Consequences of a price incentive on free riding and electric energy consumption

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Edited by William C. Clark, Harvard University, Cambridge, MA, and approved February 3, 2017 (received for review September 13, 2016)

This article shows that a simple monetary incentive can dramatically reduce electric energy consumption (EEC) in the residential sector and simultaneously achieve a more desirable allocation of EEC costs. The analyses are based on data from a policy experiment conducted in 2011 and 2012 by a private housing company in about 1,800 apartments. Roughly 800 of the tenants (treatment group) were subject to a change from having unlimited EEC included in their rent to having to pay the market price for their own EEC. This change was achieved by installing EEC meters in each apartment. Tenants in the other 1,000 apartments (control group) experienced no policy change and were subject to apartment-level billing and metering during the entire study period. Using a quasiexperimental research design and daily data on EEC from 2007 to 2015, we estimate that apartment-level billing and metering permanently reduce EEC by about 25%. Moreover, we show that households reduce EEC immediately after being informed that they will be billed for EEC, the reduction is larger when the production cost is higher, and the reduction in EEC comes almost exclusively from households with very high EEC before the policy change. Finally, we show that apartment-level billing and metering are cost-effective, with a cost per reduced kilowatt hour of US$0.01, and for each invested dollar, the social value of reductions in air pollution, including CO_2 emissions, is $2.

sub metering | environment | smart meters | energy conservation | quasiexperiment

Limiting adverse effects on individuals and societies from climate change requires effective governance of the global environment (1). Because current private incentives to reduce energy consumption are weaker than the collective incentives to prevent global warming (and other negative side effects of energy consumption), the problem can be described as a tragedy of the commons (2). Societies throughout history have used different strategies to overcome the commons problem (3). Although it has proved easier to develop effective strategies for management of local public goods (commons) than global public goods, like the climate, ineffective management at the local level still contributes to massive overuse of energy.

In this article, we evaluate the effectiveness of a well-defined strategy—apartment-level billing and metering—to handle this local commons problem. Tenants in many housing areas are allowed to consume unlimited electric energy without paying the costs of their own consumption. With this type of contract between the tenant and the landlord, the landlord typically pays the utility bills and adds a fixed share of the total costs to the rent of each tenant. When unlimited consumption of electric energy (or other resources; e.g., water or heating) is included in the rent for tenants, they have no monetary incentive to reduce consumption, because the cost of their consumption is typically shared among a large number of tenants.

As shown below, solving this local problem can help us manage global problems, like climate change. One solution is to install apartment-level meters and bill individual tenants directly for electric energy consumption (EEC). An attractive feature of this strategy is that it may fulfill all five criteria for effective governance of commons as identified by Dietz et al. (4): (*i*) resources can be easily monitored, (*ii*) the local economic and social circumstances are rather stable, (*iii*) there are functioning social networks within the community, (*iv*) outsiders can be excluded from the resource pool, and (*v*) the strategy is supported by the resource users. However, the adoption of this strategy varies greatly between countries. For instance, installation of EEC meters is required by law in all newly built housing units in the United States, whereas estimates concerning India suggest that ∼20 million electricity customers are not metered at all and hence, are not billed according to their consumption (5).

Apartment-level billing and metering have been evaluated extensively by various interest organizations claiming it to be a successful strategy. The strategy is also becoming more and more widely used. It is, therefore, quite surprising that only a few small-scale studies have evaluated this strategy according to scientific standards (6, 7). Although these studies have found substantial reductions in EEC, they were based on small samples with limited possibilities to characterize the mechanisms at play.

Several studies, however, have found that the price elasticity for EEC is typically rather low (8, 9). Alternative nonprice incentives have, therefore, been put forward as potentially being more effective than price incentives (10). Large-scale experimental studies have indeed shown that nonprice incentives, such as feedback containing information about neighbors' EEC (11) or environmental or health consequences of EEC (10), may substantially reduce EEC. Feedback about potential monetary savings from lowering EEC, however, does not seem to be effective (10, 12). These studies provide information concerning the potential savings from lowering EEC at current prices but do not

Significance

We show that a simple and common price incentive is highly effective in reducing electric energy consumption (EEC). When EEC is billed and metered at the apartment level compared with when tenants have unlimited EEC included in the rent, annual EEC falls by about 25%. Moreover, the reduction in EEC comes almost exclusively from households with very high EEC before the policy change. The results suggest that most tenants benefit, whereas only a small group of free riders stand to lose from this policy change. The policy is cost-effective, with a cost per reduced kilowatt hour of US$0.01, and for each invested dollar, the social value of reductions in air pollution, including CO_2, is $2.

