Toxic Recycling: The Cost of Used Lead-Acid Battery Processing in Mexico

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Lead pollution and exposure in the 21st century

- Lead pollution exposure, even at low levels, has large health costs, especially for children (Ara et al. 2015).
- Regulatory actions like removing lead from gasoline and paint have successfully reduced pollution and exposure levels, especially in rich countries (U.S. EPA 2014).
- Measures to address lead exposure can cause a shift in pollution from rich to lower-income settings with weaker environmental regulations (Copeland et al. 2022).
- We study one such setting, and estimate the cost of this shifted pollution on children's cognitive development in recipient communities.

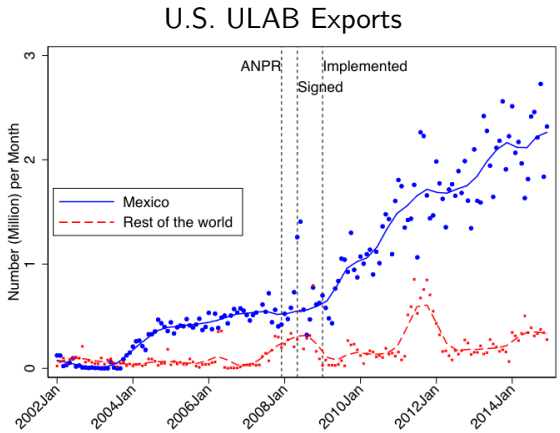
Overview of the study

- We estimate the cross-border costs of a U.S. policy change that caused a lead-intensive polluting industry, used lead acid battery (ULAB) recycling, to shift from the U.S. to Mexico.
- **What is the effect of an influx of lead-intensive industrial activity from the U.S. on Mexican students' learning?**
- We find this influx:
  - Decreased math and Spanish test scores by 0.05-0.07 standard deviations for students living in recipient communities;
  - Effects persist and are stronger in more marginalized communities.

Our contributions

- **Trade and the environment**: Keller & Levinson (2002); Hanna (2006); Cherniwchan & Najjar (2020); Antweiler et al. (2001); Copeland et al. (2021)
- We extend this literature by estimating the effects of exported pollution on recipient communities.
- **Effects of lead pollution exposure on cognitive development**: Rau et al. (2015); Aizer et al. (2018); Zheng (2021); Gronqvist et al. (2020); Persico et al. 2020; Hollingsworth et al. (2022)
- We contribute to the sparse literature estimating these effects in low- and middle-income countries, where the vast majority of exposure occurs today (Larsen & Sánchez-Triana 2023).

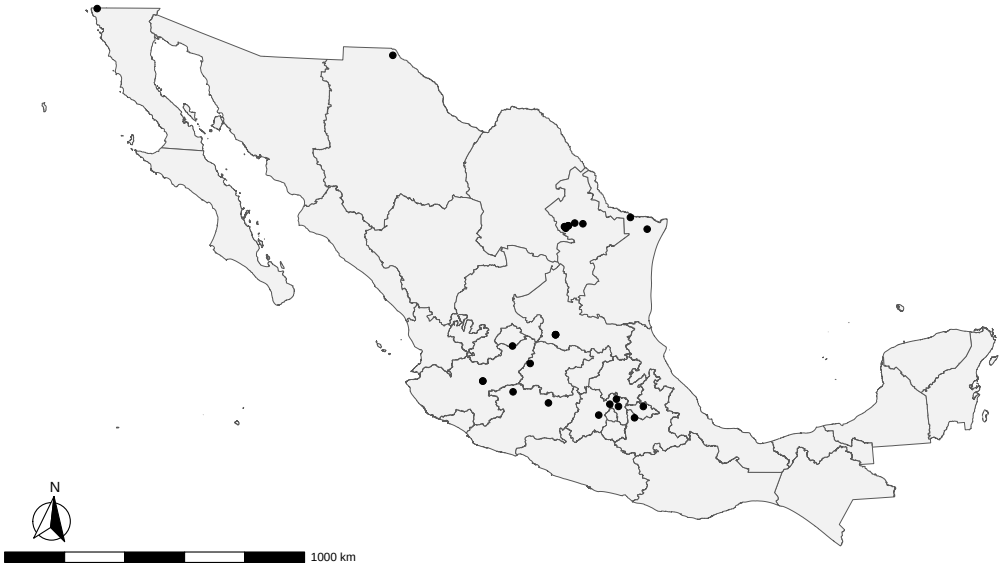
Used-lead acid battery recycling shifts to Mexico



