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What we can learn from five naturalistic field experiments that failed to shift commuter behaviour

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Across five field experiments with employees of a large organization ($n = 68,915$), we examined whether standard behavioural interventions ('nudges') successfully reduced single-occupancy vehicle commutes. In Studies 1 and 2, we sent letters and emails with nudges designed to increase carpooling. These interventions failed to increase carpool sign-up or usage. In Studies 3a and 4, we examined the efficacy of other well-established behavioural interventions: non-cash incentives and personalized travel plans. Again, we found no positive effect of these interventions. Across studies, effect sizes ranged from Cohen's $d = -0.01$ to $d = 0.05$. Equivalence testing, using study-specific smallest effect sizes of interest, revealed that the treatment effects observed in four out of five of our experiments were statistically equivalent to zero ($P < 0.04$). The failure of these well-powered experiments designed to nudge commuting behaviour highlights both the difficulty of changing commuter behaviour and the importance of publishing null results to build cumulative knowledge about how to encourage sustainable travel.

Twenty-four per cent of global energy-related CO_2 emissions result from transportation[1]. Drastic reductions in emissions must take place in the current decade to avoid expensive and potentially catastrophic climatic events[2]. A primary source of emissions within the control of individual decision makers (versus corporate actors) is the use of single-occupancy vehicles (SOV).

Most individuals commute to work every day: US workers spend an average of 200 h per year commuting[3], while UK workers spend an average of 250 h (Lloyds Bank, unpublished data). Seventy-six per cent of Americans drive alone to work in their car[4].

Correlational studies find that car commuters have significantly higher levels of self-reported stress compared to rail commuters in Canada[5], and report lower levels of life satisfaction in the USA[6]. In fact, research from the UK has demonstrated that driving to work is associated with an increased risk of developing high blood pressure and having a higher body mass index[7], putting citizens at increased risk for cardiovascular death[8].

To reduce congestion, pollution and potentially increase citizens' health, it is critical to encourage individuals to engage in alternative forms of commuting, such as carpooling or taking transit. Due to far-reaching success in other policy domains, 'nudges' have gained attention as a potential lever to reduce the use of SOVs and encourage alternative forms of transportation[9,10].

Nudges are modifications to the decision-making environment that are non-coercive, easy to avoid and do not substantially change economic incentives[11]. The most widely cited definition explicitly states that "to count as a mere nudge, the intervention must be easy and cheap to avoid"[11]. Common examples include information provision[12], asking people to come up with specific plans[13] and simplifying or making it easier for people to perform a desired behaviour[14]. Nudges are considered a cost-effective policy tool and are effective at shaping a diverse range of behaviours including tax compliance, energy reduction, vaccination attainment and retirement planning (see ref. [15] for cost-effectiveness calculations). Attesting to their widespread use, as of 2018, >200 'nudge units' were operating in governments and institutions globally[16].

While there is a large body of research that seeks to uncover the barriers of sustainable travel, it is largely situated within the transportation literature and does not typically measure behaviour (the main outcome of nudge studies). Indeed, most previous research has relied primarily on cross-sectional, self-reported correlational surveys and qualitative focus groups[17–19]. To overcome the limitations of previous research, and to capitalize on growing interest from policy makers, we designed several large-scale field experiments to test whether behaviourally informed interventions could encourage sustainable commuting behaviours—such as registering for a carpool platform or taking the bus to work rather than driving.

Across five experiments involving 68,915 employees, we tested the impact of well-researched behavioural interventions shown to be effective in other contexts, including reducing friction costs, peer testimonials, loss framing and small financial incentives[14,15] (see details below). Our outcomes of interest included any shift away from driving alone, such as carpooling, taking public transport or active commuting (that is, biking or walking). Because we worked with a large employer, we could study employees who would not otherwise select into commuter behaviour studies or seek out information about sustainable commuting options. Employees did not know that they were in a study or that their behaviour was being recorded, which is a critical feature of our experiments because people often act differently when they know that their behaviour is being monitored[20]. Our paper therefore seeks to contribute to the literature by providing robust evidence for various behavioural interventions that are often recommended but seldom experimentally tested.

In Study 1 ($n = 54,887$), we tested the efficacy of sending behaviourally informed letters on carpooling behaviour. Employees were randomly assigned to one of four conditions. In the control condition, employees did not receive a letter. In the first treatment condition, employees received a standard letter containing information

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about a carpooling service previously offered by their workplace. In the second treatment condition, employees received a letter designed to reduce friction costs. In the third treatment condition, this letter included two testimonials. We tested the efficacy of these interventions based on research showing that they shifted behaviour in other domains.