Author contributions: M.E., S.E., and I.P. designed research, performed research, analyzed data, and wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1615290114/-/DCSupplemental.

evaluate responses to variation in prices. Apartment-level billing and metering, however, imply that the price is raised (typically from zero to market price) and also, that the information feedback on EEC is improved. Apartment-level billing and metering, therefore, constitute a salient and large price change. Behavioral responses to price changes have been shown, in the context of tax changes, to be larger the more salient the tax change is (13, 14).

However, it is important to realize that price increases may sometimes have unintended effects. If the price is initially zero and consumption is not extremely high, it is likely that some social norm restricting consumption exists. As argued by Gneezy and Rustichini (15), price increases may, in such situations, erode the social norm and potentially lead to increased consumption. Moreover, it is well-known that, if energy costs are shifted from the landlord to the tenant, any conservation efforts on behalf of the tenant may be offset by a decrease in conservation efforts by the landlord, the so-called split incentives problem (16). From a theoretical perspective, it is thus clear that apartment-level billing and metering as a strategy have some attractive features, especially in providing a salient price increase, but that concerns about the effectiveness are also warranted because of the potential erosion of social norms restricting EEC or the split incentives problem.

By evaluating a large-scale policy experiment conducted by a Swedish private housing company covering 1,800 apartments over 9 y (2007–2015), we are able to provide four important pieces of empirical evidence on the effectiveness of the apartment-level billing and metering strategy. First, we show that having to pay the market price for EEC rather than having unlimited consumption included in the rent reduces total EEC in the affected area by nearly 25%. The reduction in EEC directly controlled by the tenants (i.e., in the apartment) is 36%. The reduction is immediate, and part of it already appears after the tenants have been informed that their EEC will be metered and billed at the apartment level (in other words, before the tenants have to pay for the electricity). The timing of the responses suggest that tenants undertake investments in more energy-efficient appliances or start experimenting with behavioral changes as soon as they have been informed about the policy change. Second, we show that the reduction in EEC is likely to be permanent, because we see no signs of diminishing effects over time. That the effect is permanent is important, because many other conservation strategies have been found to become less effective over time (17, 18). Third, the EEC reduction is larger during the winter months, when lighting and additional heating are in higher demand (cooling is uncommon in Sweden) and the marginal cost of electric energy production is the highest (19). Fourth, almost all of the reduction in EEC comes from tenants with very high EEC in the prebilling period—that is, from a few free riders who privately benefited greatly from sharing the costs with their neighbors. In sum, our evaluation shows that apartment-level metering and billing are highly effective in reducing EEC.

Context

The policy change was conducted by a private housing company in Sweden. The available data cover EEC from ∼1,800 apartments located in two areas close to Stockholm in Sweden. The apartments have one to four bedrooms and were built during the 1960s and 1970s. In this region, daylight hours vary from about 4 h in December to more than 20 h in June. The mean temperature in December is about 3°C, and in June, it is 15°C. The landlord provides the tenants in both areas with a refrigerator, a freezer, and a stove with an oven. Hot and cold water and district heating are included in the rent. Tenants are able to add more appliances, like a dishwasher, a microwave, or a washing machine, through the landlord by paying a higher monthly rent. More appliances may also be bought and installed by the tenant. All households have lighting, and most, if not all, have a TV and a computer. Some may have additional electric radiators, but few, if any, have air conditioning.

In one of the areas, tenants were subject to apartment-level metering and billing already from 2006, before our study period begins. Apartments in this area belong to the control group in the evaluation. Apartments in the other area, which we define as the treatment group, had EEC measured with bulk meters only (covering several apartments and common areas) until 2011. As a consequence, it was not possible to bill each tenant for his own EEC. Instead, unlimited EEC was included in the rent. Note that bulk meters were used in both areas in addition to apartment-level meters during the entire study period.

However, in 2011, the landlord suggested that apartment-level metering and billing should be implemented in the entire area. After negotiations with local representatives of the Swedish union of tenants, an agreement was reached, and the implementation was started. The price of electricity was set to SEK1.435/kWh or US$0.19/kWh (SEK7.5/US$), including taxes (it was US$0.2/kWh in the control area, and the price has been constant over time in both areas). To compensate the tenants, the rent was reduced by SEK43.2 (US$5.8) per square meter and year. An average-sized apartment in the treated area had a rent decrease equivalent of 2,041 kWh/y. According to the landlord, the cost for installing the apartment-level meters was SEK2 million (US$270,000), and the maintenance costs have been negligible. Note that landlords are not free to unilaterally implement this type of reform but have to reach an agreement with the Swedish union of tenants. According to the landlord, the reduction in energy costs surpassed the rent reduction and the investments costs. Note, however, that, although the investment costs for this strategy may vary greatly depending on house characteristics, they have been falling over time.

