Extrinsic rewards and crowding-out of prosocial behaviour

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The law of supply is a fundamental principle of economics and states that any increase in price will increase the quantity supplied. In the case of prosocial behaviour, however, increasing rewards have reduced supply, posing a challenge to standard economic theory. Attempts to study such ‘crowding-out’ have been limited by their small scale and the inherent difficulties posed by calibration of experimental tests. We analyse a large-scale natural experiment in the environmental domain consisting of 20,370 independent observations derived from aggregation of approximately 27 million individual decisions. We find that aggregate supply of prosocial behaviour is ‘s-shaped’, demonstrating how attempts to increase prosocial behaviour using monetary rewards can be counter-productive. Our study shows that results derived from a small set of data points collected from an underlying s-shaped data-generating process are vulnerable to misinterpretation, and that proxy measures of intrinsic motivation ought to be collected to ensure theoretical advance.

Prosocial behaviour among humans is commonplace and permeates every aspect of our lives. We donate blood and money to charities and contribute to the public good in the form of tax payments, teamwork and recycling. Although prosocial behaviours are ubiquitous, they are often under-supplied and fall short of the socially optimal level. This contributes to a range of contemporary global problems such as water shortages, antimicrobial resistance and depletion of natural resources. If such shortcomings are due to insufficient incentives, the law of supply from standard micro-economic theory offers a simple solution: any subsidy, tax break or extrinsic monetary reward ought to increase prosocial behaviours. If, however, extrinsic incentives crowd-out existing intrinsic prosocial motivations, such rewards can lead to a net reduction in prosocial behaviour, implying limitations to the price mechanism for improving social outcomes.

Previous research on the crowding-out of prosocial behaviour has yielded mixed results. On the one hand, crowding-out has been documented in a range of domains. In the context of blood donations, Richard Titmuss first suggested that explicit extrinsic rewards might be counter-productive, a prediction later corroborated among women (but not men) in a field experiment. Fines have also increased undesirable behaviours such as length of hospital stay, increased late kindergarten pick-ups and reduced cooperation. Moreover, evidence from brain scans shows that monetary sanctions encourage neural activity associated with self-interested decision-making and mitigate activity associated with social reward evaluation. On the other hand, a number of studies have failed to detect any crowding-out effect. Examples include lottery and standard incentives, which have also succeeded in increasing blood donations, and small gifts that have successfully reduced paper waste. Overall, the literature on motivational crowding-out is inconclusive.

This paper investigates the effect of an exogenous increase in extrinsic reward in the prosocial domain of recycling. We analyse a unique natural experiment resulting from the Swedish Central Bank’s (Sveriges Riksbank) decision to withdraw from circulation the SEK 0.5 coin (approximately USD 0.07). From 1 October 2010, when the SEK 1 coin became the lowest denomination, recyclable beverage cans carrying a deposit of SEK 0.5 were gradually replaced by cans carrying an SEK 1 deposit (approximately USD 0.14). As a result, per can expected reward from recycling gradually increased from SEK 0.5 in September 2010 and finally converged on SEK 1 in January 2014. For the average recycling customer returning 18 cans this meant an increase in expected reward from SEK 9 to 18 (approximately USD 1.2 to 2.5) over this period. This gradual change allows us to estimate the supply of recycling over the whole range of values between SEK 0.5 and SEK 1 as a function of expected reward, and the exogenous decision by the Swedish Central Bank to remove the SEK 0.5 coin allows us to interpret this as a natural experiment.

Data on recycling and deposits are collected and stored by the recycling company Returpack. The company provided us with a balanced panel of monthly aggregated recycling data for a period of 42 months, spanning 485 branches of one of Sweden’s largest chain stores. We complemented this with census data on median income from Statistics Sweden (Statistiska Centralbyråen) and voting data from the Swedish Election Authority (Valmyndigheten), measured at the postcode and municipal level, respectively. The panel spans the whole period, August 2010 to January 2014, during which the increase in expected reward occurred. The analysed data set contains 20,370 independent observations of aggregate monthly recycling quantities measured at the store level, corresponding to approximately 27 million individual recycling decisions.

In line with motivational crowding theories, we find support for an s-shaped aggregate supply curve for recycling. When expected reward increases, the quantity of recycled cans first increases up to an inflection point, after which it decreases, and the supply curve becomes negatively sloped. This decrease in recycling continues until it reaches another inflection point, after which the supply curve once again becomes positively sloped, giving rise to an s-shaped graph for the supply curve. We also find that the intercept and the two inflection points on the estimated relationship

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depend on our proxy measure for intrinsic environmental motivation. Because the crowding-out effect is dependent on pre-existing levels of prosocial motivation, this provides additional support for motivational crowding theories. This dependency, combined with the S-shaped supply curve pattern, can help reconcile the mixed literature on motivational crowding-out.

We exploit data generated by a large-scale natural experiment to examine motivational crowding-out by evaluating the effect of exogenously induced variation in reward on the supply of prosocial behaviour. Although past research has shown that introducing extrinsic rewards to promote prosocial behaviour can be counter-productive in a range of domains, our study differs from past research in several important ways. First, past studies are only able to collect a few data points on the underlying relationship between reward and prosocial behaviour, which can lead to the misinterpretation of empirical results, as support either for standard economic theory or for an alternative (but incorrect) crowding-out theory. These data enable us to overcome this limitation, potentially reconciling the mixed results emerging from the literature and substantially constrain the set of plausible crowding-out theories. Second, previous studies have typically not complemented their behavioural data with any proxy measure of intrinsic motivation level, which precludes testing the dependency of the crowding-out effect on motivation levels (for an exception, see ref. ). Here we use the share of votes for the Green Party as a measure of willingness to participate in pro-environmental activities. Third, participants in our study are unaware that they are participating in an experiment, in contrast to the case in a laboratory, which is a methodological advantage when studying social behaviour. Finally, many studies are considerably smaller and may not constitute representative samples of the studied population, which is important for the external validity and replicability of estimated results.