Source: Tanaka et al. 2022

- In 2009 the U.S. tightened the National Ambient Air Quality Standard for lead from 1.5 micrograms per cubic meter to 0.15.
- After 2009, ambient lead levels fell to below the new standard (EPA 2023), and
- ULAB recycling shifted to Mexico (Tanaka et al. 2022).

Data - Location of 26 ULAB recycling plants in Mexico

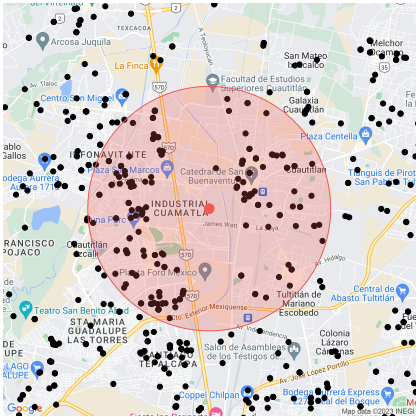


Data - Test scores, school locations, and community characteristics

	Distance to ULAB facility	
	Near ($<$ 2 miles)	Far (2 - 50 miles)
Math scores	534 (64)	530 (77)
Spanish scores	533 (60)	520 (69)
Number of observations	9,859	737,667
Distance to ULAB facility	1.37 (0.44)	21.9 (13.7)
Adult education	9.16 (1.10)	7.46 (2.09)
Access to sewer	0.90 (0.07)	0.79 (0.26)
Formal sector employment rate	0.52 (0.13)	0.43 (0.21)
Gini index	0.41 (0.03)	0.42 (0.04)
Malnutrition rate	7.55 (5.93)	17.8 (13.8)
Number of observations	414	32,001

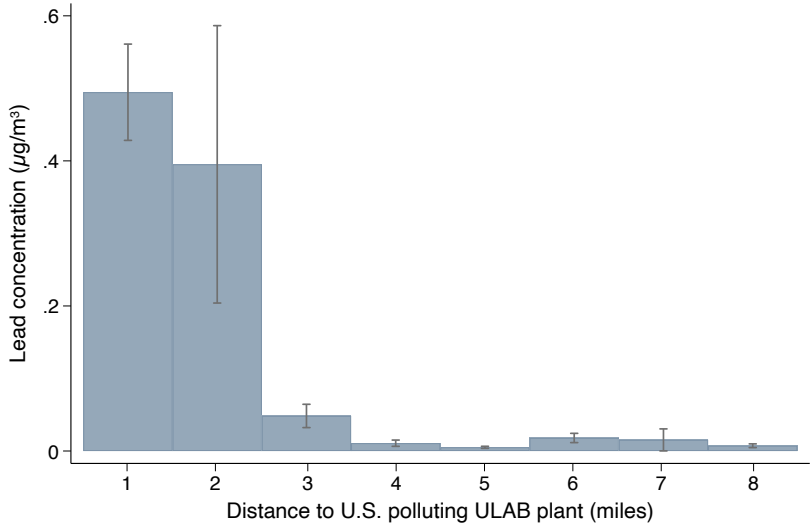
Note: Means and standard deviations are reported. Top panel reports classroom-year observations; bottom reports school observations.