The implementation of the apartment-level metering and billing was conducted in three steps. First, in June of 2011, the landlord informed all of the tenants that EEC meters were going to be installed in all apartments. The landlord also informed the tenants that they would have to pay the market price (US$0.19/kWh) for their EEC but that they would be compensated by a rent reduction. Second, meters were installed in all apartments during the last weeks of November and the beginning of December of 2011. Third, the billing started on March 1, 2012.

Two additional features of the context are worth emphasizing. The tenants are not recruited to participate in a study and are not aware of their EEC being analyzed for research purposes. These features are important advantages, because we avoid systematic selection of participants and the risk of obtaining biased estimates if tenants behave differently when they know that their behavior is observed by researchers, the so-called Hawthorn effect (20). More details about the apartments and the two areas can be found in *SI Appendix*, section A.

Data

We have access to two different datasets (Datasets S1–S3). The first covers 9 y (January 1, 2007 to December 31, 2015) of daily EEC from 22 bulk meters (72,065 data points in total), each covering the total EEC for the apartments connected to each bulk meter (on average, 80 apartments per bulk meter) and associated common areas (outdoor lighting, stairwells, laundry rooms, etc.). These data originate from the energy provider. The second dataset consists of hourly data from the apartment-level meters. However, these data are only available after the installation in the treatment area (January 1 to December 31, 2012). The apartment-level EEC data originate from the company managing the metering and providing the billing service for the landlord. We use the data from the apartment-level meters to analyze heterogeneous effects among high and low consumers. From the landlord, we have information on apartment characteristics, such as monthly rent, size of the apartment, number of rooms, etc. We aggregate the data to a daily level, which gives us 635,824 data points from 1,742 meters. Additional details on the data are provided in *SI Appendix*, section B.

Estimation Method

We use the policy change as a natural experiment and divide apartments into treatment and control groups as described above. We observe EEC for both groups before and after the treatment took place. We estimate the joint causal effect of the billing and metering policy (the treatment) with a difference in differences strategy (21). Using this method, we obtain the average treatment effect over the posttreatment period. The key assumption for obtaining unbiased causal effects of the policy change is that EEC in the treatment group would have evolved similarly to that of the control group if they would not have been subject to the policy change. This assumption is commonly referred to as the parallel trend assumption. A second important assumption is that the control group is not affected by the treatment (commonly referred to as stable unit treatment value assumption). We discuss these assumptions in *SI Appendix*, section D and present several tests, which validate that the assumptions are likely to be fulfilled. The outcome variable is seasonally adjusted EEC in kilowatt hours per square meter, normalized to represent annual consumption if consumption is constant at the level of that day for a full year. It is measured at the daily and bulk meter level. SEs are clustered at the bulk meter level.

To analyze the dynamics of the effect, we vary the definition of the treatment period slightly in the different analyses. This variation allows us to estimate different effects during various parts of the posttreatment period. We use the apartment-level data in a similar difference in differences model for an analysis of heterogeneous responses with respect to initial EEC. In that analysis, the SEs are clustered at the apartment level. Details on seasonal adjustment and model specifications are provided in *SI Appendix*, section C.

Results

Evidence I—A Large and Immediate Reduction in EEC. From Fig. 1, it is evident that the policy change caused a large and immediate reduction in EEC. Already after the announcement of the policy change, we see a reduction in EEC. We estimate this reduction to be 6.2% as shown by the first bar in Fig. 2 (details regarding all results and estimation models are presented in *SI Appendix*, sections C and E). After the meters had been installed, EEC drops further. The combined effect of the announcement and the installation of meters is estimated to be 18.1%. These two estimates need some additional elaboration. The immediate reduction in EEC already after the announcement suggests that tenants undertake investments in more energy-efficient appliances. It is in the interest of tenants who are about to change a broken light bulb or buy a new TV to consider how much energy it will consume. Unplugging existing devices, however, is not in the interest of the tenant at this point in time. Although this logic also applies during the period when the meters had been installed but billing had not yet started, it is quite plausible that tenants started a trial and error type of evaluation using the feedback from the meters concerning which kinds of behavioral changes seem to be worthwhile. However, both investments in more energy-efficient technology and behavioral adaptations may be gradual, and it is, therefore, not possible to quantify how much of the reduction is the result of either of the two explanations. Reductions in both plug load and lighting, however, seem to be common methods for reducing EEC, at least in response to information feedback (10).