In addition to improving our understanding of prosocial behaviour and informing policies intended to promote social outcomes, our study has implications for economic models of individual decision-making. In most models, when crowding-out occurs it is because intrinsic motivation has vanished and is unlikely to be restored. Alternatively, any positive amount of extrinsic reward will result in a drastic reduction in the supply of prosocial behaviour. Our study suggests that the process of crowding-out prosocial behaviour is much more gradual, and that positive but relatively modest rewards can improve aggregate social outcomes at a lower cost. Future efforts ought to be directed towards understanding how such opportunities could be harnessed.

Results
We calculate monthly expected reward per recycled can as the weighted mean of recycled SEK 0.5 and SEK 1 deposit cans. Because distribution of cans with different deposits varies across store locations in a given month, so does expected reward. Figure 1 illustrates the gradual increase in expected reward E[r_t] and average quantity of cans recycled over time, across all stores in the sample, by month. The median of the expected reward gradually increases from SEK 0.5 and converges on SEK 1, because restocking with cans carrying an SEK 1 deposit depends on individual store sales and producer stock. Because expected reward differs across stores, both within and over time, it induces the variation necessary to examine the continuous relationship between reward and behaviour. Naturally, expected reward distributions are narrower at the beginning and end of the study period because most cans are carrying a deposit of either SEK 0.5 or SEK 1 respectively, whereas the transition period is characterized by wider reward distributions (Extended Data Fig. 1).

Store-level quantity of cans recycled ranges from 19,751 to 36,944 and tracks broad beverage consumption patterns, exhibiting highs in summer months and lows in winter months (Extended Data Fig. 2). Overall, both measures follow expected patterns.

To assess the relationship between expected reward and prosocial behaviour, we combine recycled quantity and expected reward in the scatter plot presented in Fig. 2, representing the aggregate supply curve. Visual inspection reveals a pattern inconsistent with standard economic theory, which predicts a monotonically increasing relationship between expected reward (price) and average quantity recycled (quantity supplied). Instead, this figure reveals a negatively sloped segment on the supply curve that begins when expected reward equals approximately SEK 0.7. This segment remains negatively sloped until expected reward equals approximately SEK 0.85, after which the supply curve appears positively sloped once more.

Table 1 reveals a non-monotonic pattern of coefficients, inconsistent with the law of supply. Crucially, an increase in expected reward level from L2 [0.6–0.7] to L3 [0.7–0.8] leads to a reduction in the quantity recycled because the coefficient on L3 [0.7–0.8] is smaller than the coefficient on L2 [0.6–0.7] and this difference is statistically significant (L2 [0.6–0.7] versus L3 [0.7–0.8]: χ²(1) = 30.43, P < 0.001, two-tailed, 95% confidence intervals (CI) = (2.0.3) versus (0.2.1.5)). Further increases in expected reward levels lead to increases in quantity recycled relative to L3 [0.7–0.8]. Although all estimated coefficients are statistically significant and different from baseline (Table 1), the coefficient on L5 [0.9–1.0] is larger than

![Fig. 1 | Percentiles of expected reward (lines) and average quantity recycled (bars) over time. The solid line represents the median and the dashed lines represent the 2.5th (lower line) and 97.5th (upper line) percentiles, spanning 95% of the expected reward E[r_t] distribution. Median expected reward increases gradually from SEK 0.5 to 1 and the average quantity recycled exhibits a seasonal pattern (n = 20,370).](image-url)
the coefficient on L3 [0.7–0.8] (L3 [0.7–0.8] versus L5 [0.9–1.0]: χ²(1) = 22.33, P < 0.001, two-tailed, 95% CI = (0.2 1.5) versus (1.2 2.9)). This overall pattern suggests a nonlinear and non-monotonic relationship between expected reward and quantity recycled, consistent with the pattern in Fig. 2. We summarize these results below. Result 1: The relationship between quantity recycled and expected reward is non-monotonic, violating the law of supply.

We now estimate quantity recycled as a polynomial function of expected reward and present our results in Table 2. Specifically, we use a linear and quadratic term in model 1 to allow for a single inflection point on the relationship, and add a cubic term in model 2 to allow for two inflection points. This approach obviates the need to specify intervals of the expected reward variable. Because a key prediction of motivational crowding theory is the income-independent interaction between price and intrinsic motivation, we add measures of income and intrinsic environmental motivation (Green votes (GV) (%)) and their interactions with expected reward to models 1 and 2. We present these as models 3 and 4, respectively.

In model 1 that the coefficient on the linear term is positive and statistically significant (β = 15.8, P < 0.001, 95% CI = (7.9 23.7)) and that the coefficient on the quadratic term is negative and statistically significant (β = −7.7, P = 0.004, 95% CI = (−12.9 −2.5)). This pattern is consistent with a single inflection point and a ‘backward bending’ supply curve. We further find in model 1 that the linear and quadratic terms remain statistically different from zero (β = 379.5 and −503.3, P < 0.001, 95% CI = (208.5 550.4) and (−734.9 −271.6)) and of the same signs as in model 1. In addition, the coefficient on the cubic term is positive and statistically different from zero (β = 218.1, P < 0.001, 95% CI = (115.7 320.5)). This pattern is consistent with two inflection points on the estimated relationship and an ‘s-shaped’ supply curve. In interaction, additional interactions between expected reward and our proxy measure for intrinsic motivation to participate in pro-environmental behaviour, GV (%), are statistically significant when the cubic expected reward term is included. Importantly, this effect is present when controlling for income and income–reward interactions (see model 4 in Table 2). Because monthly dummy variables are included, these estimations control for the seasonal effects apparent in Fig. 1 (see also Supplementary Tables 1 and 2 for additional robustness tests).