Data and identification strategy



- Data:
  - Location of recycling facilities and all pre-K through grade 12 schools in Mexico.
  - Math and Spanish test scores from a national standardized test conducted between 2006-2013.
  - Demographic and socio-economic community characteristics in 2005.
- Identification strategy: Compare test scores before and after 2009 between students studying near a battery recycling facility versus those slightly farther away

Using U.S. lead monitors to determine buffer



Estimation method - Two-way fixed effects

$$y_{segt} = \alpha_{seg} + \delta_t + \beta(Near_s \times Post_t) + \varepsilon_{segt} \quad (1)$$

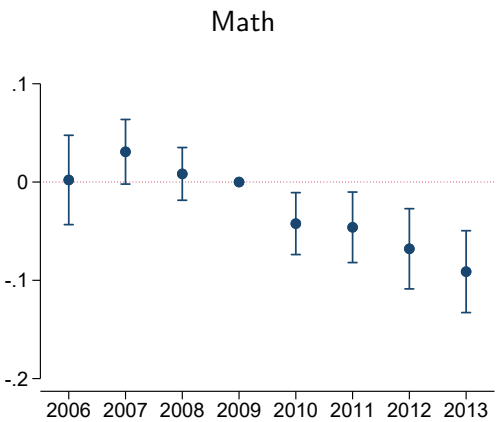
- The data is an annual panel of school-session-grade observations.
- Outcomes are the mean, standardized test scores, math or Spanish, in the school-session-grade-year.
- We include year, school-session-grade, and, in some specifications, nearest plant by year fixed effects ($\gamma_{p(s)t}$).
- Standard errors are clustered at the school level.

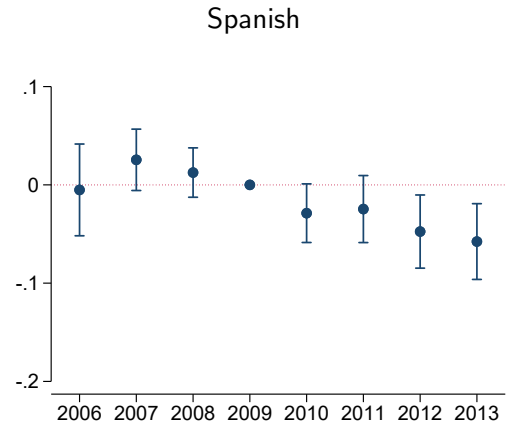
Results - Math and Spanish

	(1)	(2)	(3)	(4)
	Math		Spanish	
Near facility X	-0.065***	-0.049***	-0.0456***	-0.0369***
Post 2009	(0.0135)	(0.0137)	(0.0126)	(0.0123)
School-session-grade FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Plant-by-year FE		✓		✓
Observations	747,524	747,524	747,475	747,475
R^2	0.513	0.522	0.571	0.576
Num. of clusters	31,999	31,999	31,999	31,999

Note: Outcomes are school-session-grade means of standardized test scores, standardized at the grade-year level. Standard errors, in parentheses, are clustered at the school level. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Results - Math and Spanish