The average reduction of EEC over the entire billing period (March 1, 2012 to December 31, 2015) is estimated to be 24.4%

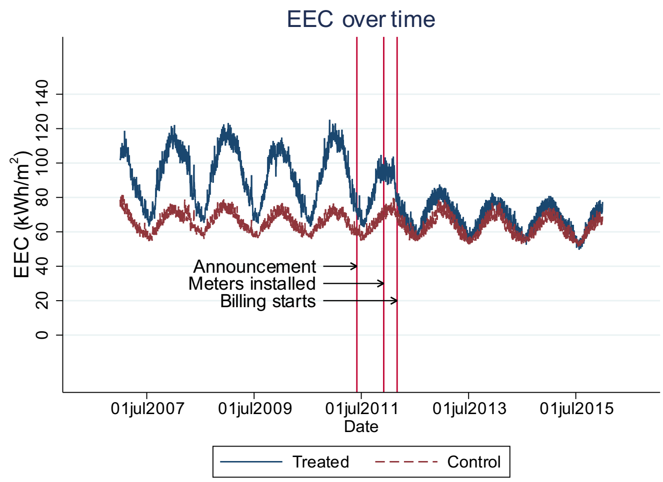

Fig. 1. Daily EEC in the treatment and control groups (kilowatt hours per square meter). A data point for a specific day shows the annual consumption if consumption is constant at the level of that day for an entire year. The vertical lines denote the times when the tenants were informed of the policy change, the meters were installed, and the billing started. The figure is based on 72,065 data points from 22 bulk meters and 3,286 d.

(Fig. 2). This effect should be interpreted as the composite effect of the price incentive and the feedback on consumption provided by the EEC meters. Because the tenants experienced a rent reduction simultaneous with the price increase, it is possible that the effect is confounded by the rent reduction. A back of the envelope calculation, however, suggests that we underestimate the reduction in EEC with, at most, 1% point (*SI Appendix*, section F has details about the calculation). The 24.4% reduction translates into an absolute reduction of about 1,600 kWh/y for a 70-m^2 apartment, which roughly corresponds to the energy used by three constantly lit 60-W light bulbs. It should also be noted that the 24.4% reduction in EEC refers to the total use of EEC per square meter of apartment and includes the use of EEC in common areas, such as stairwells, cellars, outdoor lighting, water heaters, etc. We estimate that about one-third of the EEC in the control group and the posttreatment period for the treatment group comes from common areas (*SI Appendix*, section G has details). If we calculate the reduction as a percentage of EEC used in the apartments (i.e., under direct control of the tenants), then the reduction is 36%. The absolute reduction of 1,600 kWh/y and apartment, however, is unaffected by choice of reference consumption. The estimated reduction in EEC is larger than what has been found in previous studies (6, 7). This difference is worth noting given that studies have found relatively low electric energy price elasticities for tenants who only pay for consumption through appliances and do not pay for heating or cooling (7, 8). In *Discussion*, we return to possible explanations as to why we find stronger effects.

Evidence II—The Effect Is Permanent. The reduction in EEC is not only immediate, but it is also persistent. Fig. 3 shows the estimated EEC reduction during the remainder of 2012 (i.e., March 1 to December 31, 2012) and during the full calendar years 2013–2015. The estimated effects should be interpreted relative to the mean EEC in the treatment group before June 1, 2011 (estimated effects on absolute reductions are reported in *SI Appendix*, Table S3). It is evident that the effect is persistent (or if anything, slightly increasing) over time. The fact that we see no signs that EEC would revert back to pretreatment levels is interesting. It means that we can be rather confident in interpreting the effect of this policy change as