Table 1 | Random effects GLS results: estimated quantity of recycled cans as a function of expected reward levels

| Dependent variable | Cans |
|--------------------|------|
| L2 [0.6–0.7]       | 2.6  (0.3) |
|                    | [2.0 3.2] |
|                    | <0.001 |
| L3 [0.7–0.8]       | 0.8  (0.3) |
|                    | [0.2 1.5] |
|                    | 0.013 |
| L4 [0.8–0.9]       | 1.5  (0.2) |
|                    | [1.0 1.9] |
|                    | <0.001 |
| L5 [0.9–1.0]       | 2.0  (0.4) |
|                    | [1.2 2.9] |
|                    | <0.001 |
| Month              | Yes |
| Constant           | 22.2 (1.2) |
|                    | [19.8 24.5] |
|                    | <0.001 |
| Observations       | 20,370 |
| Groups             | 485 |

Overall, regression analysis results are consistent with predictions of crowding-out theories.

Result 2: Signs on estimated coefficients on expected reward and their interactions with the intrinsic motivation measure are consistent with predictions of motivational crowding theories.

We now turn to analysis of the postestimation result based on model 4 in Table 2. Figure 3a represents linear predictions of quantity recycled as functions of expected reward, for three levels of our intrinsic motivation measure, GV (%), corresponding to the 10th percentile (2.54), the median (5.76) and the 90th percentile (13.87) of the GV (%) distribution. Overall, a higher level of GV (%) is associated with a higher level of recycling for each expected reward level, consistent with our interpretation of the measure as a proxy for willingness to participate in pro-environmental behaviour. The negative segment on each curve represents the crowding-out effect, which is more pronounced for higher levels of GV (%). This suggests that the crowding-out effect is heterogeneous with respect to intrinsic motivation, in line with motivational crowding theories.

A sufficient condition for motivational crowding-out is a negative marginal effect of any price on quantity supplied. Figure 3b–d presents average marginal effects of expected reward on quantity recycled, evaluated over the whole range of expected reward from 0.5 to 1, by each level of GV (%). For all levels, point estimates of marginal effects are initially positive, followed by a negative segment, and finally positive once more as expected reward increases over the range. Negative segments below the zero-line identify a net negative crowding-out effect. Confidence intervals indicate
Importantly, the crowding-out effect is dependent on pre-existing levels of intrinsic motivation. Our analysis of marginal effects therefore rejects the hypothesis embedded in the law of supply—positive marginal effects of price on quantity supplied for all prices—and provides evidence in favour of motivational crowding theory. We summarize these results below.

Result 3: Negative marginal effects of expected reward on quantity recycled provide direct evidence for motivational crowding-out. The crowding-out effect is heterogeneous with respect to pro-environmental motivation.

To illustrate the importance of these effects for policy, Table 3 presents the predicted global and local maximum and minimum of quantity recycled, and the maximal crowding-out effect. The latter is calculated as the difference between the local maximum and local minimum quantities for levels of GV (%) on the basis of model 4 in Table 2. Calculation of the monthly per store effect reveals that the crowding-out effect is substantial. In absolute terms, it ranges from 451 to 2,359 cans at the 10th percentile (2.54) and 90th percentile (13.87) levels of GV (%), respectively. Evaluated at the average level of GV (%), the crowding-out effect is 1,093 cans. Aggregated across stores in the study sample, this implies a crowding-out effect of 5,616,000 cans annually. In material terms, this is approximately equivalent to 1,123 m³ of waste, weighing at least 81 tonnes, or $1.12 \times 10^6$ kWh. Extrapolation to the whole Swedish market implies a crowding-out effect of 89 million cans annually, corresponding to 16,183 m³ of waste, weighing at least 1,168 tonnes, or $16.18 \times 10^6$ kWh. To recover from the crowding-out effect, expected reward would need to increase from 0.88 to 0.98, equivalent to an 11.36% increase. Overall, these results clearly illustrate the existence of limitations when using relative price mechanisms for the design of incentives intended to increase prosocial behaviour, in terms of both the desired effect and the cost-efficiency of interventions.

### Table 2: Random effects GLS results: estimated quantity of recycled cans as a function of expected reward, including GV, income and their interactions with expected reward

| Model | 1 | 2 | 3 | 4 |
|-------|---|---|---|---|
| Dependent variable | Cans | Cans | Cans | Cans |
| $E[r_{i,t}]$ | 15.8 (4.0) [7.9 23.7] | 379.5 (87.2) [208.5 550.4] | 85.2 (26.9) [32.6 137.8] | 1279.4 (346.4) [600.4 1958.4] |
| $E[r_{i,t}]^2$ | -7.7 (2.7) [-12.9 -2.5] | -503.2 (118.2) [-734.9 -271.6] | -47.8 (17.3) [-81.7 -13.9] | -1682.5 (462.5) [-2588.9 -776.0] |
| $E[r_{i,t}]^3$ | 218.1 (52.3) [115.7 320.5] | 722.4 (209.3) [328.7 1116.2] | <0.001 | <0.001 |
| GV | 1.7 (0.4) [1.0 2.3] | -8.7 (4.1) [-16.7 -0.7] | <0.001 | 0.033 |
| GV - $E[r_{i,t}]$ | -0.4 (1.4) [-3.2 2.3] | 43.2 (18.4) [7.2 79.2] | 0.760 | 0.019 |
| GV - $E[r_{i,t}]^2$ | 0.5 (0.9) [-1.3 2.3] | -58.7 (24.5) [-106.7 -10.7] | 0.582 | 0.017 |
| GV - $E[r_{i,t}]^3$ | 25.9 (10.6) [5.1 46.7] | 0.015 |
| Income | -0.2 (0.4) [-0.9 0.6] | 13.5 (4.4) [4.8 22.1] | 0.691 | 0.002 |
| Income - $E[r_{i,t}]$ | -3.4 (1.6) [-6.5 -0.4] | -61.3 (20.0) [-100.5 -22.2] | 0.027 | 0.002 |
| Income - $E[r_{i,t}]^2$ | 1.9 (1.0) [-0.1 3.9] | 81.1 (26.6) [28.9 133.3] | 0.060 | 0.002 |
| Income - $E[r_{i,t}]^3$ | -34.9 (11.5) [-57.6 -12.3] | 0.002 |
| Month | Yes | Yes | Yes | Yes |
| Constant | 16.0 (1.5) [13.2 18.9] | -69.7 (20.3) [-109.6 -29.9] | 8.3 (7.0) [-5.5 22.1] | -272.4 (77.3) [-423.9 -120.9] |
| Observations | 19,885 | 19,885 | 19,885 | 19,885 |
| Groups | 485 | 485 | 485 | 485 |
| R-squared | 0.206 | 0.208 | 0.209 | 0.213 |
| Within | 0.003 | 0.011 | 0.057 | 0.057 |
| Between | 0.012 | 0.012 | 0.066 | 0.066 |