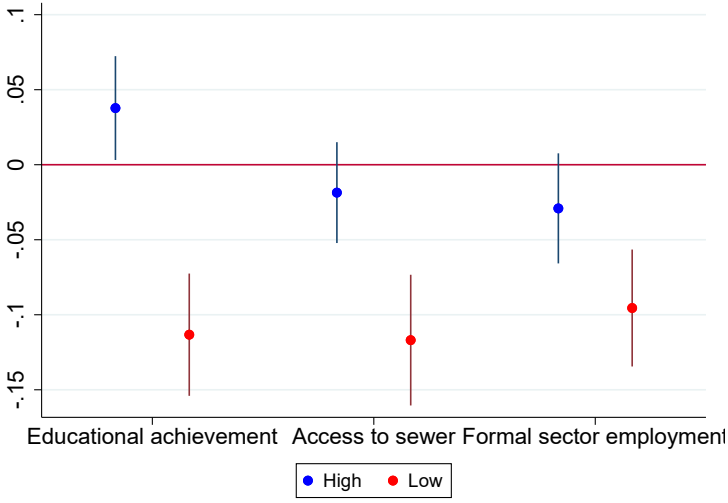




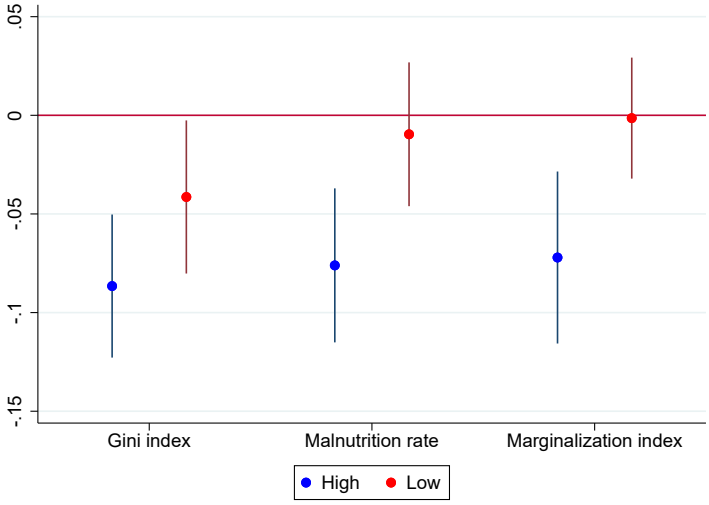
Robustness checks

- Are results confounded by increased economic activity that may also accompany the 2009 increase in recycling activity?
  No, results are the same when defining exposed group as those near *and* downwind of plant. Wind
- Are results driven by people moving in response to the increase in ULAB recycling (e.g. Chen et al. 2022)?
  No, results are the same when assigning students to near vs. far based on pre-2009 location. Student-level ITT
- How sensitive are our estimates to violations of the parallel trends assumption?
  Parallel trends sensitivity

Heterogeneity by community characteristics



Heterogeneity by community characteristics



Discussion

- We study a case where environmental regulation in one country, the U.S., caused environmental degradation in another, Mexico. We estimate the effects of this increased lead pollution on students' cognitive development in Mexico.
- The post-2009 increase in recycling negatively affected math and Spanish test scores of grade-school students living around the plants. We estimate effects of negative 0.05-0.07 standard deviations.
- These effects are stronger in communities with already lower levels of education, employment, etc. at baseline.
- Costs of lead exposure estimates from rich countries may underestimate effects in lower income settings, where most exposure occurs today.

Additional slides

Test score results - Defining exposure using wind

- Post-2009 growth in ULAB recycling could also mean increased economic activity, e.g. increase in labor demand, people moving in, increase demand for services
- Redefine exposed group to be schools near to *and* downwind from a plant
- We identify downwind schools:
  - Using data from the Global Wind Atlas
  - As those downwind from prevailing winds, i.e. the modal wind direction

Test score results - Wind results on math tests

Back to robust

	(1)	(2)	(3)	(4)
	30°downwind cone		90°downwind cone	
	Math	Math	Math	Math
Near facility X	-0.0510	-0.0632	-0.0778***	-0.0678**
Post 2009	(0.0587)	(0.0577)	(0.0290)	(0.0280)
School-session-grade FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Plant-by-year FE		✓		✓
Observations	747,524	747,524	747,524	747,524
R^2	0.513	0.522	0.513	0.522
Num. of clusters	31,999	31,999	31,999	31,999

Note: Outcomes are school-session-grade means of standardized test scores, standardized at the grade-year level. Standard errors, in parentheses, are clustered at the school level. * p<0.1, ** p<0.05, *** p<0.01.