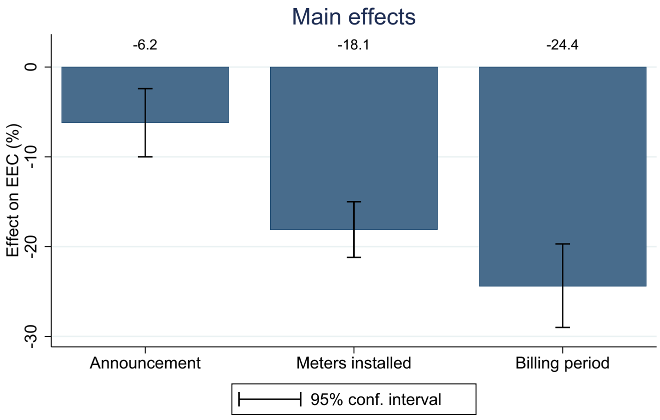

Fig. 2. The effect of the policy change is estimated to be a reduction in EEC by 6.2% during the announcement period, 18.1% during the period after the meters had been installed but before billing started (December 1, 2011 to February 29, 2012), and 24.4% during the period after billing was introduced (March 1, 2012 to December 31, 2015). All effects are relative to the mean EEC in the treatment group before June 1, 2011 (92.99 kWh/m^2). All estimates are statistically significant at the 1% level. The figure is based on 72,065 data points from 22 bulk meters and 3,286 d. More details on the estimated model are provided in *SI Appendix*, section C.2, and detailed regression results are in *SI Appendix*, Table S2.

permanent. That the effect appears to be permanent is a clear merit of this strategy, especially because Delmas et al. (17), in a metaanalysis of studies, found that the longer the researchers had monitored EEC in connection to feedback strategies without price incentives, the lower the estimated reduction in EEC.

Evidence III—The Effect Varies by Month. Fig. 4 shows how the reduction in EEC varies over the year in the posttreatment period. In the summer months, when demand for EEC is lower, we estimate the effect of the policy change to be smaller in both relative and absolute terms. The winter months are darker, and the outside temperatures are lower. As a consequence, people spend more time indoors with increased use of appliances. Moreover, the demand for lighting and additional heating is also higher. With higher consumption, the room for energy conservation increases. During the summer months, when EEC is generally low, most tenants are likely to find it difficult to further reduce their EEC. The fact that the reduction in EEC is larger during the winter months is an attractive feature of this strategy, because both demand for EEC and the marginal cost of producing EEC are the highest in those months in Sweden (19).

Evidence IV—The Effect Stems from High Consumers Reducing EEC. We use data from the EEC meters installed in the individual apartments to analyze from which type of tenants the reduction in EEC stems. We only have access to data from apartment meters from January 1 to December 31, 2012. However, we know that part of the reduction of EEC already occurred before January 1, 2012. With this caveat in mind, we divide the apartments into 10 groups based on the deciles of EEC during January of 2012 (i.e., more than 1 mo before the tenants had to pay for EEC). We do this separately for the control group and the treatment group. We then compare the changes in EEC between corresponding deciles in the treatment and control groups between January and December. The results are shown in Fig. 5. We find an evident and remarkably large reduction in EEC among the group with the highest consumption in January of 2012. For all of the other groups, the change in EEC is much smaller or statistically insignificant. This pattern—that the tenants with the highest prebilling EEC are reducing EEC the most—is also found when we do the analysis separately for one-, two-, and three-room apartments. With regard to four-room apartments, however, we see no such pattern (*SI Appendix*, section E.1).

These results suggest that there is a limited group of tenants who use much more electric energy when the cost of their consumption is spread out over all of the tenants in the area, a behavior that is typically referred to as free riding. Most of the tenants do not seem to change their consumption because of the policy change, which is also highly interesting and suggesting that, in this context, most consumers do not change their EEC in response to the monetary incentive. The implications of this finding are very important. Our estimates suggests that one-half of the total reduction in EEC comes from the 10% of tenants having the highest EEC and that two-thirds of the total reduction comes from only 20% of the tenants. It shows that the distribution of the costs of EEC may be shifted to what is likely to be perceived as fairer by the tenants. One of the key features for a strategy to be effective in the governance of common pool resources is that the strategy is accepted by the users. The only obvious losers from letting the tenants pay for their own consumption are the small group of free riders, which is likely to be accepted by most tenants. Although a small group of individuals who benefit disproportionately from the status quo often is successful in opposing changes that benefit the larger group, this phenomenon was not observed in this context. The outcome in our context may partly be explained by all tenants, both winners and losers, being represented by one organization (the local group from the Swedish union of tenants) who negotiated with the landlord. It should also be noted that the landlord or the neighbors could not identify free riders before the apartment-level meters had been installed.