Robust standard errors clustered on id are given in parentheses and 95% CI in square brackets as [low high] with exact P values below (no brackets). The estimated coefficient (H0) is equal to zero for all tests (chi-squared test, two-sided). No adjustment has been made for multiple comparisons.
Discussion

This study shows that providing extrinsic monetary rewards to increase prosocial behaviours can have both intended and unintended consequences, and the observed outcome will depend on the net balance of two opposing forces. On the one hand, the price effect of increasing extrinsic monetary rewards is always positive. On the other hand, increasing extrinsic monetary rewards can have a negative effect on intrinsic motivation to participate in prosocial behaviour, in this case recycling. If an extrinsic reward causes a sufficiently large reduction in intrinsic motivation, the net effect of reward on quantity supplied is negative, because the effect on intrinsic motivation dominates the price effect. The theoretical literature offers two main candidate explanations consistent with an s-shaped aggregate supply curve, as observed in this study.

Signalling theory emphasizes the use of behaviour to signal intrinsic motivations to oneself, or to others, when motivated by image concerns\textsuperscript{11,13}. It explains the s-shape as the result of how the net balance of the positive price effect and the negative effect on signal value evolves as reward increases\textsuperscript{11,13}. Although the price effect is always positive, the presence of a reward casts doubt about the underlying reason for engaging in prosocial behaviour because it becomes harder to infer whether behaviour is motivated intrinsically or by the reward. Behaviour therefore becomes an increasingly noisy signal of intrinsic motivation and its value gradually diminishes as rewards continue to increase. When reward begins to increase from a relatively low level, the price effect first dominates the negative signal value effect, leading to a net positive effect on supply. Although signal quality falls as reward increases, the net effect of reward on supply remains positive as long as the price effect dominates. This accounts for the initial positively sloped segment on the supply curve. When reward reaches a sufficiently high level, however, behaviour becomes too noisy a signal of intrinsic motivation.

Table 3 | Linear predictions of average monthly quantity recycled and crowding-out effect in thousands, by GV (%) 

| Linear predictions of average monthly quantity recycled and crowding-out effect in thousands | GV (%) = 2.54 | GV (%) = 5.76 | GV (%) = 6.46 | GV (%) = 13.87 |
|---|---|---|---|---|
| Local maximum quantity | 20.5 | 26.0 | 27.2 | 39.9 |
| Local minimum quantity | 20.0 | 25.0 | 26.1 | 37.5 |
| Crowding-out effect | 0.5 | 1.0 | 1.1 | 2.4 |
| Crowding-out effect (%) | 2.2 | 3.8 | 4.0 | 5.9 |

GV (%) values correspond to the 10th percentile, median, mean and 90th percentile (2.54, 5.76, 6.46, 13.87, respectively) (see the source data for Fig. 3).

Fig. 3 | Linear predictions and marginal effects. Linear predictions of quantity recycled as a function of expected reward by levels of GV (%) combined with average marginal effects of expected reward on linear prediction with 95% CI. a, Non-monotonic linear predictions as a function of expected reward consistent with a crowding-out effect. Lines represent linear predictions of quantity recycled as a function of expected reward by levels of GV (%) corresponding to the 10th percentile (blue line), the 50th percentile (red line) and the 90th percentile (green line). b–d, Ranges of negative marginal effects, and statistical significance at $<5\%$ level for GV (%) levels of 2.54 (b), 5.76 (c) and 13.87 (d). Solid lines represent point estimates of average marginal effects on linear predictions and fields represent 95% CI (see the source data for Fig. 3 for full statistical results). Overall, results suggest that the crowding-out effect is heterogeneous with respect to level of GV (%) ($n = 19,885$).
The negative effect begins to dominate the price effect, causing a net negative effect of reward on supply. This accounts for the negative segment on the supply curve. As reward continues to increase and becomes sufficiently high, its negative effect on signal value becomes relatively low because signal quality has already deteriorated. At this point, the positive price effect will again dominate, accounting for the second positively sloped segment on the curve, completing the s-shape at the individual level. Because the mechanism generates an s-shape at the individual level, this theoretical prediction is also consistent with an s-shaped aggregate supply curve. In the context of our study, self-signalling is always possible, but a desire to signal good behaviour to others cannot be ruled out because recycling areas are usually served by more than one machine, and others may be waiting in line to recycle. Exploring the relative contribution of each signalling source might provide a fruitful direction for future research on this topic.

A second explanation is offered by ‘moral disengagement’. This is predicted to occur when the introduction of an extrinsic reward initiates within the decision-maker a process of cognitive re-evaluation of behaviour, placing less weight on its moral and ethical aspects of behaviour and more on extrinsic costs and benefits. This was the mechanism famously suggested by Richard Titmuss when predicting that a small monetary incentive would crowd-out blood donations because it is unlikely to compensate for the time and effort needed to donate blood. Moral disengagement has been corroborated across studies using different subject pools, economic and effort needed to donate blood. Moral disengagement has been detected. Moreover, because theoretical interpretation hinges crucially on whether a negative segment is preceded by a positive segment, researchers may incorrectly favour one crowding-out theory over another. In this way, the s-shaped pattern found here can help explain the body of mixed results in the literature on motivational crowding-out.

