Online Material and Methods (MM) Appendix

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Earnhart, Dietrich and Paul J. Ferraro (ORCID: 0000-0002-4777-5108). **The Effect of Peer Comparisons on Polluters: A Randomized Field Experiment among Wastewater Dischargers.** *Environmental and Resource Economics.*

The study's pre-analysis plan (PAP), data, and analysis code are available at (https://osf.io/6u7t8/). As noted in the PAP, we confirmed with the Johns Hopkins University (Homewood) Institutional Review Board and the University of Kansas Human Subjects Committee that this project does not qualify as human subjects research. The subjects are organizations. We collected no human subject data. Nevertheless, our study design complies with the Belmont Report principles for research.

1. Peer Comparisons

We focused our peer comparisons on a conventional pollutant for municipal wastewater treatment facilities – biological oxygen demand (BOD). BOD is defined as the amount of oxygen utilized by microorganisms in oxidizing carbonaceous and nitrogenous organic matter. Essentially, BOD is a measure of the "strength" of wastewater: the greater the concentration of degradable organic matter, the higher the BOD. When discharged into waterways without treatment, degradable organic matter depletes dissolved oxygen resources of the receiving waters, damaging the aquatic ecosystems (Mihelcic and Zimmerman, 2014).

While BOD is a common measure of performance for wastewater treatment facilities, there is no method to measure BOD directly. Instead, facilities estimate BOD levels by incubating water samples in a controlled environment and measuring oxygen consumption over time. The standard incubation time period for BOD limits and discharge reporting is 5 days. The result of this test is called the 5-day biological oxygen demand (BOD_5).

The sampling protocol for measuring BOD_5 differs based on the presence of nitrogen: not nitrogen inhibited and nitrogen inhibited. In the case of monthly limits, both types of sampling protocols prove relevant. Of the monthly data records used for our study, 8.4 % provide data on BOD measured when nitrogen inhibited and 91.6 % when not nitrogen inhibited. When calculating a discharge ratio for a single facility in a period, only one of the two relevant BOD pollutants provides non-missing data on both limits and measurements. Thus, we are not aggregating between the two types of BOD at the level of our unit of analysis. Still, we acknowledge that the monthly sample contains data on both BOD types. All the quarterly data relate to BOD measured without nitrogen inhibition.

We purposively did not choose other pollutants for our peer comparisons. Total suspended solids (TSS) also represent a conventional pollutant commonly discharged by municipal wastewater treatment facilities. It is the second most prevalent pollutant for facilities in our sample. Thus, its use would lower the commonality of the pollutant across facilities. As important, according to conversations with a wastewater engineer, municipal facilities possess more scope to adjust BOD than TSS (Pers. Comm., E. Bouwer, 2016). Facilities can lower their BOD discharges in two ways. The less expensive, and rapid, method is to increase the time that the waste residue is subject to biological treatment. Once a facility approaches its design capacity, however, increasing the residence time requires more tanks. Increasing the number of tanks requires investments that may take three to five years to implement. This form of secondary treatment can usually lower the BOD concentration to about 15 mg/L. To reduce concentrations below this level typically requires adding tertiary treatment, which is a much larger investment and may take even longer to implement.

We gathered publicly available data on BOD limits and discharges. The EPA stores data on discharge limits and reported discharges for all major and some minor facilities in the EPA Integrated Compliance Information System (ICIS) database. The EPA makes these data publicly

available through both the EPA Water Pollutant Loading Tool and Enforcement and the Compliance History Online (ECHO) portal. We use the underlying ICIS data to construct peer comparisons of municipal wastewater facilities in Kansas. Nearly all facilities in our sample discharge from a single pipe. However, 1.8 % of the monthly data records and 0.2 % of the quarterly data records provide information on a second pipe. we ignore the second pipe. In general, facilities use second pipes infrequently. Without data on wastewater flow, we are not able to weight the importance of the second pipe. Given the limited presence of a second discharge pipe and our fear of mistakenly and dramatically undermining the importance of the first pipe by using an unweighted average, we simply ignored data on any second pipe's limits and measurements.