Discussion

We would like to discuss a few aspects of our findings. First, the results clearly show that a shift from having EEC included in the rent to letting the tenants pay for their own EEC leads to a substantial and permanent reduction in EEC. We estimate that the investment cost per reduced kilowatt hour is US$0.01, which is lower than the US$0.02–$0.29/kWh reported for several other energy conservation strategies (11, 22, 23). Moreover, we estimate that each invested dollar leads to $2

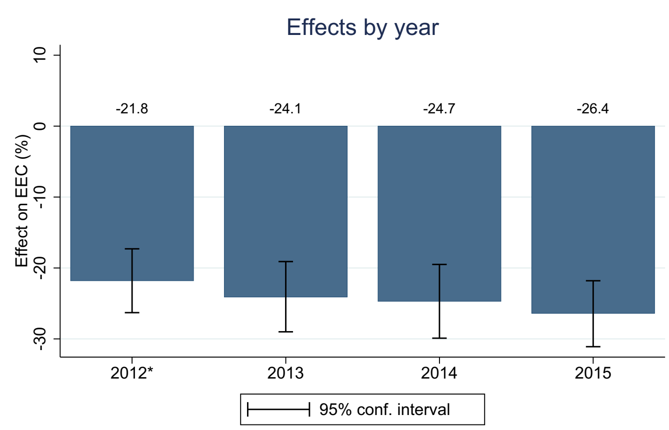

Fig. 3. The effect of the policy change is estimated to be a reduction in EEC of 21.8% during the remainder of 2012 (March 1 to December 31), 24.1% during 2013, 24.7% during 2014, and 26.4% during 2015. All effects are relative to the mean EEC in the treatment group before June 1, 2011 (92.99 kWh/m^2). All estimates are statistically significant at the 1% level. The figure is based on 72,065 data points from 22 bulk meters and 3,286 d. More details on the estimated model are provided in *SI Appendix*, section C.4, and detailed regression results are in *SI Appendix*, Table S3.

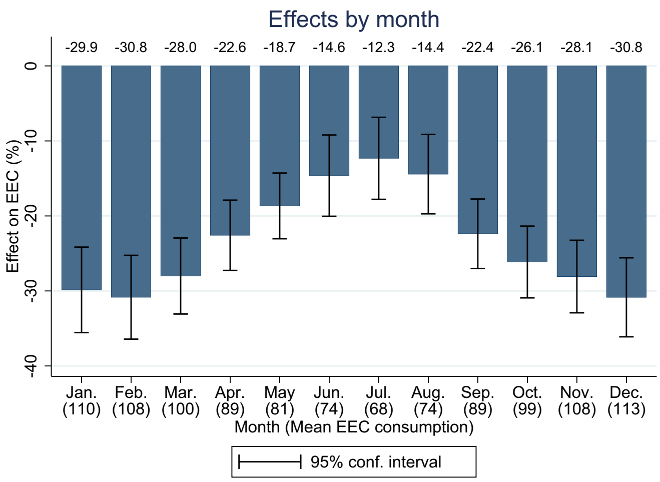

Fig. 4. The reduction in EEC caused by the policy change is estimated to vary between 14.6% in July and 30.8% in December. All effects are relative to the mean EEC in the treatment group for the corresponding month in the pretreatment period (before June 1, 2011). All estimates are statistically significant at the 1% level. The estimates are based on 66,264 data points from 22 bulk meters and 3,012 d. More details on the estimated model are provided in *SI Appendix*, section C.5, and detailed regression results are in *SI Appendix*, Table S4.

in reduced costs from carbon dioxide and other air pollutants. The calculations are based on the average Organization for Economic Cooperation and Development (OECD) energy input mix in electric energy production and the social cost of carbon used by, for example, the US Environmental Protection Agency [discussed by Greenstone et al. (24)] and general external damage numbers from the work by Muller et al. (25). The apartment-level billing and metering strategy is not, however, necessarily beneficial from a private economic perspective, which motivates government subsidies or other regulations to encourage private investments. In our context, the benefit to the landlord exceeded the costs, because the small group of free riders paid a large fraction of the costs, whereas a large group of tenants benefitted from the implementation (*SI Appendix*, section H has more details regarding the cost–benefit analyses).

Although our results come from a specific context, we see no reason why they would not be informative with regard to the possible effects of similar changes in other countries or climate zones. Whereas the magnitudes of the effects are likely to vary depending on the types of appliances used by the tenants (e.g., if air conditioners are used) and the price of electricity, the important finding here is that tenants will become conscious about their energy consumption and avoid EEC that provides little value to themselves. This finding is likely to be informative also if tenants were billed and metered on the apartment level for other utilities, such as heating or hot water.