Second, uncertainty over pre-existing levels of intrinsic motivation further complicates calibration because of differences in inflection points on the supply curve. This compromises the legitimacy of aggregate-level comparisons between groups unless a reliable measure of intrinsic motivation is available. Such measures are, however, inherently difficult to obtain because intrinsic motivation is not observable directly. Instead, it has to be inferred from observational or stated preference data, but neither type of data can solve this problem on its own. Revealed preference data do not provide information about underlying motivations, and stated preference data may be subject to measurement error when respondents are unaware of their true motivation, reluctant to respond or justify their behaviour post hoc. Despite successfully identifying the crowding-out effect, our results suggest that the crowding-out effect is most likely to occur for relatively low levels of reward and that caution must be exercised when interpreting empirical results in this domain.

The findings presented here need to be viewed in light of two main limitations. First, the study sample is drawn from the general Swedish population, which can be characterized as WEIRD (western, educated, industrialized, rich and democratic). Although it is not possible to determine a priori whether our results represent a general finding with respect to human decision-making across
cultures, the heterogenous within-study effect found here suggests that variation in population characteristics may be particularly important for assessing the generality of the crowding-out phenomenon. Second, the range and level of reward analysed in our study are both narrow and low in a Swedish context. Although low rewards are thought to be particularly prone to crowding-out effects, we cannot rule out that aggregate supply of prosocial behaviour will not exhibit additional benefits in bending segments outside the range of reward observed in our study. Preference heterogeneity and aggregation allow for crowding-out effects both above and below this range. These limitations together imply that the presence of crowding-out effects remains an empirical question, necessitating careful testing of reward levels previous to any large-scale policy implementation.

In conclusion, our analysis of a large natural experiment finds that a higher level of prosocial behaviour can be incentivized at lower cost. Models of prosocial decision-making can be improved by recognizing the role of interactions between extrinsic and intrinsic rewards. Finally, empirical studies attempting to understand the crowding-out phenomenon must estimate supply over a denser and wider range of values, and collect data on proxy variables of intrinsic motivation for participation in prosocial behaviours to avoid misinterpretation of results and support effective policies.

Methods

Data and natural experiment. In March 2009, the Swedish Central Bank decided to withdraw the SEK 0.5 coin from circulation, effective from 1 October 2010. From October onwards, recyclable beverage cans carrying a deposit of SEK 0.5 were gradually replaced by cans carrying a deposit of SEK 1 as SEK 0.5 cans were recycled and removed from circulation. As a result, the expected reward from returning the can is returned to a recycling machine. Each store owns its machine(s), but maintenance, collection of recycled material and repayment to the store are managed by Returpack, a non-profit organization in charge of the recycling system. Returpack collects information on what and how much is recycled at each store, and aggregates this information monthly to return the correct deposit to each individual store.

Kooperativa Förbundet, one of the largest grocery retail chains in Sweden, provided us with monthly data on all of their 683 stores covering most Swedish counties. The data, relevant period from August 2010, two months before the new SEK 1 deposit cans were introduced, to January 2014 (T = 42), the last period where expected reward is statistically different from 1 (two-tailed t-test: t(484) = –6.582, P < 0.001, mean = 0.999, 95% CI (0.999 0.999)). The data include each store location, municipality, county, postcode and items recycled. To achieve a balanced panel data set, any store with incomplete data was excluded. This resulted in a panel consisting of detailed recycling information for 485 stores distributed across Sweden, containing 20,370 independent observations of monthly aggregates of recycled quantity, corresponding to approximately 27,454 million individual decisions.

From Statistics Sweden we retrieved additional data on median income at the postcode level and voting data at the municipality level. Finding a measure for intrinsic motivation is inherently challenging because motivation can be observed only indirectly using proxy variables. Here we use the proportion of people who voted for the Green Party (Mijlipartiet) in the 2010 municipal election, denoted GV (%). The participation rate in the election was 84.63%, and the proportion of people who voted for the Green Party varied across municipalities from 0.3% to 16.6%. Data from the SOM Institute (SOM Institutet) reveal that the Green Party is generally regarded as a single-issue party focusing on the environment and that the majority of the party’s voters report the environment as their greatest concern19. Using this measure relies on the assumption that Green Party voters are more likely to be intrinsically motivated to participate in pro-environmental activities compared to voters in the general population. Finally, to control for pure income effects we used store postcode to match data on median residential income retrieved from national tax records. These two measures allow us to test if the crowding-out effect depends on the level of intrinsic motivation, above and beyond the pure income effect.

Statistical analysis. The outcome variable is store-level monthly quantity of recycled cans in thousands, denoted ‘Cans’. The independent variable of main interest is expected reward from recycling calculated as the proportion of SEK 0.5 cans multiplied by SEK 0.5 plus the proportion of SEK 1 cans multiplied by SEK 1, for each period t. The average customer recycling 18 cans, saw an increase in expected reward from SEK 9 to 18 (USD 1.25 to 2.5) over the study period.

We present regression analysis of Cans as a function of expected reward levels E[r,t]. The continuous expected reward variable is divided into five equal intervals. These are used to create dummy variables equal to one if expected reward takes a value within the specified interval, or else zero. This approach allows us to examine the relationship between recycled quantity and expected reward without making a priori assumptions about functional form.

We use the one period lag of expected reward due to the time lag between purchasing or collecting cans and recycling them in store. This is a better measure of the expected reward at the time of purchase and was informed by a customer survey implemented by Returpack, designed with the expressed purpose of mapping the recycling habits of the general Swedish population. The survey found that the median customer recycles once a month (Supplementary Fig. 1).

Table 2 presents regression analysis of Cans as nonlinear functions of expected reward. To allow for estimation of the non-standard supply curve shapes predicted by crowding-out theories, we use specifications including second- and third-degree polynomials of expected reward. These different specifications allow for all possible patterns predicted by crowding-out theories: forward and backward bending supply with a quadratic term, E[r,t]2, and an s-shaped supply curve with a cubic term, E[r,t]3.

