Stormwater Regulation and Land Use

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Introduction

- When circumventing regulation cheaper than complying, agents relocate their activity
- Can limit the effectiveness of policies to regulate certain activities
  - Buying more cars to circumvent emissions regulations (Davis 2008)
  - Relocating emissions elsewhere (Fowlie 2009)
  - Buying more garbage bags when plastic grocery bags are restricted (Taylor 2019)

Introduction

- I study land use responses to American stormwater regulation
- EPA regulates using MS4 permits, requiring some local governments to regulate land development in Urbanized Areas
  - Land development $\rightarrow$ impervious surfaces $\rightarrow$ stormwater runoff
- If developers see these regulations as costlier than relocation, they may develop elsewhere
- I study development patterns in and around MS4 localities in four states (DE, MD, PA, VA)

Developers see stormwater regulations as costly

May 10, 2016

Proposed Stormwater Control Regulations Would Increase Burden on Builders, Developers

Developers Beware: Significant Changes in Store for General Storm Water Permits for Construction Activities
May 2008
by Robert L. Falk, Jamon Bollock

September 20, 2021

State Stormwater Program Amendments Significant for Those Affected by Post Construction Stormwater Permits

State stormwater permit would stall housing, infrastructure

How might developers respond?

- Compliance
  - Maintain the same development patterns with new BMP requirements
- Adjustment
  - Adjust development patterns to disturb less area and incur lower compliance costs
- Relocation
  - Develop in an unregulated area nearby instead

Research Question

- How do developers respond to MS4 regulation?
  - Do they develop less in regulated areas? (Adjustment)
  - Do they relocate to unregulated areas nearby? (Relocation)
- What are the relative magnitudes of these effects?
- What does this mean for the effectiveness of MS4 regulation to reduce pollution from stormwater?

Preview of Results

- How do developers respond to MS4 regulation?
  - Do they develop less in regulated areas?
    - **Yes**
  - Do they relocate to unregulated areas nearby?
    - **Yes**
- What are the relative magnitudes of these effects?
  - Back-of-the-envelope: For every **1 acre** of impervious surface ↓ **in regulated areas**, **0.24 acres ↑ in surrounding areas**
- What does this mean for the effectiveness of MS4 regulation?
  - Total effect **unclear**

Contributions

- **New:** Leakage of urban development
  - Past research studying other activity, agricultural land (Searchinger et al., 2008; Davis, 2008; Fowlie, 2009; Adda and Cornaglia, 2010; Jacobsen and van Benthem, 2015; Bento et al., 2015; Hertel, 2018 Gibson, 2019; Taylor, 2019)
- **New:** Broad analysis of the effects of stormwater regulation on impervious surfaces
  - Past research uses case studies (Keeley, 2007; Crisostomo et al., 2014; Fedorchak et al., 2017; Chalfant, 2018; Malinowski et al., 2020; Rieck et al., 2021)
- Show that regulation induces development patterns consistent with accelerated urban sprawl
  - Past literature unclear (Burchfield et al., 2006; Irwin and Bockstael, 2007; Polyakov and Zhang, 2008; Dempsey and Plantinga, 2013; Turner et al., 2014; Burnett, 2016; Zhang et al., 2016)

Roadmap

- Background
  - MS4 Permits
  - Conceptual Framework
- Data and Research Design
- Main Results
- Secondary Results
  - Treatment Effects by Watershed Imperviousness
  - Spillover Effects by Distance
  - Spillover Effects to Other Land Uses
  - Spillover Effects to Urban Clusters
- Discussion and Conclusion

Policy Background

- Stormwater discharges is regulated under the Clean Water Act (CWA) by the EPA
  - Large cities were regulated in the 1990s
  - Smaller cities (those with Urbanized Area) were regulated after 2000
    - These Phase II MS4s are my focus
- Localities with MS4s generally must apply for an MS4 permit (Nat'l Assoc. of Clean Water Agencies, 2018)

What Does a Regulated Locality Have to Do?

- Localities with MS4 permits must demonstrate compliance with six Minimum Control Measures. Details
  - Two of these require ordinances to increase regulation, inspection, and implementation of stormwater management on construction MCM4 MCM5
- These requirements, in particular, may change land developer behavior
- Localities usually only have to implement these practices within the MS4, i.e., their Urbanized Area (40 C.F.R. § 122.32(a)(1))
  - Variation in Urban/Rural classification can be used to test for enforcement extent

Roadmap

Thought Experiment: What are Developer Incentives?