Moreover, we find that about two-thirds of the total reduction in EEC comes from the tenants with the 20% highest prebilling EEC. This result means that most consumers do not change their EEC all that much from the introduction of a price incentive. The fact that a small fraction of the population is highly price-sensitive, whereas the rest do not change their rate of consumption in response to a price increase is interesting and has also been shown by Reiss and White (8). In our context, this result suggests that only about one-fifth of the tenants free ride on their neighbors in this regard. Although the share of free riders is likely to depend on local social norms and social networks in the neighborhood (3), it highlights that the response of the typical consumer may not be informative when it comes to the overall effect of this type of energy conservation strategy. This insight has important implications for the design of studies trying to estimate the effect of energy conservation strategies. If participation in studies is voluntary, it is likely that the key free riders will be underrepresented, and conclusions regarding the effectiveness of the strategy may be misleading. That our study includes these free riders is likely to be an important explanation as to why we find relatively large reductions in EEC.

A concern regarding shifting the costs of EEC from the landlord to the tenants is that it reduces the incentives for the landlord to invest in energy-efficient technology (16). However, our results show that EEC falls substantially in the entire housing area. Hence, any increase in EEC coming from counteracting incentives for the landlord, at least in our setting, seems to be dwarfed by the reduction in EEC coming from behavioral adjustments by the tenants.

The global potential reduction of EEC from universally implementing apartment-level billing and metering is very difficult to estimate. In Sweden, slightly less than one-half of the population lives in multifamily dwellings. However, of those living in multifamily dwellings, it has been estimated that between 5 and 15% have EEC included in their rent (26). US Energy Information Administration reports that, in the United States, less than 10% have EEC included in their rent (27). Both Sweden and the United States are, therefore, still able to further exploit the energy-saving potential from apartment-level billing and metering, although much has already been exploited. However, when it comes to other utilities, such as hot water and heating, the energy-savings potential is still largely unexploited in both Sweden and the United States. In many other countries, however, it is still common to have EEC included in the rent. For instance, in Ontario, Canada, it has been reported that 26% of the population lives in multifamily dwellings and that 75–90% of these have unlimited EEC included in their rent (7). In India and other countries with less developed power grids, the savings potential is likely to be very large. Any assessment of the potential of apartment-level billing and metering must necessarily rely on strong and simplifying assumptions. In an attempt to assess the

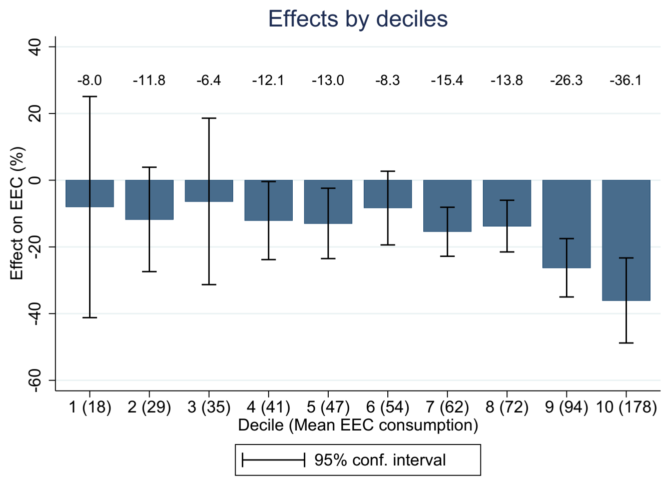

Fig. 5. The reduction in EEC caused by the policy change varies with prebilling EEC. For the six deciles with lowest EEC in January of 2012, we see small or statistically insignificant reductions in EEC between January and December of 2012. For deciles 7 and 8, the reduction is modest (around 15%), and for the deciles 9 and 10, we see very large reductions (26.3 and 36.1%, respectively). All effects are relative to the mean EEC in the respective deciles in January of 2012. The figure is based on 106,256 data points from 61 d and 1,742 apartment meters. More details on the estimated model are provided in *SI Appendix*, section C.6, and detailed regression results are in *SI Appendix*, Table S5.

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potential of implementing this strategy in all apartments in all OECD countries, we find that EEC could be reduced by 226 TWh/y, which is 50% more than the EEC consumed in Sweden or about 5% of the annual consumption in the United States (*SI Appendix*, section I).

We argue that apartment-level billing and metering are likely to be technologically possible and economically justified in a broad set of contexts and hence, a very attractive energy conservation strategy. Most of the local resource users may benefit, and only a small fraction of free riders lose from the implementation of apartment-level billing and metering.