Reducing friction costs—or making services easier to use—can encourage follow-through[14]. For example, in one experiment, people were 22% more likely to fill out a form to pay their taxes on time when they received a mailer directing them to a website where they could immediately complete the relevant paperwork[21]. Thus, in the current study, our second treatment condition prominently featured the link to a form where employees could register to carpool.

Peer testimonials can also improve pro-environmental attitudes. In one experiment, people's intentions to engage in pro-environmental behaviour (that is, buying greener products) increased after reading a peer testimonial (versus no peer endorsement) because the message was seen as more trustworthy[22]. Peer testimonials also send a signal about descriptive norms by showing that peers engage in the focal behaviour, increasing uptake[23]. Building on this research, our third treatment condition prominently featured peer testimonials. In this condition, we included pictures of peers. This decision was based on research showing that social information presented alongside images is more effective than social information presented on its own[24].

As described above, there is extant experimental research showing that psychologically informed direct mailings can shift behaviours with positive externalities (for example, tax repayment)[21]. Nevertheless, we found limited evidence examining the effectiveness of reducing friction costs and peer testimonials on increasing carpooling behaviour among employees of a large organization. Thus, Study 1 provides a valuable road test of several ideas shown to be effective at encouraging behaviours with positive externalities in diverse contexts.

In Study 2 ($n = 871$), we tested two other behaviourally informed interventions designed to increase carpooling behaviour for employees already registered for the carpooling service: personalized recommendations and opportunity cost reminders. Specifically, we tested a control email against two treatment emails. The first treatment email featured 'carpool matches' and the second treatment email featured matches and an opportunity cost reminder. In the match condition, participants were provided with personalized recommendations about potential carpool matches (employees who lived nearby and with whom they could share a ride).

We made this decision based on pilot data and empirical literature. Before launching these experiments, an external firm surveyed employees on behalf of our partner organization (see Methods). In this survey, thousands of employees reported that they would carpool if they could find a 'match' with another employee with a similar shift schedule and commute. While the carpool system already provided matches, this intervention highlighted these matches in an email, ensuring that employees did not have to log into the system to search for them. There is also a large body of research showing that consumers desire carpooling matching services. It is worth noting that a significant amount of this literature is dedicated to the matching algorithms themselves as opposed to the uptake of the matches once they are provided (see ref. [25]).

In the 'match and opportunity cost' reminder condition, we highlighted the financial benefits of carpooling. We made this decision based on large-scale survey research showing that people do not carpool in part because they underestimate the financial costs of driving alone[26]. We also made this decision based on judgement and decision-making research showing that people do not spontaneously recognize opportunity costs. When deciding between two similar goods, individuals are more likely to choose a less expensive consumer good when they are explicitly reminded of the surplus cash that they would have to spend on something else[27]. Since people are unlikely spontaneously to recognize the costs of driving alone, we hypothesized that providing this information would increase employees' interest in carpooling. Building on previous transportation and decision-making research, Study 2 provides a test of whether providing matches and reminding people of the opportunity costs of failing to carpool would encourage employees to become more active in a ride-sharing service they had already joined.

In Study 3a ($n = 7{,}564$) we attempted to increase the use of public transportation, as measured by discounted travel product purchases, by offering a free bus trial. Previous studies have shown the effectiveness of free bus trials for increasing ridership; however, these studies suffer from numerous methodological limitations. For example, one randomized experiment tested the impact of a 1-month free trial in Kyoto, Japan. In this experiment, the free bus trial increased ridership by 20%; however, this study involved only 43 people who self-selected to participate[28]. Another randomized experiment, conducted in Copenhagen, Denmark with 1,000 drivers, found that free 1-month trials increased bus ridership during the month from 5 to 10%. This self-reported behaviour change did not persist after the intervention period[29].

Self-reported data are subject to reporting biases such as demand effects. When people are asked to report on socially desirable behaviours, like sustainable commuting, they often report on what they believe the question-asker wants to hear—especially if they are rewarded for this behaviour. This is problematic, because recipients of free bus trials could be motivated to lie about bus ridership. Study 3a does not suffer from the limitations of (1) low statistical power, (2) selection bias or (3) demand effects due to reliance on self-reported commuting behaviour. Our randomized controlled trial is highly powered, includes all eligible employees (versus employees who self-selected into the study) and examines actual behaviour (versus self-reported behaviour). Thus, it provides a valuable contribution to the current literature.

In Study 3b ($n = 4{,}732$), we followed up with participants in the treatment group from Study 3a who did not take advantage of the free bus trial. In this follow-up study, we wanted to encourage employees to become frequent bus users (as measured by discounted travel product purchases). We randomly assigned these employees to receive either a control or a treatment email.