The panel structure of our data allows for random effects GLS model estimation. To correct for the presence of heteroskedasticity and autocorrelation, we use all models using robust standard errors. Finally, empirical studies attempting to understand the empirical patterns predicted by crowding-out theories, necessitating careful testing of reward levels previous to any large-scale policy implementation.

In conclusion, our analysis of a large natural experiment finds that a higher level of prosocial behaviour can be incentivized at lower cost. Models of prosocial decision-making can be improved by recognizing the role of interactions between extrinsic and intrinsic rewards. Finally, empirical studies attempting to understand the crowding-out phenomenon must estimate supply over a denser and wider range of values, and collect data on proxy variables of intrinsic motivation for participation in prosocial behaviours to avoid misinterpretation of results and support effective policies.

![Figure 3](https://example.com/figure3.png)

Figure 3 presents postestimation results based on model 4 in Table 2 using the Margins command in Stata 13. To illustrate the supply curve shape at varying levels of GV (%), Fig. 3a presents linear predictions of quantity recycled as functions of GV (%), Fig. 3b–d display marginal marginal effects at varying levels of GV (%). All point estimates of marginal effects are accompanied by their 95% CI (see also the source data for Fig. 3).

Finally, Table 3 presents predicted crowding-out effects on the basis of model 4 in Table 2. For each level of GV (%), the local maxima and minima of linear predictions for quantity recycled from Fig. 3a are provided. These values correspond to the inflection points on each estimated supply curve, and their difference consequently correspond to the size of the crowding-out effect provided in Table 3.

Data availability

The data that support the findings of this study are available for replication from the corresponding author on request. The data cannot be made publicly available due to property rights held by COOP and Statistics Sweden. Source data are provided with this paper.
Extended Data Fig. 1 | Box plot of expected reward $E[r_t]$ by year. The center line denotes the median; box limits denote first and third quartiles; whiskers denote the highest (lowest) value within 1.5x the interquartile range, measured from box limits; points denote outliers defined as observations larger (smaller) than 1.5x the interquartile range measured from box limits (n = 20,370).
Extended Data Fig. 2 | Box plot of quantity of recycled cans by year. The center line denotes the median; box limits denote first and third quartiles; whiskers denote the highest (lowest) value within 1.5x the interquartile range, measured from box limits; points denote outliers defined as observations larger (smaller) than 1.5x the interquartile range measured from box limits (n = 20,370).
Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

- The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement
- A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
- The statistical test(s) used AND whether they are one- or two-sided
- A description of all covariates tested
- A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
- A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
- For null hypothesis testing, the test statistic (e.g. F, t, r) with confidence intervals, effect sizes, degrees of freedom and P value noted
- Give P values as exact values whenever suitable.
- For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
- For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
- Estimates of effect sizes (e.g. Cohen’s d, Pearson’s r), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection
- No software was used

Data analysis
- Stata 13

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:
- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The data that support the findings of this study are available for replication from the corresponding author upon request. The data cannot be made publicly available due to property rights held by COOP and Statistics Sweden.
Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

- Life sciences
- Behavioural & social sciences
- Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

| Sample size | Describe how sample size was determined, detailing any statistical methods used to predetermine sample size OR if no sample-size calculation was performed, describe how sample sizes were chosen and provide a rationale for why these sample sizes are sufficient. |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Data exclusions | Describe any data exclusions. If no data were excluded from the analyses, state so OR if data were excluded, describe the exclusions and the rationale behind them, indicating whether exclusion criteria were pre-established. |
| Replication | Describe the measures taken to verify the reproducibility of the experimental findings. If all attempts at replication were successful, confirm this OR if there are any findings that were not replicated or cannot be reproduced, note this and describe why. |
| Randomization | This is not relevant to the study since this is a natural experiment |
| Blinding | This does not apply since our data was naturally generated |

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

| Study description | Data is quantitative |
| Research sample | Kooperativa Förbundet (KF), one of the largest grocery retail chains in Sweden, provided us with monthly data on all of their 683 stores covering most Swedish counties. The data span the relevant time period from August 2010, two months before the new SEK 1 deposit cans were introduced, to January 2014 (T=42), the last period where expected reward is statistically different from 1 (two-tailed t-test: t(484) = -6.582, P < 0.001, mean = 0.999, 95% Confidence Intervals = [0.999 0.999]). The data include each store location, municipality, county, postcode and recycled items, and is representative of the Swedish population. |
| Sampling strategy | Since this is secondary data generated by a natural experiment, sample size was not actively chosen. The sample consists of 20,370 independent observations of monthly aggregates of recycled quantity, corresponding to approximately 27,454 million individual decisions. Several methods exist for power calculation and a conservative approach suggest the study is of very high power; in the case of our most complex model with 22 predictors, a small effect size (f) with significance level 0.05 and power 0.9 requires a sample of 1398 independent observations. Our sample exceeds this threshold by a factor of at least 14. |
| Data collection | Returpack, a non-profit organisation in charge of the recycling system, collects information on what and how much is recycled at each machine (digitally), and aggregates this information monthly in order to return the correct deposit to each individual store. |
| Timing | Collection is continuous, preceded the study period, and is still ongoing. There is no gap in data collection. |
| Data exclusions | We use panel data techniques to estimate the average treatment effect. The achieve a balanced panel we excluded those store where data was incomplete (e.g., is a store had opened or closed). After exclusions, we were left with complete time series for 485 of 683 stores. |
| Non-participation | This is not applicable since this is a natural experiment. |
| Randomization | This is not applicable since this is a natural experiment. |

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

| Study description | Briefly describe the study. For quantitative data include treatment factors and interactions, design structure (e.g. factorial, nested, hierarchical), nature and number of experimental units and replicates. |
| Research sample | Describe the research sample (e.g. a group of tagged Passer domesticus, all Stenocereus thurberi within Organ Pipe Cactus National Monument), and provide a rationale for the sample choice. When relevant, describe the organism taxa, source, sex, age range and |
any manipulations. State what population the sample is meant to represent when applicable. For studies involving existing datasets, describe the data and its source.