ACKNOWLEDGMENTS. We thank the housing company that provided data and implemented the policy change. We also thank Adrian Adermon, Niklas Bengtsson, Jan Brueckner, Henry Ohlsson, and Joacim Tåg (seminar participants at the 72nd Annual Congress of the International Institute of Public Finance, Umeå University and the 2016 Swedish Economics Meeting) for valuable comments and suggestions. Financial support from the Jan Wallander and Tom Hedelius Foundation is gratefully acknowledged.

1. IPCC (2014) Climate change 2014: Synthesis report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report to the Intergovernmental Panel on Climate Change, eds Pachauri RK, Meyer LA (IPCC, Geneva).
2. Hardin G (1968) The tragedy of the commons. The population problem has no technical solution; it requires a fundamental extension in morality. *Science* 162(3859): 1243–1248.
3. Ostrom E (1990) Governing the Commons: The Evolution of Institutions for Collective Action (Cambridge Univ Press, Cambridge, MA).
4. Dietz T, Ostrom E, Stern PC (2003) The struggle to govern the commons. *Science* 302(5652):1907–1912.
5. Depuru SSSR, Wang L, Devabhaktuni V (2011) Electricity theft: Overview, issues, prevention and a smart meter based approach to control theft. *Energy Policy* 39(2): 1007–1015.
6. Munley VG, Taylor LW, Formby JP (1990) Electricity demand in multi-family, renter-occupied residences. *South Econ J* 57(1):178–194.
7. Dewees D, Tombe T (2011) The impact of sub-metering on condominium electricity demand. *Can Public Policy* 37(4):435–457.
8. Reiss PC, White MW (2005) Household electricity demand, revisited. *Rev Econ Stud* 72(3):853–883.
9. Reiss PC, White MW (2008) What changes energy consumption? Prices and public pressures. *Rand J Econ* 39(3):636–663.
10. Asensio OI, Delmas MA (2015) Nonprice incentives and energy conservation. *Proc Natl Acad Sci USA* 112(6):E510–E515.
11. Allcott H (2011) Social norms and energy conservation. *J Public Econ* 95(9-10):1082–1095.
12. Schultz PW, Estrada M, Schmitt J, Sokoloski R, Silva-Send N (2015) Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms. *Energy* 90: 351–358.
13. Chetty R, Looney A, Kroft K (2009) Salience and taxation: Theory and evidence. *Am Econ Rev* 99(4):1145–1177.
14. Bradley S (March 23, 2016) Inattention to deferred increases in tax bases: How Michigan homebuyers are paying for assessment limits. *Rev Econ Stat*, 10.1162/REST_a_00597.
15. Gneezy U, Rustichini A (2000) A fine is a price. *J Legal Stud* 29:1–17.
16. Gillingham K, Harding M, Rapson D (2012) Split incentives in residential energy consumption. *Energy J* 33(2):37–62.
17. Delmas MA, Fischlein M, Asensio OI (2013) Information strategies and energy conservation behavior: A meta-analysis of experimental studies from 1975 to 2012. *Energy Policy* 61:729–739.
18. Allcott H, Rogers T (2014) The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. *Am Econ Rev* 104(10): 3003–3037.
19. Lucia JJ, Schwartz ES (2002) Electricity prices and power derivatives: Evidence from the Nordic power exchange. *Rev Deriv Res* 5(1):5–50.
20. Landsberger HA (1957) Hawthorne Revisited: A Plea for an Open City (Cornell Univ, Ithaca, NY).
21. Meyer BD (1995) Natural and quasi-experiments in economics. *J Bus Econ Stat* 13(2):151–161.
22. Davis LW, Fuchs A, Gertler P (2014) Cash for coolers: Evaluating a large-scale appliance replacement program in Mexico. *Am Econ J Econ Policy* 6(4):207–238.
23. EIA (2013) Electric Power Annual 2011 (US Department of Energy, Washington, DC).
24. Greenstone M, Kopits E, Wolverton A (2013) Developing a social cost of carbon for US regulatory analysis: A methodology and interpretation. *Rev Environ Econ Policy* 7(1):23–46.
25. Muller NZ, Mendelsohn R, Nordhaus W (2011) Environmental accounting for pollution in the United States economy. *Am Econ Rev* 101(5):1649–1675.
26. Energieffektiviseringsutredningen (2008) Ett energieffektivare Sverige (Fritzes, Stockholm).
27. USEIA (2009) 2009 RECS Survey Data: Consumption & Expenditures. *CE2.1 Fuel consumption totals and averages, U.S. homes.* (US Energy Information Adminsitration, Washington, DC). Available at www.eia.gov/consumption/residential/data/2009/. Accessed February 17, 2017.