In the treatment email, we emphasized the amount of money that employees had missed out on by not using the free bus pass that they were offered. This intervention builds on the psychology of loss aversion, which shows that people respond more powerfully to losses than to equivalent gains[30]. Loss-aversion interventions have been shown to effectively shape other behaviours (for example, registering to become an organ donor[21] and reducing use of plastic bags[31]).

Lastly, in Study 4 ($n = 1{,}095$), we tested the impact of personalized travel plans (PTPs) on reducing SOV behaviour as measured by self-reported commuting behaviour. We corroborated these self-report measures with observed behavioural measures, including carpool registrations and discounted travel product purchases. These PTPs provided tailored information to each employee about routes, transit schedules, travel discounts and carpool matches that best suited their needs.

We included this intervention to clarify the otherwise mixed literature examining whether and how PTPs and informational interventions can encourage sustainable travel[17,32,33]. In a recent review of the success of PTPs in eight UK regions, researchers found that PTPs reduced SOV use by 11%. However, this report relied entirely on self-reported outcomes and quasi-experimental designs[34]. An additional meta-analysis of 17 studies (only six of which were randomized controlled trials) found reductions in SOV use ranging from 1 to 14.7%. Only six of the studies included in this meta-analysis

reached statistical significance[35]. Previous PTP studies—including those reported in the above meta-analysis—typically used crude self-reported outcome measures and were evaluated by the companies providing the PTP (resulting in a potential conflict of interest)[34]. Our study, which includes more than one thousand participants and a mix of self-report and behavioural outcomes, provides a reliable test of the impact of PTPs on commuting behaviour. As a result, this study could help to clarify the mixed literature on the benefits of PTPs.

To summarize, across studies, we tested several behaviourally informed interventions in distinctive ways. In Study 1, we provided a test of whether and how behaviourally informed letters increased carpooling behaviour. In Study 2, we examined whether matching and opportunity cost reminders encouraged inactive members of a carpool service to ride together to work. In Study 3a, we provided a large, robust experimental test examining whether free bus trials increased regular ridership. In Study 3b, we followed up with participants who did not use the free bus trial, and we conducted an experiment examining whether loss framing could motivate non-compliant actors to shift their commuting behaviour. In Study 4, we attempted to clarify the mixed findings on the benefits of PTPs by implementing a large field experiment that examined both self-reported and actual commuting behaviour. Together, these studies address whether, when and how behaviourally informed interventions reduce SOV use. See Table 1 for additional study details.

We conducted these studies at an airport outside a major European city of over 75,000 employees. Forty-nine per cent of employees reported commuting by SOV, as indicated by a report commissioned by the employer from an external research firm. Most SOV commuters (61%, or approximately 22,000 employees) reported they would consider carpooling, and 41% of SOV drivers expressed finding a match as a key barrier. The airport's infrastructure made it an ideal location: it was very well connected to subway, rail and bus infrastructure, there was a pre-existing carpool service that used an algorithm to match employees with colleagues with similar commutes, and carpoolers had access to a 24/7 emergency ride home and priority parking.

Results

We retrospectively calculated that we had 80% power to detect effect sizes ranging from Cohen's $d = 0.03$ to $d = 0.19$ across studies. We report these effect sizes using d, which is a measure of the standardized difference between means. Despite high statistical power to detect small effects, we failed to detect any significant shifts in commuter behaviour due to our behaviourally informed messages or small incentives. See Fig. 1 for a visualization of the effect sizes observed across studies.

We also conducted two one-sided tests (TOST) to test whether the treatment effects were equivalent to zero[36]. In this context, there is no consensus on what constitutes a meaningful smallest effect size of interest (see Supplementary Information for more details). Consistent with ref. [37], we used a minimum detectable effect size of 80% power for our equivalence test. Using this method, we found significant results using TOST for four of the five studies (Studies 2–4). Thus, the observed treatment effects in these four studies were statistically equivalent to zero and thereby reject effects as large or larger than those we consider meaningful ($P < 0.04$, for all P values (see Supplementary Table 2)). We now proceed to document the results for each study separately. When reporting t-tests, we use two-sided tests. Data distribution was assumed to be normal, but this was not formally tested.

Study 1. Carpooling recruitment. Employees were randomly assigned to receive a letter or no letter. Those who received a letter received one of three behaviourally informed letters. Employees who received a letter were more likely to register for the carpooling system than those who did not (0.22% compared with 0.05%, $t_{(17,614)} = 4.2628$, $P < 0.001$, $d = 0.055$, 95% confidence interval (CI) [0.04, 0.07]). We collapsed across the three treatment conditions, since there were no differences across them. For further details about these condition-specific analyses, see Supplementary Information. In raw numbers, 33 employees who received a letter signed up for the carpooling system (out of 14,987). In contrast, 20 individuals who did not receive a letter signed up for the system (out of 39,900). Only seven employees from this study became active members (who activated their carpooling registration and became eligible to use the benefits available for carpoolers, such as priority parking and emergency rides home). Four of seven newly active members were in the control condition.