- How does a developer maximize profit in a circular city with a single city center?
  - Consumers of development pay more for easy access to the city center
  - MS4 permit requirements increase development costs close to city center, lowering profits there
  - A developer right on the regulatory boundary can move a little further away, getting slightly a lower price and much lower cost
- Developers will take advantage of relocation if they have flexibility
- If they can't relocate, they may adjust disturbed area to lower compliance costs
- If developers can neither relocate nor adjust size, then either absorb/pass costs or cease development

Translating Intuition to Empirics

- Two effects of interest
  - **Treatment effect**: what happens to impervious surface *in regulated areas* after regulation?
  - **Spillover effect**: what happens to impervious surface *right outside of regulated areas* after regulation?

Interpreting Possible Estimates

- The **signs of these effects** can tell us about which intuitive story is holding true:
  - Developers relocate beyond regulatory boundaries
    - Treatment Effect < 0; Spillover Effect > 0
  - Developers remain but use less impervious surface (1 acre rule / some drop in development)
    - Treatment Effect < 0; Spillover Effect $= 0$
  - Costs are too small relative to development benefits
    - Treatment Effect $= 0$; Spillover Effect $= 0$
- The **relative magnitudes** will give us additional insight:
  - Not all reductions are displaced; some are just disturbing less area. Development is somewhat flexible.
    - $|\text{Treatment Effect}| > |\text{Spillover Effect}| > 0$
  - Development is very flexible, relocating 1-for-1
    - $|\text{Treatment Effect}| \approx |\text{Spillover Effect}| > 0$

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Data

- Remote sensing land use data (30m resolution, years 2000-2019)
  - Global Impervious Surface Area (Zhang et al 2021)
    - Whether or not a 30m cell has impervious surface; yearly
  - National Land Cover Database
    - Amt. of impervious surface, other land uses; every few years
- Rollout of MS4 permits to localities in DE, MD, PA, and VA
- Unit of analysis: Census block

Research Design

- **Problem**: a simple comparison of regulated (exposed) areas to unregulated (unexposed) areas will not account for systematic differences
  - e.g., regulated localities tend to be more populous than unregulated ones, and likely have more impervious surface overall
- **Solution**: Use a panel structure of data in a difference-in-differences framework, accounting for baseline differences and common shocks
- Identification Assumption: Absent regulation, impervious surfaces would have changed at the same rate in treated (exposed) and untreated (unexposed) areas
  - Will show support for this in a few slides

Empirical Strategy

- Two-stage difference in differences (Gardner 2021) to address heterogeneous treatment timing Detail
  - First stage: difference out Census block averages and common shocks
  - Second stage: regress residualized outcomes on indicators for treatment (spillover) Estimating Equation
- Intuition for designing sample areas comes from (Butts 2021)
  - **Treatment effect**: Compare early-treated to later-treated Map
    - Eventually-regulated localities are the most reasonable control group
    - Urbanized Area blocks in localities with MS4 permits
  - **Spillover effect**: Compare Rural surroundings of treated places to the Rural surroundings of untreated urban places Map
    - Rural periphery vs. rural periphery, not distant rural areas
    - Spillover radius: 5 miles from a treated block Evidence for this Radius