As true for most municipal wastewater treatment facilities operating in the US, Kansas municipal facilities face only limits based on concentration (namely milligrams of pollutant per liter of effluent or mg/L). Permits issued to municipal facilities place limits on the maximum and average BOD levels. Based on the concentration limits and measurements, for each facility in a time period (e.g., month), we calculated the discharge ratio separately for the maximum limit and the average limit. (The availability of data on discharge limits and measurements does not different between these two bases.) Then we calculated the average of two basis-specific discharge ratios to generate a facility-period-specific discharge ratio.

From this facility-period-specific discharge ratio, we calculated a facility's average discharge ratio over the calendar year of 2016. As noted in the main text, facilities may face only monthly limits, only quarter limits, or both types. In the calendar year of 2016, nearly all facilities faced either only monthly limits or only quarterly limits. We used monthly data for those facilities facing only monthly limits and only quarterly data for those facilities only quarterly limits. For the three facilities that faced both types, we averaged the two frequency-specific measures to calculate a facility-specific discharge ratio for the calendar year of 2016.

We then assessed the distribution of average discharge ratios across the population of municipal treatment facilities and identified each facility's point on that distribution. This identification represents the professional peer comparison.

2. Randomized Treatment Assignment

We randomly assigned treatment to a subset of Kansas municipal facilities. In order to minimize the presence of missing data during the post-treatment period, we processed data on discharge limits and measurements twice. In April 2016, we identified 361 NPDES-permitted municipal wastewater treatment facilities in Kansas with at least one non-missing BOD_5 compliance ratio during the period between April 2015 and March 2016. In April 2017, we identified 357 NPDES-permitted municipal wastewater treatment facilities in Kansas with at least one non-missing BOD_5 compliance ratio during the period between January 2016 and December 2016, the period that would be used to construct the peer comparison. We eliminated 24 facilities from the first 361 facilities that reported no discharges in the 2016 calendar year; similarly, we eliminated 29 facilities from the second 357 facilities that never reported a discharge between April 2015 and March 2016. We assume the resulting sample of 328 facilities represents the subset of the target population most likely to report at least one discharge measurement during the post-treatment assignment period.

For the randomized treatment assignment, we blocked on key variables. We calculated a facility's average 2016 discharge ratio to capture the facility's compliance history. We then used the quartile in which the facility's average discharge ratio fell as a blocking covariate. For the other blocking variables, we rounded up any positive average value to one. Our chosen assignment design aimed to randomize half of the sample to receive the intervention letter. We used Stata v14 to randomize. We posted the randomization code and anonymized data for calendar year 2016 on the Open Science Forum (OSF) project page.

3. Delivery of Treatment

To the treated facilities, we sent a two-page letter and a single-page graphic. Figure S1 of this MM appendix presents an example image of the two-page letter, with the name of the facility masked. Figure 2 of the main article presents an example image of the single-page graphic. We sent these materials in a single certified mailing using the U.S. Postal service to each NPDES-contact person in the treatment group. We acknowledge that multiple people may jointly make wastewater management decisions and the presence of multiple decision-makers may vary across facilities. We are unable to assess heterogeneity in the treatment effect based on this attribute of the decision context.

To send our treatment letters, we used contact information provided by the Bureau of Water within the Kansas Department of Health and Environment, which administers the NPDES program in the state of Kansas. The information provided was not complete or fully up-to-date for 19 facilities. For these facilities, our research assistants sent email messages and made phone calls in order to confirm each facility's contact person's name and address. During these communications, the research assistants did not inform the email/call recipient of the reason for confirming the correct contact name and address. Nevertheless, we acknowledge that these communications may have increased the salience of our treatment letter for these facilities.

4. Semi-structured Interviews with Facility Managers

The pollutant-specific discharge ratios for individual facilities are not publicly available, although the data to construct them are publicly available. To download and process the requisite data would take dozens of hours for someone with familiarity with the DMR Pollutant Loading Tool or ECHO portal. For other measures of facility-specific compliance, the information available to facility managers is likewise challenging to secure. The most widely known source

is the very limited comparison information provided by the annual awards presented by the National Association of Clean Water Agencies.[1]

Thus, we claim that our peer comparisons provided new information to facility managers. To substantiate this claim, during the months of April and May 2019, a research assistant, Marisa Henry, interviewed randomly-selected facility managers at four major facilities and eight minor facilities. We purposively waited to conduct these interviews until immediately after we had downloaded the end-line data (20 months after sending the treatment letters). As noted in the PAP, to explore longer-run impacts of the treatment, we aim to collect additional discharge data on the facilities in the experiment. Therefore, we did not wish to conduct interviews on more than a dozen managers, for fear that the interviews could affect the treated facility managers' behaviors, and thereby complicate inferences from future data collection efforts. We strategically chose facilities for these interviews. We chose five facilities from the lowest discharge ratio quartile, four facilities from the second or third quartiles, and three facilities from the highest quartile, of which one had a discharge ratio above one (i.e., out of compliance).