Study 2. Carpooling activation. Employees who were registered to the carpooling system but who were not active members (that is, did not declare that they were part of an active carpool and were not receiving carpooling benefits) were sent one of three emails ($n = 871$). All emails included a link where employees could log into the carpooling system and find potential carpool partners. About one-third of employees in each treatment group opened the email. Email open-rates did not differ between conditions (control, 30.53%, matching email, 35.82%, matching and opportunity cost email, 28.55%; $F_{(2,\ 997)} = 0.859$, $P = 0.424$, $\eta^2 = 0.002$, 95% CI [−0.003, 0.01]). The percentage of employees who clicked the link did not differ between conditions (control, 9.15%, matching email, 9.97%, matching and opportunity cost email, 9.63%; $F_{(2,\ 997)} = 0.064$, $P = 0.939$, $\eta^2 = 0.00$, 95% CI [−0.002, 0.006]). The effectiveness of the two matching emails compared to the control email approximated zero ($t_{(599)} = 0.324$, $P = 0.746$, $d = 0.00$, 95% CI [−0.15, 0.15]). We collapsed across the two treatment conditions because there were no differences between them. For further details about condition-specific analyses, see Supplementary Information. Only one employee from this study became an active carpooler.

Study 3a. Free bus trial. Employees who were not bus users, and who lived along bus routes, were randomly assigned to one of two conditions. Employees in the first condition received a letter that told them about bus routes near them, as well as how to purchase discounted transit cards through their employer. Employees in the second condition received the same letter, along with vouchers for a 7-d free bus trial. While 103 (out of 7,330) individuals in the treatment group used at least one of their free trial vouchers, we were unable to detect a statistically significant difference (even for small effects; see Supplementary Table 2 for further details) between conditions in the purchase of subsidized transit cards, and the effect size was negligible (control, 1.30%, treatment, 1.12%, $t_{(4,608)} = -0.684$, $P = 0.494$, $d = -0.01$, 95% CI [−0.06, 0.03]).

Study 3b. Follow-up feedback for bus trial. Recipients of the free bus trial and who did not take advantage of the trial (that is, those who did not use any of the free vouchers during the trial week) were randomly assigned to one of two conditions. Half were randomly assigned to a control group, who received no follow-up letter. The other half were randomly assigned to receive a letter that highlighted the cost of the free trial that they had missed out on, along with information about how they could still take advantage of discounted travel. The experimental (loss aversion) follow-up letter had no impact on the purchase of transit cards, and the effect size was negligible (1.03% in the control, 0.96% in the treatment, $t_{(4,707)} = -0.258$, $P = 0.797$, $d = -0.01$, 95% CI [−0.06, 0.05]).

Study 4. Personalized travel plan. We provided employees with travel plans that included personalized information about potential carpooling matches, bus/train routes and times, transit pass discounts and bike routes. We also provided employees with the option of signing up for a one-on-one session with the airport commuter team (21 employees signed up). The primary outcome measure was the difference in the number of SOV trips taken across conditions (compared to a baseline survey). Although

