect others' well-being, such as participating in social movements that advocate gender and racial equality, through perceptions of personal impact. Likewise, our findings can be applied to other spaces, such as hospitals, college dormitories, schools, and workplaces, where social density in people's immediate environments may also affect the processes leading to altruistic behavior. These possibilities could be explored in future research.

We also contribute to the understanding of prosocial behavior in rural and urban environments. Specifically, people who live in urban regions are known to be less attentive to others' needs than their rural counterparts (35), a difference attributed to greater levels of stress (31) and higher anxiety in interactions with dissimilar others (29) in urban environments. In contrast, our results suggest that urban and rural dwellers are equally concerned with the welfare of others but that rural ones perceive their actions to have more impact. Our findings are conceptually related to "diffusion of responsibility" (15) as an explanation for why people help less in urban (vs. rural) regions. That is, both rural and urban inhabitants may attend to the needs of others, but the presence of other potential helpers in more crowded environments may undermine perceived responsibility to initiate action. Perceived impact and responsibility are interrelated but may nonetheless produce different outcomes (36) that future research should investigate.

The regional variation in the influence of prosocial concern on vaccination observed in our studies naturally brings us to discuss the disparities in rural and urban health. Specifically, reports have shown that the rate of pneumococcal vaccination is 40% lower in rural (vs. urban) communities (37), that fewer adolescents in rural (vs. urban) areas receive human papillomavirus (HPV) and meningococcal conjugate vaccines (38), and that the rural–urban disparity in vaccination is more severe for recommended vaccines than required vaccines (39). At the structural level, policy makers aim to increase access to health care services in rural regions to close the immunity gaps, whereas, at the communication level, many health care professionals and health officials are working toward increasing knowledge and awareness of vaccines (39). Our findings contribute to these efforts by proposing a prosocial emphasis of vaccination as an effective communication strategy that can particularly benefit the rural regions. Importantly, our observed effects persisted even when controlling for education level, household income, and access to health insurance, the leading causes of rural–urban health disparities. In addition, our effects held over and above several factors that could vary across rural and urban communities, including perceived risk of infection, perceived vaccine efficacy, perceived vaccine knowledge, perceived ease of vaccination, and perceived norm for vaccination. These results underscore the robustness of our effects.

Despite the implications of our findings, there are several remaining questions that could be addressed in future research. Specifically, future research could explore situations in which prosocial concern may yield less willingness to vaccinate than individual concern. For example, when people are explicitly informed that the majority of their community is immune to a particular infectious disease, the positive effect of prosocial concern may disappear because individual vaccination may appear to have little impact. In such cases, appealing to the individual rather than the prosocial benefits may be advisable. Future work could also validate our findings in non-American countries, where vaccination rates have been shown to be lower in rural than urban communities, including China (40), India (41), and Nigeria (42). Future work could also examine whether our findings generalize to other types of vaccines that were not tested in the current work, particularly the HPV, the measles, mumps, rubella, and the meningococcal conjugate vaccines, all of which have lower adherence in vulnerable rural communities (38). Lastly, future work could explore whether our findings generalize to other health behaviors with important social consequences. Although study 3 examined intentions to vaccinate against COVID-19, the vaccine is not yet available. Other recommended steps to reduce transmission for oneself and others include maintaining physical distance, wearing face masks, and handwashing (43). Prosocial concern and social density may turn out to be critical for these preventive behaviors as well.

Materials and Methods

Ethics Statement. The studies involved human subjects and complied with the ethical standards of the American Psychological Association. All participants across studies 1, 2, and 3 provided informed consent to use their data for scientific purposes without their identity being disclosed. Study 1 was approved by the institutional review board of the University of Pennsylvania, and studies 2 and 3 were approved by the institutional review board of the University of Illinois at Urbana–Champaign. All studies were considered to pose negligible risk, and therefore were approved as exempt research.

Study 1. Participants (n = 2,490) were recruited as part of a large panel study on perceptions of infectious diseases and vaccination (*SI Appendix*, Table S7). The data were gathered by NORC (National Opinion Research Center) at the University of Chicago between September 2018 and October 2019 at six different time points (time 1 = September 2018, time 2 = November 2018, time 3 = January 2019, time 4 = March 2019, time 5 = May 2019, time 6 = October 2019). The frame comprised a probability-based and nationally representative sample of American adults. Most participants completed the survey online (n = 2,289), whereas a small group completed the survey on the phone. Most participants completed the survey in English (n = 2,436), whereas a small group completed the survey in Spanish.