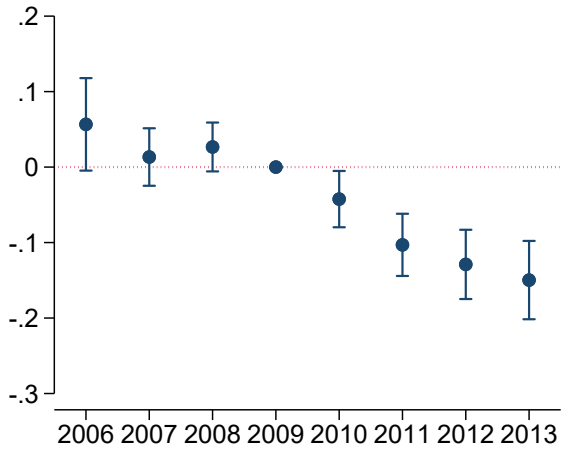
Test score results - TWFE at student level, math scores

Back to robust

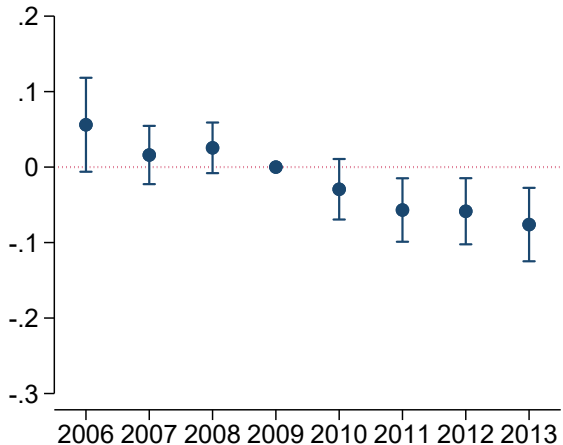
	(1)	(2)	(3)	(4)
			ITT	
	Math	Math	Math	Math
Near facility × Post 2009	-0.104***	-0.0635***	-0.111***	-0.0568***
	(0.0120)	(0.0126)	(0.0111)	(0.0113)
Year	✓	✓	✓	✓
Individual FE	✓	✓	✓	✓
Plant-by-year FE		✓		✓
Observations	74,538,672	74,538,672	39,116,468	38,701,165
R^2	0.679	0.682	0.659	0.667
N clusters	114,659	114,659	114,413	107,186

Note: Outcomes are test scores, standardized at the grade-year level. Standard errors, in parentheses, are clustered at the school level. * p<0.1, ** p<0.05, *** p<0.01. In columns 4 & 5 student locations are "frozen" in 2008.

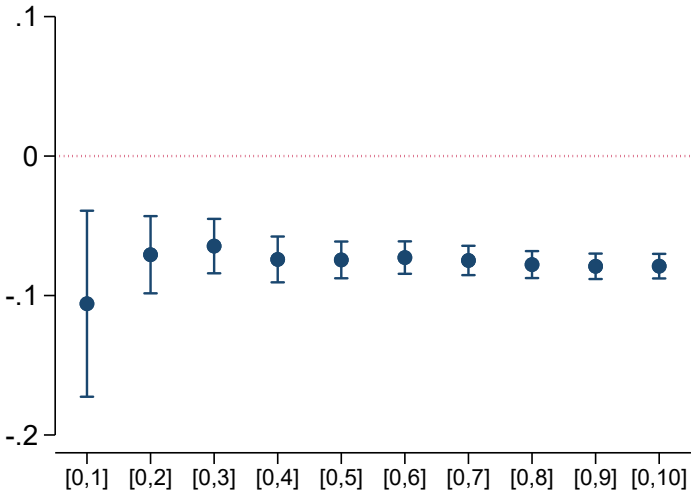
Test score results - Student-level event study, math scores