Table 1 | Summary of interventions

Study	Psychological barriers addressed	Psychologically informed intervention strategies	Hypotheses	Interventions tested in this paper
1. Increasing registration for carpool service	• Lack of awareness of the carpooling scheme, of potential carpool matches and of the cost savings of carpooling (versus driving alone) • Anticipated regret in case of emergency or unexpected personal event (for example, sick child needing to be picked up from school) • High friction costs associated with registering • Lack of awareness of peers engaging in carpooling behaviour	• Make savings salient and disclose costs[14] • Minimize anticipated regret by emphasizing access to emergency ride in case of unexpected circumstances requiring more flexible mobility[60] • Testimonials addressing perceived barriers and correcting misinformation[23] • Make desired action easy and reduce friction cost[14] • Testimonial photographs[24] • Messenger effects (message delivered by peers in addition to corporate messaging)[22]	• Mailing letters that inform employees of the airport carpooling service and that also address psychological barriers, such as minimizing anticipated regret, reducing registration friction costs and providing testimonials from peers, will increase registration for the service and ultimately increase carpooling compared to letters that do not address these psychological barriers. • Sending letters that address two key psychological barriers shown to prevent carpooling—lack of awareness and misinformation about the prevalence of potential matches—would increase carpooling compared to sending no letters (that is, taking no additional action).	Sending letters to increase carpooling registration: • Control (no letter) • Standard letter • Call to action letter • Testimonial letter
2. Increasing carpool use among employees already registered for the carpooling service	• Misinformation about prevalence of potential matches • Lack of awareness of opportunity costs of driving alone	• Highlight opportunity costs[27]	• Providing registered carpool members with specific potential matches would reduce friction costs associated with finding a match and becoming an active carpool member. • Highlighting the opportunity cost of driving alone to work, along with providing matches, would further increase carpooling as compared to other standard behaviourally informed messages.	Sending emails to registered carpoolers to actively carpool (as measured by registration of the carpool unit, to access priority pass): • Control email • Matching email • Matching email and opportunity cost made salient
3. Increasing the number of employees who travel by bus	• Negative perceptions of public transit • Ambiguity aversion • Status quo bias	• Free trial to help overcome negative perceptions and reduce uncertainty[28] • Highlight monetary equivalence of the incentive[27] • Exploit loss aversion[30]	• Providing a 1-week free trial to test whether using the bus will increase registration for heavily discounted travel products and ultimately increase bus use as compared to not receiving the free trial. • Following up with those who did not use the free trial, we hypothesized that promoting the heavily discounted travel products and employing a loss frame could increase take-up for the discounted products and ultimately increase bus use as compared to providing no follow-up information.	Offering a 1-week free bus trial to increase bus use (as measured by discounted travel pass purchases): • Letter with route and discount information • Letter and offer of a 1-week free trial Sending follow-up letters to those who did not partake in the free bus trial to increase bus use: • Control (no follow-up letter) • Follow-up letter
4. Reducing the number of SOV trips through delivery of a personalized travel plan	• Lack of information • Perceived high search costs	• Provide personalized information[17,32,33] • Include information on travel discounts	Providing tailored information about various alternative modes of travel, potential carpooling matches, discounted products and other benefits all in one place (a personalized travel plan) could reduce the amount of SOV trips employees take when commuting to work.	Emailing a PTP with tailored journey information and information about discounted travel products: • Control (no PTP) • PTP

self-reporting is not without risk of measurement error, the participants in this trial had no incentive to be untruthful. Furthermore, we cross-validated these self-report measures with objective secondary measures, including the number of people who registered for the carpooling system and the number who purchased discounted transit passes. The first outcome measure was the number of days in the past 5 d when an individual drove an SOV to work (range 0–5). We found no effect of delivering a PTP on commuting behaviour ($n = 1{,}095$). Specifically, the effect size for the change in the number of days driven in the previous 5 d was negligible ($\beta = 0.00$, d.f. = 840, $P = 0.992$, $d = 0.01$, 95% CI [−0.13, 0.14]). We triangulated self-reported measures with observed behaviours, and found no differences between the two conditions in terms of carpool registration rates or transit pass purchases.

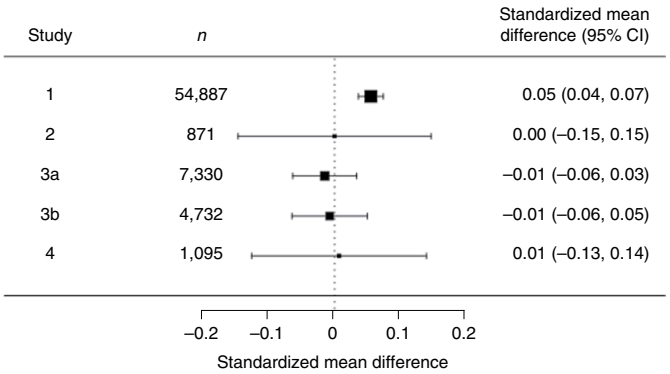

Fig. 1 | Forest plot illustrating negligible effects of the five studies by showing the standardized effect size (Cohen's *d*) and 95% CI associated with each sample. The size of each square is determined by the sample size: Study 1 ($n = 54{,}887$, $d = 0.05$, 95% CI [0.04, 0.07]); Study 2 ($n = 871$, $d = 0.00$, 95% CI [−0.15, 0.15]); Study 3a ($n = 7{,}330$, $d = -0.01$, 95% CI [−0.06, 0.03]); Study 3b ($n = 4{,}732$, $d = -0.01$, 95% CI [−0.06, 0.05]); Study 4 ($n = 1{,}095$, $d = 0.01$, 95% CI [−0.13, 0.14]).