The interviews provide useful insights. Half of the managers remembered receiving the letter; the other half did not, but one of these managers was new to the job. Nearly all of the managers expressed an interest in the information. The most common comments relate to the construction of the peer group. In particular, managers stated that, although they found the peer comparisons intriguing, they would prefer that their facilities' peer group include only facilities that serve populations of similar size and composition (particularly residential:industrial ratios), experience similar rainfall, and operate similar treatment processes.

Based on these interviews, we conclude that most facilities found the letters memorable, the rankings salient, and the peer group acceptable for comparison. This said, some of the interviewees identified dimensions on which facilities differ yet about which we made no

[1] https://www.nacwa.org/about-us/awards/peak-performance-awards/peak-past-honorees

adjustments. In particular, our peer comparisons do not adjust for the types of industrial users discharging into a municipal wastewater collection system or the type of treatment process. These distinctions need not matter meaningfully. First, municipal wastewater treatment facilities possess legal authority to control discharges from industrial users, thus, the peer comparisons are apt as long as we broaden the notion of wastewater management. This broad interpretation is consistent with statements offered by interviewed facilities; for example, one facility reported that it could lower its BOD discharges by controlling better the influent into its treatment process. Second, our measure of compliance is less vulnerable to variation in industrial users' discharges since we focus exclusively on the concentration of BOD. Third, decisions over treatment processes are clearly part of wastewater management. Thus, we see no need to partition facilities based on a choice variable. Lastly, the interviewed facilities identified an array of management steps available for reducing BOD discharges. While some of these steps require substantial equipment or infrastructure investment, several steps are feasible in the short run, such as increasing the time in treatment, installing new filters, or expanding the use of chemical additives.

5. Pre-treatment and Post-treatment Data

To create an "aggregated quarterly data set" from our sample of monthly and quarterly dischargers, we calculated the discharge ratio for each relevant month or quarter. Then we aggregated all monthly discharge ratios to a quarterly frequency based on the quarter-specific mean. Finally, we merged the aggregated monthly and quarterly discharge ratios. Of the 328 facilities in our sample, 11 facilities faced monthly limits and quarterly limits at some point over the sample period (but not necessarily in the same quarter). In these 11 cases, we calculated the average of the aggregated monthly discharge ratio and quarterly discharge ratio when both are non-missing in the same quarter.

Facilities facing monthly limits may differ from facilities facing quarterly limits. This MM appendix provides additional details on the conditions that drive this difference. According to NPDES documentation (https://www3.epa.gov/npdes/pubs/pwm_chapt_08.pdf), agencies should impose more frequent reporting from facilities (e.g., monthly rather than quarterly reporting) when the following conditions hold:

1. "A highly variable discharge should require more frequent monitoring than a discharge that is relatively consistent over time (particularly in terms of flow and pollutant concentration)."
2. "The monitoring frequency might need to be increased at facilities where the treatment facility is nearing design capacity."
3. "If the treatment method is appropriate and achieving high pollutant removals on a consistent basis, monitoring could be less frequent than for a plant with little or insufficient treatment."
4. "A facility with problems achieving compliance generally should be required to perform more frequent monitoring to characterize the source or cause of the problems or to detect noncompliance."
5. "The monitoring frequency could be increased if the discharge is to sensitive waters or is near a public water supply."
6. "To accurately characterize the discharge, the monitoring frequency might be increased for wastewaters with highly toxic pollutants or where the nature of the pollutants varies."
7. "The monitoring frequency for a wastewater discharged in batches infrequently should differ from that for a continuous discharge of highly concentrated wastewater or a wastewater containing a pollutant that is found infrequently and at very low concentrations."

8. “If a facility has seasonal discharge limitations, it might be appropriate to increase the monitoring frequency during the higher production season, and reduce the frequency during the off-season.”