Results - Student-level event study, Spanish scores

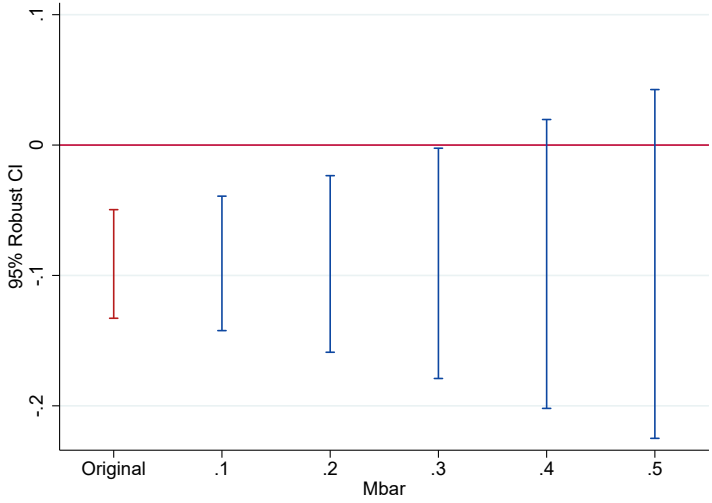


How far do we detect effects?

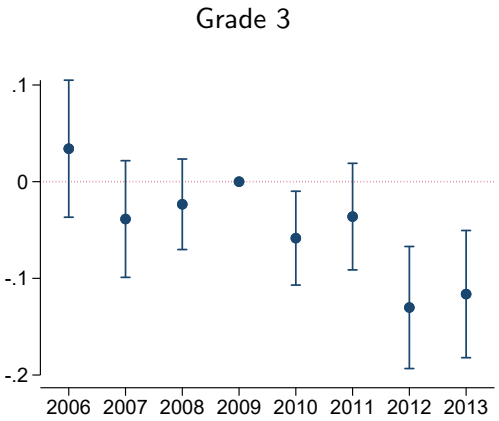


Sensitivity to violations of parallel trends assumption

Back to robust



Test score results - Math event studies by grade



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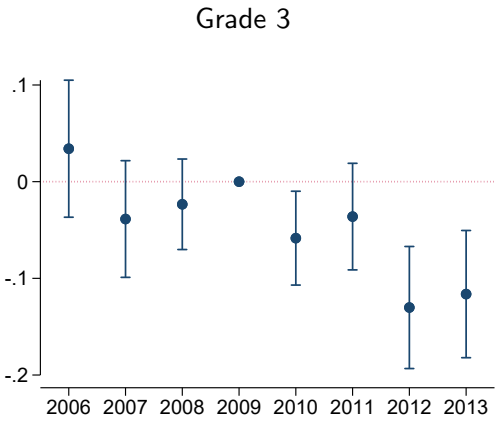