Discussion

We tested a series of nudges, ranging from simple framing interventions to more resource-intensive, non-coercive and easily avoidable interventions—such as signing up for an in-person meeting with the commuting team to discuss personalized travel plans. Across studies, we found no evidence that these nudges shifted commuter behaviour. In Study 1, we tested a letter and email campaign to increase carpooling and, through our interventions, we significantly increased the proportion of employees who registered for an employer-provided carpooling service; however, the effect size was small[38]. Moreover, this increase in registrations had no impact on the objective behaviours we were trying to shift. Although we sent 15,000 letters, only 33 employees registered for the carpool service. One month later, three employees who received a letter were active carpoolers. In Study 2, we tested the efficacy of an email campaign designed to encourage inactive registered carpooling users to become active members. Once again, this intervention had no meaningful impact. In Studies 3a and 3b, with a different population, we tested the impact of a 1-week free bus trial. We observed no improvement in registration for discounted bus passes. In Study 4, we evaluated the impact of personalized travel plans on SOV use. PTPs did not reduce the number of times people reported driving on their own to work, even when these plans were offered alongside a one-on-one intensive travel planning meeting.

From our studies there are three inferences we can make that are derived from our specific context, but that can generalize more broadly to the use of behaviourally informed interventions to reduce SOV use.

First, our studies suggest that people do not always reveal their true intentions or barriers to sustainable commuting. Across our studies, we provided participants with information that should have increased their ability to follow through with their self-reported intentions of engaging in more sustainable commuting behaviour (because they revealed that this information would probably shift their behaviour as part of the employee travel survey, and during several interviews we conducted before undertaking this research). Based on the central tenets of the theory of planned behaviour, we expected this information to change employee behaviour[39]. This highly cited theory suggests that behaviour change is made up of three ingredients: information, intentions and self-efficacy. This theory has been used to explain when, whether and how people engage in common environmental behaviours such as using public transportation and recycling[40,41].

Because employees reported strong intentions to carpool, we expected them to act on their intentions to reduce their SOV behaviour when they were provided with information or matches designed to make this behaviour simpler. Our results—and in particular the results of Studies 1 and 3—contrast this prediction. For example, when we notified employees of the first step of carpooling (registration), less than 1% of contacted employees signed up for the carpooling service (Study 1). Employees stated that they would be more likely to take use public transport if they had discounted travel. Nonetheless, less than 1.5% of the employees that we contacted shifted their behaviour when given a free bus trial or notified of subsidized bus passes (Study 3).

Thus, increasing self-efficiency through information and making it easier for people to follow through on their intentions might not be enough to increase carpooling. This could be because people's stated barriers and future plans about their commuting behaviours may not reflect their true intentions. Future research should target other barriers that prevent employees from carpooling and which they might be more reticent to admit on self-report surveys, such as hesitation to talk with an employee they do not know[42] or having a strong positive emotional connection to their car[43]. The ingrained nature of driving, and the fact that driving is connected to perceptions of autonomy[44], status and power[45], could make it very difficult to change.

Second, our studies suggest that, in some contexts, more heavy-handed interventions—such as congestion charges, parking bans, public transportation infrastructure investment and other mandates—may be necessary to achieve a significant shift in commuting behaviour. Similar arguments have been made in discussions about lowering smoking rates[46] and carbon emissions[47]. When heavy-handed approaches are used, the best correlational research suggests that such approaches are also effective at reducing the level of driving[48–50]. For example, dynamic tolling, road pricing and congestion charges, as well as enhancing the quality of public transportation, are linked to lower rates of SOV driving behaviour and reduced pollution (see Beland and Brent, unpublished manuscript, for a review).

When considering the use of nudges versus more heavy-handed interventions, based on our studies, there is a specific contextual factor worth noting, which is a key limitation of this work. In this organization, a parking space, worth thousands of dollars a year, was provided to employees for free. Thus, nudges might be more likely to succeed when employees bear the full costs of parking. Consistent with this argument, there are initial (non-experimental) studies showing that personalized travel plans are more likely to shift commuting behaviour when free parking is taken away[51].

Finally, our failure to shift behaviour sheds light on settings where nudges could be more or less likely to succeed. Recent literature[15] suggests that nudges are cost efficient in most domains, such as a US$100 return per dollar spent on increasing retirement savings[52] compared with a US$1.24 return per dollar spend on US tax incentives[53], or an increase of 1.53 students enrolled in university per US$1,000 spent, compared to a negligible increase due to tax credits[54,55]. Nevertheless, this previous research considered only a limited number of domains, specifically those where the target behaviour was consistent with an individual's self-interest (for example, saving for their own retirement) and where the nudge helped the individual perform a one-off beneficial action from which they directly reaped the benefits over months and years (for example, the decision to enroll in a retirement savings plan). As a result, these efficiencies might not be true across all policy domains. Energy reduction shares important properties with sustainable travel (for example, changing behaviour to mitigate climate change or decrease energy demand). While social comparison letters[12] have been shown to be more cost effective than discounts, incentives or education[56], a recent paper finds that