Prosocial concern. Prosocial concern for vaccination was measured at time point 1 by asking participants how worried they would be about infecting their family members, neighbors, coworkers, and strangers, respectively, if they did not get the flu vaccine (1 = not worried at all, 4 = very worried). Because there was a high internal consistency among the items (alpha = 0.88), we averaged the four items into a single index (M = 2.32, SD = 0.88). We note that, when individual items are analyzed separately, the pattern of results remains stable (*SI Appendix*, Tables S2–S5).

Social density. Social density was gauged in three ways. First, each participant was geocoded to generate an indicator of metropolitan statistical area (44). Metropolitan statistical areas are delineated at the county level, such that, from participants' zip code, county-level demographic information was first extracted, and, if a county had at least 50% of the population residing within urban areas of 10,000 or more population, or contained at least 5,000 people residing within a single urban area of 10,000 or more population, the participant was coded as residing in a metropolitan area. Following this procedure, a participant with a zip code 85016 (Maricopa County, AZ) was coded as 1, whereas a participant with a zip code 99921 (Marion County, WV) was coded as 0. Second, we computed density at the state level, by first classifying participants' zip code into states and calculating the population density for each respective state (45). For example, a participant with a zip code 85016 received a score of 64.0445, which corresponds to the population density in the state of Arizona. Third, we obtained information on the proportion of urban land area for each state (46). For example, a participant with a zip code 85016 received a score of 0.02, which corresponds to the proportion of urban land area in the state of Arizona.

Vaccination. Vaccination behavior, which was our key dependent variable, was measured across time points 2 through 6. Specifically, at each time point, participants were asked, "Have you gotten the flu vaccine this season or not." We created a binary variable, vaccination (yes = 1, no = 0), which indicates whether participants received the vaccine at any point during time points 2 through 6.

Demographics and covariates. Demographic questions were measured at time point 1, including gender (1 = male, 2 = female), age (1 = 18 y to 24 y, 7 = 75+ y), ethnicity (1 = White/non-Hispanic, 2 = Black/non-Hispanic, 3 = other/non-Hispanic, 4 = Hispanic, 5 = two or more/non-Hispanic, 6 = Asian/non-Hispanic), political orientation (1 = very liberal, 5 = very conservative), religiosity (1 = yes, 0 = no), education (1 = less than high school diploma, 4 = Bachelor's degree and above), household income (1 = less than \$5,000, 18 = \$200,000 or more), employment status (1 = yes, 0 = no), and health insurance status (1 = yes, 0 = no). Additional items that could potentially covary with social density to influence vaccination were also measured at time point 1. Specifically, we measured perceived risk of infection (How likely, if at all, do you think you are to get infected with the flu this flu season?; 1 = none at all, 4 = a great deal), perceived vaccine efficacy (How effective, if at all, do you think the flu vaccine will be at preventing the flu among those who get the vaccine this season?; 1 = none at all, 4 = a great deal), perceived vaccine knowledge (How much do you think you know about the flu vaccine?; 1 = none at all, 4 = a great deal), perceived ease of vaccination (How difficult or easy is it for you to get the flu vaccine?; 1 = very difficult, 4 = very easy), and perceived norm for vaccination (How likely, if at all, do you think people who are important to you will get the flu vaccine in a typical year?; 1 = none at all, 4 = a great deal). We also obtained an index of ethnic diversity that may covary with social density to affect prosocial concern. The state-level diversity index represented the likelihood that two persons chosen at random from the same area belong to different race or ethnic groups (47). Correlations between social density, prosocial concern, and the covariates are reported in *SI Appendix*, Table S6.

Study 2. Two hundred and forty US-based participants recruited through Mechanical Turk completed an online "consumer health" survey (*SI Appendix*, Table S7).

Procedures. Upon entering the survey, participants were informed that the survey contained two unrelated parts, the first part being a consumer experience survey and the second part being a health survey. In the first part, we presented participants with an image of a store (48), and asked them to spend a few moments examining the store as if they were to buy a pair of shoes from it. In the low-density condition, participants were presented with an image of a less attended store (containing four people). In the high-density condition, participants were presented with an image of a crowded store (containing 35 people). To facilitate the imagined experience in the store, we further asked participants to spend a few minutes describing their thoughts and feelings in the store.