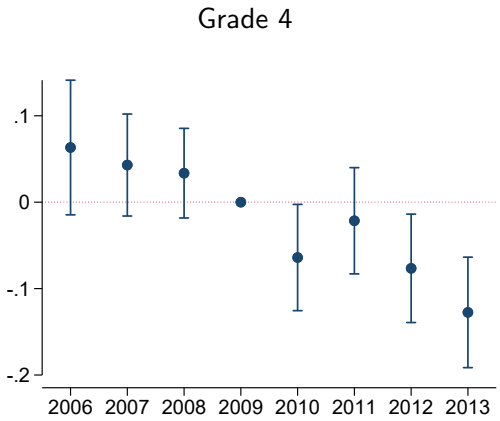

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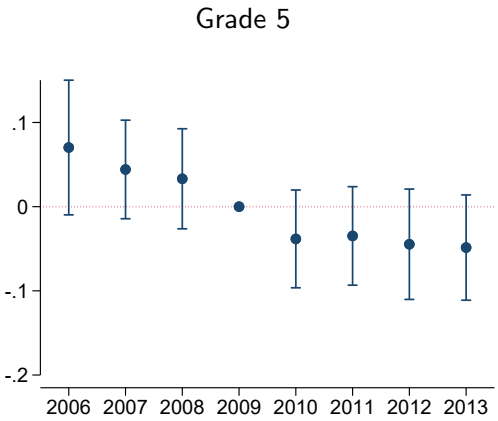
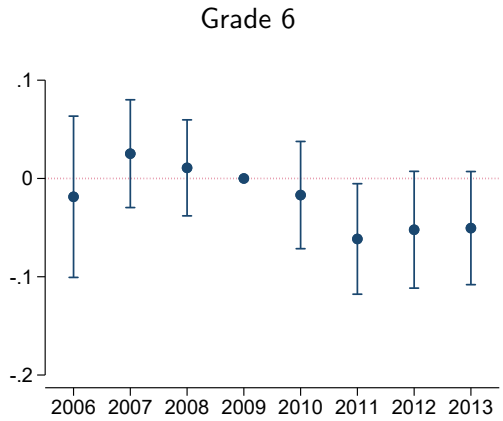
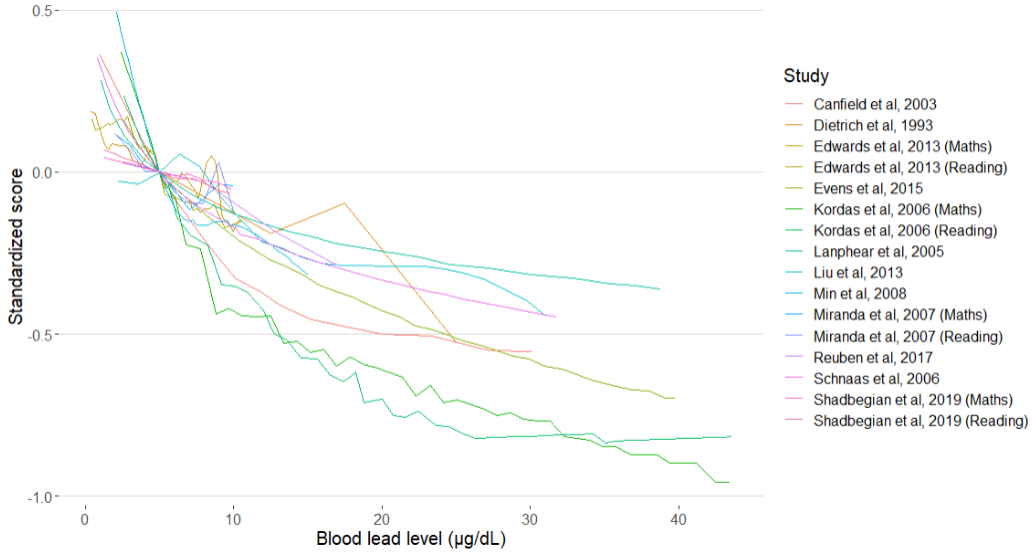
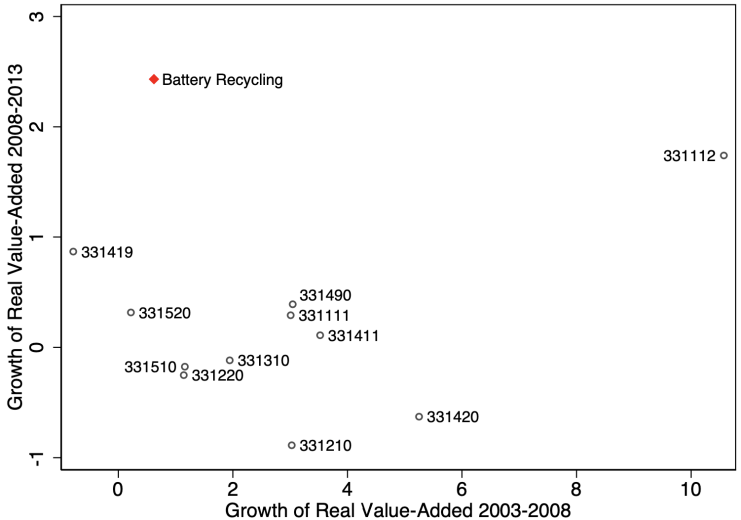




Comparisons to other studies from the medical literature



Growth of Mexican battery recycling, relative to similar industries



Source: Tanaka et al. 2022

A ULAB facility in Mexico