many of the energy savings for this nudge persisted even after the original occupants moved, indicating that much of the energy reduction was not achieved by changing habitual behaviour but rather through a one-off capital improvement to the home[57]. Similarly, our research shows that it is very difficult to change commuting behaviour—which is a habitual, daily action. Building on these findings, we believe that more research should be directed toward examining the efficacy of interventions designed to shift behaviour through major purchases (for example, electric cars) or restructuring of work schedules (for example, working from home once per week), as opposed to shifting habitual actions (for example, turning off lights before leaving the house or carpooling to work).

Nudge theory is a new and growing field, and the interventions used in nudge studies often have direct policy implications. Publishing null results, or the results of studies with limited success[58,59], is necessary to ensure that policy makers do not waste time and money pursuing solutions to pressing challenges that are unlikely to yield favourable outcomes. Our research is concerned with a collective action problem that requires people to change a habitual (versus one-time) behaviour. Our results suggest that nudges may be less effective in shifting habitual behaviours in general and commuting behaviour in particular.

Methods

Our research complies with all relevant ethical regulations. The Behavioural Insights Team provided ethical guidelines, reviewed a protocol and approved the study. Informed consent was waived by the Behavioural Insights Team's ethics review committee, because it was deemed no more than minimal risk and was also agreed to by the field site partner. Data collection and analysis were not performed blind to the conditions of the experiments. Demographic information was not collected from the participants in these studies.

Sample characteristics. Every 5 years, a third-party market research firm is hired by our partner organization to collect data on employee travel behaviours and attitudes. In the survey conducted 1 year before our partnership started, most employees reported that their commutes were <45 min (59%), but 24% of employees had commutes >1 h.

Study 1: Carpooling recruitment. The organization had a sizeable number of members registered to their carpool system (8,000) and active carpoolers (2,000). These large numbers increased the probability that employees who signed up or used the carpooling platform would successfully find a match.

Participants. To determine our sample for Study 1, we excluded all employees who lived in the city centre, as well as those who lived along commuter rail and bus routes. We also excluded addresses with multiple employees because they could be informally carpooling, making it hard to isolate treatment effects. After these exclusions, we were left with a sample of 54,931 employees. Our budget allowed us to send only 15,000 letters to airport employees. Thus, we randomly assigned 15,000 of the 54,931 eligible employees into one of four conditions: a no-action control group, a standard letter that addressed perceived barriers to carpooling, the same letter that highlighted the registration link, and the standard letter with peer testimonials.

Procedure. We mailed letters to the 15,000 individuals in the treatment group. The first letter provided information about the benefits of carpooling. The next letter was identical, but also included a call to action asking employees to register for the carpooling service. The final condition consisted of information identical to that in the first letter, but also featured testimonials and photographs of two employees who successful found matches and who reported saving hundreds of dollars per year via carpooling. Two months later, we checked the records from the employers' online carpooling service to assess whether individuals from the treatment and control groups had registered for the carpooling service. We excluded 44 employees who registered for the programme between the time we assigned participants to conditions and when the letters were sent.

Study 2: Carpooling activation. We randomly assigned 928 registered, but inactive, members of the carpooling service to one of three conditions: control, matching (with details of up to three matches based on location and shift times) and matching and opportunity cost salience.

Procedure. We emailed participants and measured the number of participants who registered for a carpool service 4 weeks later.

Study 3a: Free bus trial—participants. We included employees who lived near a bus route, did not live with another employee and were not registered bus users, leaving a sample of 7,564.

Procedure. Our pilot survey revealed that the main self-reported barriers to taking public transportation were the lack of nearby services and the fact that taking public transportation often took longer than driving. We used this opportunity to advertise new transit routes to employees living in communities where these new services were being introduced. Based on the survey data, we tested a free bus trial to provide employees who had never taken the bus with the opportunity to experience the benefits. We sent letters to all eligible employees, informing them of the bus services in their area, the low cost of commuting by bus, the amount of money they would save by registering for a discounted travel pass and the convenience of the bus. Our sample comprised employees living in two different towns with new bus routes. The prices between towns varied (based on distance from the airport). Thus, when we randomized, we stratified by town. Half of those who received the letter also received 1 week's worth of free bus tickets that were to be used during a specified free-trial week. We collected individual-level data on who used the free ticket. One month later, we collected condition-level data on registration for a transit pass.