References

Mihelcic, J. and J. Zimmerman (2014), *Environmental Engineering: Fundamentals, Sustainability, Design*, Hoboken, N.J. Wiley

Figure S1 – Example Images of Two-sided Treatment Letter (no graphic)

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From: Dietrich Earnhart, Professor, Center for Environmental Policy, University of Kansas
Paul Ferraro, Professor, Johns Hopkins University

To:

[redacted]
c/o City Clerk
[redacted] Wastewater Treatment Facility
[redacted]
[redacted], KS [redacted]

Why am I getting this letter?

Peer Comparisons of Compliance among Kansas Municipal Dischargers

Your municipal wastewater treatment facility, [redacted] Wastewater Treatment Facility, is regulated under the Clean Water Act by the Kansas Department of Environment and Health (KDHE), in concert with the Environmental Protection Agency (EPA). The KDHE lists you as the facility's contact person for the National Pollutant Discharge Elimination System (NPDES).

Based on our conversations with wastewater treatment experts in Kansas, we believe municipal wastewater facilities are not sure how their compliance performance differs from their Kansas peers. We have initiated a project that aims to provide this information.

We hope you find it useful!

What is a compliance ratio and why should I care?

To give you some sense of **how your compliance with your NPDES discharge limits compares to your Kansas peers' compliance**, we have extracted publicly available data from the EPA Integrated Compliance Information System (ICIS) database and assembled these data in a more easily understood format. We focus on the extent of compliance, which we measure as the *discharge-to-limit ratio*: the ratio of your wastewater discharges to the permitted discharge limit. **A lower discharge-to-limit ratio indicates *better* compliance with a facility's discharge limit.**

See the example in box →

Discharge-to-Limit Ratio

Wastewater discharges are recorded as a concentration, in milligrams of pollutant per liter of water discharged (mg/L). Say Facility A's discharge limit for a pollutant is 30 mg/L and it discharges 15 mg/L. Its *discharge-to-limit ratio* then equals 0.50. If the facility's discharge limit changes from 30 mg/L in the winter to 12 mg/L in the summer, yet the discharge level stays the same, then the facility's discharge-to-limit ratio would also change: from 0.50 in winter to 1.25 in summer. Say Facility B faces the same winter discharge limit, but discharges 45 mg/L in the winter. Its discharge-to-limit ratio equals 1.50. Comparing the two facility ratios, we conclude that Facility A has better compliance in the winter.

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The discharge-to-limit ratio allows one to measure the **extent of compliance** for any discharge limit, even when a facility's discharge limit varies over time. More importantly, this compliance ratio allows one to compare the extent of compliance across multiple facilities, even when each facility faces a different discharge limit. By comparing the two facilities' compliance ratios, one can assess which facility complies to a greater extent with its discharge limit and which complies less. **Facilities with lower compliance ratios comply to a greater extent.**

Kansas municipal facilities discharge a variety of pollutants. In order to facilitate comparison across facilities, **our calculations of the compliance ratio focus on the most prominent pollutant among Kansas municipal facilities: Biological Oxygen Demand (BOD).** For each facility, we use the facility's BOD discharge limits and its actual BOD discharges to calculate its 2016 compliance ratio, which is the average ratio over the 12-month period between January and December 2016.

So how does my facility compare with other facilities in Kansas?

Based on these facility averages, we are able to generate a distribution of all facilities' average compliance ratios. We graphically present this distribution in the enclosed figure. Each facility is represented once in this distribution. At the bottom of the distribution is the facility with the smallest compliance ratio – it is found at the extreme left of the graph where the curve begins (minimum ratio = 0.04). At the top of the distribution is the facility with the largest compliance ratio – it is found at the extreme right of the graph where the curve ends (maximum ratio = 1.92). In the middle of the distribution is the median compliance ratio (0.44) – half of the facilities have compliance ratios above this value and half have compliance ratios below this value.

Have questions or want to provide us with feedback?

You are most welcome to call Professor Earnhart at 785-864-9119 or email him at earnhart@ku.edu.

If you are not the NPDES contact person for your municipal facility, we request that you deliver our letter to the correct NPDES contact person.

Your Facility's 2016 Compliance Ratio (lower is better)**: 0.13**
Your facility's percentile: **13th percentile** (see star on the graph)

In other words, **13%** of Kansas municipal facilities comply with their discharge limits to a greater extent than your facility complies with your limits**.**