**Sampling strategy**
Note the sampling procedure. Describe the statistical methods that were used to predetermine sample size OR if no sample-size calculation was performed, describe how sample sizes were chosen and provide a rationale for why these sample sizes are sufficient.

**Data collection**
Describe the data collection procedure, including who recorded the data and how.

**Timing and spatial scale**
Indicate the start and stop dates of data collection, noting the frequency and periodicity of sampling and providing a rationale for these choices. If there is a gap between collection periods, state the dates for each sample cohort. Specify the spatial scale from which the data are taken.

**Data exclusions**
If no data were excluded from the analyses, state so OR if data were excluded, describe the exclusions and the rationale behind them, indicating whether exclusion criteria were pre-established.

**Reproducibility**
Describe the measures taken to verify the reproducibility of experimental findings. For each experiment, note whether any attempts to repeat the experiment failed OR state that all attempts to repeat the experiment were successful.

**Randomization**
Describe how samples/organisms/participants were allocated into groups. If allocation was not random, describe how covariates were controlled. If this is not relevant to your study, explain why.

**Blinding**
Describe the extent of blinding used during data acquisition and analysis. If blinding was not possible, describe why OR explain why blinding was not relevant to your study.

**Did the study involve field work?**

- Yes
- No

**Field work, collection and transport**

**Field conditions**
Describe the study conditions for field work, providing relevant parameters (e.g. temperature, rainfall).

**Location**
State the location of the sampling or experiment, providing relevant parameters (e.g. latitude and longitude, elevation, water depth).

**Access & import/export**
Describe the efforts you have made to access habitats and to collect and import/export your samples in a responsible manner and in compliance with local, national and international laws, noting any permits that were obtained (give the name of the issuing authority, the date of issue, and any identifying information).

**Disturbance**
Describe any disturbance caused by the study and how it was minimized.

**Reporting for specific materials, systems and methods**

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

### Materials & experimental systems

- n/a Involved in the study
- Antibodies
- Eukaryotic cell lines
- Palaeontology and archaeology
- Animals and other organisms
- Human research participants
- Clinical data
- Dual use research of concern

### Methods

- n/a Involved in the study
- ChIP-seq
- Flow cytometry
- MRI-based neuroimaging

**Antibodies**

**Antibodies used**
Describe all antibodies used in the study; as applicable, provide supplier name, catalog number, clone name, and lot number.

**Validation**
Describe the validation of each primary antibody for the species and application, noting any validation statements on the manufacturer’s website, relevant citations, antibody profiles in online databases, or data provided in the manuscript.

**Eukaryotic cell lines**

**Policy information about cell lines**

**Cell line source(s)**
State the source of each cell line used.
Authentication

Describe the authentication procedures for each cell line used OR declare that none of the cell lines used were authenticated.

Mycoplasma contamination

Confirm that all cell lines tested negative for mycoplasma contamination OR describe the results of the testing for mycoplasma contamination OR declare that the cell lines were not tested for mycoplasma contamination.

Commonly misidentified lines

(See ICLAC register)

Name any commonly misidentified cell lines used in the study and provide a rationale for their use.

Palaeontology and Archaeology

Specimen provenance

Provide provenance information for specimens and describe permits that were obtained for the work (including the name of the issuing authority, the date of issue, and any identifying information). Permits should encompass collection and, where applicable, export.

Specimen deposition

Indicate where the specimens have been deposited to permit free access by other researchers.

Dating methods

If new dates are provided, describe how they were obtained (e.g. collection, storage, sample pretreatment and measurement), where they were obtained (i.e. lab name), the calibration program and the protocol for quality assurance OR state that no new dates are provided.

Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.

Ethics oversight

Identify the organization(s) that approved or provided guidance on the study protocol, OR state that no ethical approval or guidance was required and explain why not.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Animals and other organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research

Laboratory animals

For laboratory animals, report species, strain, sex and age OR state that the study did not involve laboratory animals.

Wild animals

Provide details on animals observed in or captured in the field; report species, sex and age where possible. Describe how animals were caught and transported and what happened to captive animals after the study (if killed, explain why and describe method; if released, say where and when) OR state that the study did not involve wild animals.

Field-collected samples

For laboratory work with field-collected samples, describe all relevant parameters such as housing, maintenance, temperature, photoperiod and end-of-experiment protocol OR state that the study did not involve samples collected from the field.

Ethics oversight

Identify the organization(s) that approved or provided guidance on the study protocol, OR state that no ethical approval or guidance was required and explain why not.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Human research participants

Policy information about studies involving human research participants

Population characteristics

See above

Recruitment

Describe how participants were recruited. Outline any potential self-selection bias or other biases that may be present and how these are likely to impact results.

Ethics oversight

Identify the organization(s) that approved the study protocol.

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Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

Clinical trial registration

Provide the trial registration number from ClinicalTrials.gov or an equivalent agency.

Study protocol

Note where the full trial protocol can be accessed OR if not available, explain why.

Data collection

Describe the settings and locales of data collection, noting the time periods of recruitment and data collection.

Outcomes

Describe how you pre-defined primary and secondary outcome measures and how you assessed these measures.
Dual use research of concern

Policy information about dual use research of concern

Hazards
Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

- [ ] Public health
- [ ] National security
- [ ] Crops and/or livestock
- [ ] Ecosystems
- [ ] Any other significant area

Experiments of concern
Does the work involve any of these experiments of concern:

- [ ] Demonstrate how to render a vaccine ineffective
- [ ] Confer resistance to therapeutically useful antibiotics or antiviral agents
- [ ] Enhance the virulence of a pathogen or render a nonpathogen virulent
- [ ] Increase transmissibility of a pathogen
- [ ] Alter the host range of a pathogen
- [ ] Enable evasion of diagnostic/detection modalities
- [ ] Enable the weaponization of a biological agent or toxin
- [ ] Any other potentially harmful combination of experiments and agents

ChIP-seq

Data deposition
- [ ] Confirm that both raw and final processed data have been deposited in a public database such as GEO.
- [ ] Confirm that you have deposited or provided access to graph files (e.g. BED files) for the called peaks.