During the second part, participants read an article about the flu vaccine. The article informed participants of the flu season, which was at its peak during the time the study was conducted. The article explained several benefits of flu vaccination. Some were individual benefits, such as reducing the chance of getting sick with the flu and reducing the risk of flu-associated hospitalization. Some were prosocial benefits, such as reducing the transmission of the flu virus in their community and protecting those who are more vulnerable to serious flu illness. After participants read the article, half of the participants were randomly assigned to recall the article and describe how they can protect others by getting the flu vaccine (i.e., prosocial concern condition). The other half of the participants were asked to recall the article and describe how they could protect themselves by getting the flu vaccine (i.e., individual concern condition). See *SI Appendix*, Table S8 for participant assignment in each of the four conditions.

Vaccination intention and perceived impact. After the writing task, we measured vaccination intention by asking, "to what extent would you be willing to get the flu vaccine?" (1 = none at all, 7 = a great deal). We measured the extent to which participants perceived that their decision to vaccinate would have an impact on others, using two items: "To what extent do you think that 'you' getting the flu vaccine will make a positive impact on other people in your community?" and "To what extent do you think that 'you' getting the flu vaccine will make a positive difference in your community?" (1 = none at all, 7 = a great deal). The two items were averaged to create a single index of perceived impact ($\alpha = 0.93$; $M = 5.07$, SD = 1.67).

Covariates. For control purposes, we also measured whether our social density manipulation affected feelings of social intimacy and affect. Specifically, participants were asked to recall their hypothetical experience in the store that was presented in the first part of the survey. We then asked participants to rate the extent to which they felt 1) in tune with other people in the store, 2) that no one really knew them well in the store (reverse-coded), 3) that they could easily find companionship if they wanted to, 4) that people were around them but not with them (reverse-coded), 5) that they were willing to engage in a conversation with other people in the store, and 6) that they were willing to exchange contacts with other people in the store (1 = none at all, 7 = a great deal). The six items were averaged to create a single index of social intimacy ($\alpha = 0.77$; $M = 3.14$, SD = 1.27). As participants recalled their hypothetical experience in the store, we further asked the extent to which their experience in the store was pleasant or unpleasant (1 = very unpleasant, 7 = very pleasant; $M = 3.70$, SD = 2.10). Participants in the high-density condition reported social intimacy ($M = 3.01$, SD = 1.36) similar to participants in the low-density condition ($M = 3.28$, SD = 1.16); $F(1,236) = 2.72$, $P = 0.10$. Prosocial concern did not affect social intimacy ($F[1,236] = 0.02$, $P = 0.90$), nor was there an interaction between social density and prosocial concern ($F[1,236] = 0.11$, $P = 0.75$). We found a significant main effect of density on participants' affect, $F(1,236) = 34.46$, $P < 0.001$, with participants feeling less pleasant ($M = 2.96$, SD = 2.04) in the high-density condition than the low-density condition ($M = 4.45$, SD = 1.88). However, prosocial concern did not influence participants' affect ($F[1,236] = 0.52$, $P = 0.47$), nor was there an interaction between social density and prosocial concern ($F[1,236] = 0.02$, $P = 0.89$).

Manipulation checks. We administered manipulation checks by asking participants how crowded they felt when imagining themselves in the store that was presented in the first part of the survey (1 = none at all, 7 = a great deal). Participants also rated the extent to which they would be worried about infecting their community members if they did not vaccinate (1 = none at all, 7 = a great deal). Participants in the high-density condition experienced more crowdedness ($M = 6.40$, SD = 1.02) than did participants in the low-density condition ($M = 3.02$, SD = 2.24); $F(1,236) = 228.29$, $P < 0.001$). Also as expected, participants in the prosocial concern condition were more concerned about infecting others if they did not vaccinate ($M = 4.83$, SD = 1.76) than were participants in the individual concern condition ($M = 4.20$, SD = 1.91; $F(1,236) = 6.87$, $P = 0.01$). We found no evidence of unintended effects of our manipulations. Specifically, prosocial concern did not affect perceived crowdedness ($F[1,236] = 1.03$, $P = 0.31$), nor was there an interaction between density and prosocial concern ($F[1,236] = 1.88$, $P = 0.17$). Furthermore, density did not affect reported concerns for others ($F[1,236] = 0.06$, $P = 0.81$), nor was there an interaction between density and prosocial concern ($F[1,236] = 0.28$, $P = 0.60$). We therefore concluded that our manipulations were successful.