The economics of transit passes. Transit passes are discounted travel tickets that employees are eligible to purchase. These passes significantly reduce the price of travel on certain forms of public transportation. For example, a round-trip ticket on one of the bus services is US$8 per day whereas a discounted transit pass is US$32 per month (the regular transit pass for non-employees is US$112 per month). If an individual intends to take the bus more than 4 d in 1 month, it is economically advantageous to buy the transit pass. For the other services advertised in the trial, a round-trip ticket is US$22 per day whereas the discounted transit pass is US$117 per month (the regular transit pass for non-employees is US$130 per month). If an individual intends to take the bus more more than 5 d in 1 month, it is advantageous to buy the transit pass.

Study 3b: Follow-up feedback for bus trial: participants. A total of 103 individuals participated in the free trial. Thus, the remaining employees in the treatment condition for Study 3a were included in the subsequent trial ($n = 4{,}936$).

Procedure. Half of the employees who received the free trial and did not take advantage of it were sent a follow-up letter that emphasized the amount of money that each had 'lost' by not participating in the free bus trial. This letter displayed the benefits of registering for a discounted transit pass. One month later, we linked registration to condition assignment.

Study 4: Personalized travel plan: participants. All employees who were based at the airport's administrative headquarters were asked by senior leaders to fill out a travel survey in January 2016. Our sample included employees who commuted to work by SOV at least 1 d in the month before completing the survey. The final eligible sample for this study was 1,095.

Procedure. All eligible participants were sent an email from the airport's commuter team with a PDF attachment of their PTP. The PTP included information of potential carpooling matches, public transportation routes and cycling routes that individuals could take to work. It included travel discounts for which employees were eligible, along with the estimated travel time and cost for each option. These emails included the option for interested individuals to sign up for a one-on-one personalized travel plan session. One month after the last commuter plan session was administered, we sent a follow-up survey (similar to the original) to examine how commuting behaviour had changed (specifically to detect a reduction in SOV use).

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Coarsened data and modified materials are available at https://osf.io/39rja/. Data and materials have been modified to protect the identity of the partner organization and its employees. Additional materials that do not violate these privacy concerns can be provided on request by the authors.

Code availability

All analyses reported in this study used the statistical software R (v.3.6.1). All R files are available publicly at https://osf.io/39rja/.

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Author contributions

Data collection and analysis was performed by A.S.K. A.S.K. drafted the original manuscript. A.V.W. provided critical revisions. Both of the authors approved the final version of the manuscript for submission.

Competing interests

The authors declare no competing interests.

Additional information

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Behavioural & social sciences study design

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Study description	The study includes five different randomized controlled trials and is a quantitative study.
Research sample	Our field site was an airport with over 75,000 employees outside of a major European city. Our sample were employees of this airport. Forty-nine percent of employees reported commuting by Single Occupancy Vehicles (SOVs) at the time of the study, as indicated by a report commissioned by the employer from an external research firm. The report also suggested that 61% of SOV commuters (approximately 22,000 employees) reported they would consider carpooling, and 41% of SOV drivers stated they would if they could find someone with a similar commute (which translates to 15,000 potential carpool registrants). The site's infrastructure made it an ideal location for our study: 1) the airport was highly connected to frequent subway, train, and bus infrastructure, 2) there was a pre-existing carpool service that used an algorithm to match employees with colleagues with similar commutes, and 3) carpoolers had access to a 24-7 emergency ride home and priority parking.
Sampling strategy	For each study we created criteria for inclusion, and the study included all eligible participants. Overall, the decision to use a sample of this airport employees was a convenience decision.
Data collection	Most data was collected using administrative data collected by the employer. There was one study (study 4) where a survey was emailed by the employer to employees before and after the intervention, and was complemented with administrative data.
Timing	Data collection began in March 2015 and ended in November 2015
Data exclusions	The only participants who were excluded from the analysis are those who should have been excluded before the study began (e.g. already registered carpoolers or commuters who already had bus passes before our trials began, but after we received the initial data for randomization).
Non-participation	No participants dropped out/declined to participate.
Randomization	Participants were randomly allocated into conditions.

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Population characteristics	See above.
Recruitment	Because we did not actively recruit, but rather included all eligible employees in our sample, our study has a lower risk of selection-bias. For Study 1 we included all employees who did not live along major public transportation routes and were not registered carpoolers. For Study 2 we included all registered but non-active carpoolers who had their addresses in the system. For Study 3a we included all employees who lived along the two bus routes included in our study. For Study 3b we used all employees in Study 3a who did not use the free trial. Finally, for Study 4, we used all employees working in a specific headquarters building. Here we only included employees who filled out the survey, so there may be selection issues; however, the survey was promoted by the executives and response rate was over 70%.
Ethics oversight	The Behavioural Insights Team

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