Data access links
For “Initial submission” or “Revised version” documents, provide reviewer access links. For your “Final submission” document, provide a link to the deposited data.

Files in database submission
Provide a list of all files available in the database submission.

Genome browser session (e.g. UCSC)
Provide a link to an anonymized genome browser session for “Initial submission” and “Revised version” documents only, to enable peer review. Write “no longer applicable” for “Final submission” documents.

Methodology

Replicates
Describe the experimental replicates, specifying number, type and replicate agreement.

Sequencing depth
Describe the sequencing depth for each experiment, providing the total number of reads, uniquely mapped reads, length of reads and whether they were paired- or single-end.

Antibodies
Describe the antibodies used for the ChIP-seq experiments; as applicable, provide supplier name, catalog number, clone name, and lot number.

Peak calling parameters
Specify the command line program and parameters used for read mapping and peak calling, including the ChIP, control and index files used.

Data quality
Describe the methods used to ensure data quality in full detail, including how many peaks are at FDR 5% and above 5-fold enrichment.

Software
Describe the software used to collect and analyze the ChIP-seq data. For custom code that has been deposited into a community repository, provide accession details.
Flow Cytometry

Plots

Confirm that:
- The axis labels state the marker and fluorochrome used (e.g. CD4-FITC).
- The axis scales are clearly visible. Include numbers along axes only for bottom left plot of group (a 'group' is an analysis of identical markers).
- All plots are contour plots with outliers or pseudocolor plots.
- A numerical value for number of cells or percentage (with statistics) is provided.

Methodology

Sample preparation
Describe the sample preparation, detailing the biological source of the cells and any tissue processing steps used.

Instrument
Identify the instrument used for data collection, specifying make and model number.

Software
Describe the software used to collect and analyze the flow cytometry data. For custom code that has been deposited into a community repository, provide accession details.

Cell population abundance
Describe the abundance of the relevant cell populations within post-sort fractions, providing details on the purity of the samples and how it was determined.

Gating strategy
Describe the gating strategy used for all relevant experiments, specifying the preliminary FSC/SSC gates of the starting cell population, indicating where boundaries between “positive” and “negative” staining cell populations are defined.

Tick this box to confirm that a figure exemplifying the gating strategy is provided in the Supplementary Information.

Magnetic resonance imaging

Experimental design

Design type
Indicate task or resting state; event-related or block design.

Design specifications
Specify the number of blocks, trials or experimental units per session and/or subject, and specify the length of each trial or block (if trials are blocked) and interval between trials.

Behavioral performance measures
State number and/or type of variables recorded (e.g. correct button press, response time) and what statistics were used to establish that the subjects were performing the task as expected (e.g. mean, range, and/or standard deviation across subjects).

Acquisition

Imaging type(s)
Specify: functional, structural, diffusion, perfusion.

Field strength
Specify in Tesla

Sequence & imaging parameters
Specify the pulse sequence type (gradient echo, spin echo, etc.), imaging type (EPI, spiral, etc.), field of view, matrix size, slice thickness, orientation and TE/TR/flip angle.

Area of acquisition
State whether a whole brain scan was used OR define the area of acquisition, describing how the region was determined.

Diffusion MRI
- Used
- Not used

Preprocessing

Preprocessing software
Provide detail on software version and revision number and on specific parameters (model/functions, brain extraction, segmentation, smoothing kernel size, etc.).

Normalization
If data were normalized/standardized, describe the approach(es): specify linear or non-linear and define image types used for transformation OR indicate that data were not normalized and explain rationale for lack of normalization.

Normalization template
Describe the template used for normalization/transformation, specifying subject space or group standardized space (e.g. original Talairach, MNI305, ICBM152) OR indicate that the data were not normalized.

Noise and artifact removal
Describe your procedure(s) for artifact and structured noise removal, specifying motion parameters, tissue signals and physiological signals (heart rate, respiration).
| Volume censoring | Define your software and/or method and criteria for volume censoring, and state the extent of such censoring. |
|------------------|------------------------------------------------------------------------------------------------------------------|

**Statistical modeling & inference**

| Model type and settings | Specify type (mass univariate, multivariate, RSA, predictive, etc.) and describe essential details of the model at the first and second levels (e.g. fixed, random or mixed effects; drift or auto-correlation). |
|-------------------------|------------------------------------------------------------------------------------------------------------------|

| Effect(s) tested | Define precise effect in terms of the task or stimulus conditions instead of psychological concepts and indicate whether ANOVA or factorial designs were used. |
|------------------|---------------------------------------------------------------------------------------------------------------|

**Specify type of analysis:**
- Whole brain
- ROI-based
- Both

**Statistic type for inference**
(See Eklund et al. 2016)

- Specify voxel-wise or cluster-wise and report all relevant parameters for cluster-wise methods.

**Correction**

- Describe the type of correction and how it is obtained for multiple comparisons (e.g. FWE, FDR, permutation or Monte Carlo).

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**Models & analysis**

| n/a | Involved in the study |
|-----|-----------------------|
|     | Functional and/or effective connectivity                      |
|     | Graph analysis                                   |
|     | Multivariate modeling or predictive analysis            |

**Functional and/or effective connectivity**

Report the measures of dependence used and the model details (e.g. Pearson correlation, partial correlation, mutual information).

**Graph analysis**

Report the dependent variable and connectivity measure, specifying weighted graph or binarized graph, subject- or group-level, and the global and/or node summaries used (e.g. clustering coefficient, efficiency, etc.).

**Multivariate modeling and predictive analysis**

Specify independent variables, features extraction and dimension reduction, model, training and evaluation metrics.