Study 3. Five hundred and sixty participants were recruited to complete an online "consumer health" survey (*SI Appendix*, Table S7). The hypotheses were preregistered through http://aspredicted.org (https://aspredicted.org/q7mb7.pdf). Participant recruitment frame comprised a nationally representative sample of American adults provided by the survey company Dynata. Dynata oversampled participants to meet their internal standards for data quality. Given that Dynata's internal standards were not part of our preregistered inclusion criteria, we used the full sample that met our preregistered inclusion criteria.

Procedures. Participants were randomly assigned to either a low-density or high-density condition and completed the same density manipulation procedure as in study 2. As in study 2, participants then read an article about a COVID-19 vaccine. The article cited an interview with the director of the NIAID. The interview covered the possibility of a COVID-19 vaccine becoming available in the foreseeable future. Some participants were randomly assigned to read about the prosocial benefits of COVID-19 vaccine, such as reducing the transmission of the virus in the community and protecting those who are more vulnerable to serious illness (i.e., prosocial concern condition). Participants were also asked to briefly summarize what they have read. Other participants were randomly assigned to read about the individual benefits of COVID-19 vaccine, such as reducing one's individual risk of contracting COVID-19 and avoiding hospitalization from the COVID-19 disease (i.e., individual concern condition). These participants were also asked to briefly summarize what they have read. See *SI Appendix*, Table S8 for participant assignment in each of the four conditions.

Vaccination intention and perceived impact. Next, we measured vaccination intention by asking, "to what extent would you be willing to get the COVID-19 vaccine?" (1 = none at all, 7 = a great deal). We also measured the extent to which participants perceived their decision to vaccinate to impact others, using two items identical to those in study 2. These items were averaged to create a single index of perceived impact ($\alpha = 0.92$; $M = 5.18$, SD = 1.78).

Covariates. We also measured whether our social density manipulation affected feelings of social intimacy ($\alpha = 0.74$; $M = 3.83$, SD = 1.26) and affect ($M = 3.36$, SD = 1.86), using the same items as study 2. Participants in the high-density condition reported feeling lower social intimacy ($M = 3.67$, SD = 1.27) than did participants in the low-density condition ($M = 4.00$, SD = 1.23); $F(1,556) = 9.29$, $P = 0.002$. Prosocial concern did not affect social intimacy ($F[1,556] = 1.22$, $P = 0.27$), nor was there an interaction between social density and prosocial concern; $F(1,556) = 0.12$, $P = 0.73$. There was a significant main effect of density on participants' affect ($F[1,556]= 12.69$, $P < 0.001$), with participants in the high-density condition feeling less pleasant ($M = 3.09$, SD = 1.93) than those in the low-density condition ($M = 3.64$, SD = 1.74). However, prosocial concern did not influence participants' affect ($F[1,556] = 1.95$, $P = 0.16$), nor was there an interaction between social density and prosocial concern; $F(1,556) = 0.20$, $P = 0.66$.

Manipulation checks. We administered manipulation checks using the same items as study 2. As expected, participants in the high-density condition experienced more crowdedness ($M = 5.70$, SD = 1.74) than did participants in the low-density condition ($M = 3.14$, SD = 2.04); $F(1,556) = 254.76$, $P < 0.001$. Also as expected, participants in the prosocial concern condition reported feeling more concerned about infecting others if they did not vaccinate ($M = 4.96$, SD = 1.82) than did participants in the individual concern condition ($M = 4.54$, SD = 1.90); $F(1,556) = 6.95$, $P = 0.01$. However, there was no evidence of unintended effects of any of our manipulations. First, prosocial concern manipulation did not affect crowdedness ($F[1,556] = 0.01$, $P = 0.91$), nor was there an interaction between density and prosocial concern ($F[1,556] = 0.10$, $P = 0.75$). Second, density did not affect reported concerns for others ($F[1,556] = 1.31$, $P = 0.25$), nor was there an interaction between density and prosocial concern ($F[1,556] = 1.18$, $P = 0.28$). We therefore concluded that our manipulations were successful. The data and codes of all three studies are available online from the Open Science Framework (OSF) (https://osf.io/y37kq/).

Data Availability. Anonymized data and codes have been deposited in OSF (https://osf.io/y37kq/).

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