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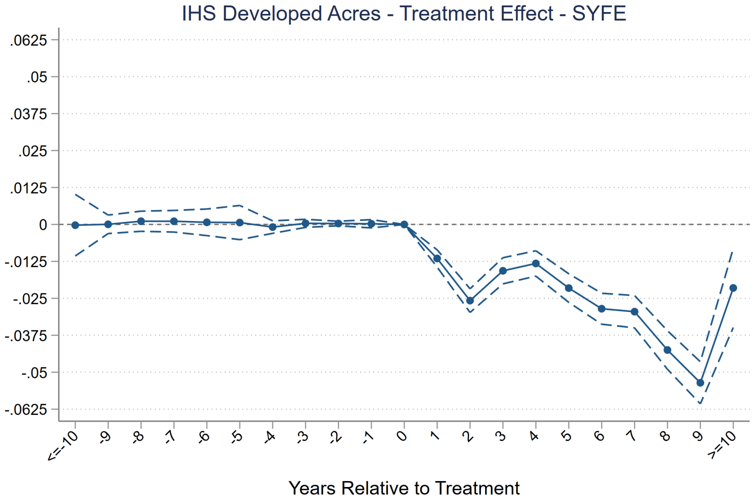
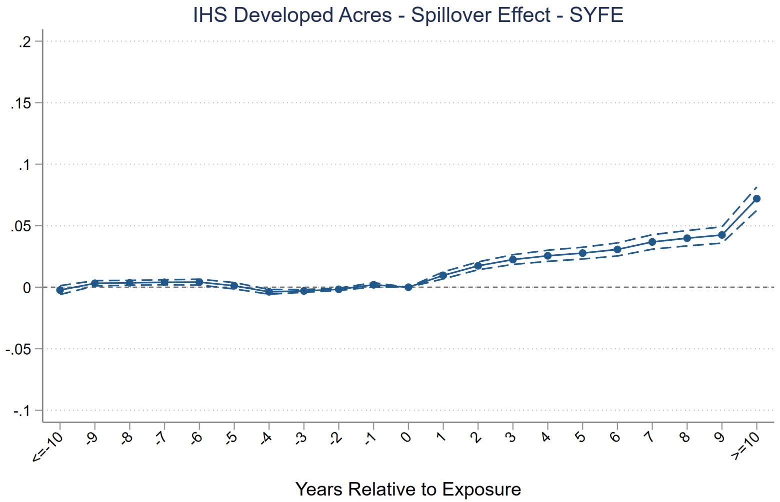
Treatment Effect Event Study

Other Fixed Effects | Table



Rural Spillover Event Study

Other Fixed Effects Table



Brief Discussion: Recalling Research Questions

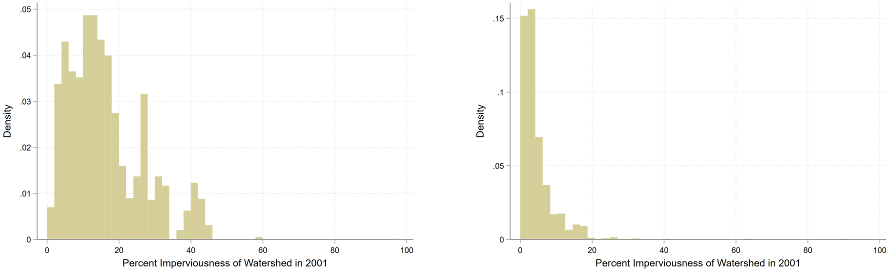
- How do developers respond to MS4 regulation?
  - Do they develop less in regulated areas?
    - **Yes: Treatment effect < 0**
  - Do they relocate to unregulated areas nearby?
    - **Yes: Spillover effect > 0**
- What are the relative magnitudes of these effects?
  - **Unclear**: estimates are not directly comparable b/c they are relative effects
  - We will calculate later
- What does this mean for the effectiveness of MS4 regulation?
  - Some "leakage"
    - **Unclear how problematic**
  - We will add more nuance in the next section

Roadmap

Watershed Imperviousness

- Evidence from ecological literature suggests that damages from impervious surfaces may be high at relatively low-levels
  - For some species, there are "threshold" levels of imperviousness between 5 and 20% (e.g., Stepenuck et al. (2002); Wang et al. (2003); Walsh et al. (2005); Utz et al. (2009)) Demonstrative Figure
- Spillovers may be particularly harmful if they go from severely impaired watersheds to marginal watersheds

Distribution of Watershed Imperviousness



Histograms of treated blocks (left) and exposed-to-spillover blocks (right) by the 2001 imperviousness of their HUC12 watershed.

Interpreting Watershed Distributions

- While most treated blocks are in watersheds $< 20\%$ impervious, a sizable minority are not
- Essentially all spillover blocks are in watersheds $< 20\%$ impervious
- **Question**: How much of the treatment effect (reduced impervious) occurs in high- vs. low-imperviousness watersheds?
  - Estimate treatment effects separately, using distinct samples of Census blocks in watersheds $>$ or $< 20\%$ impervious

Treatment Effect by Watershed Imperviousness

Other Fixed Effects Table

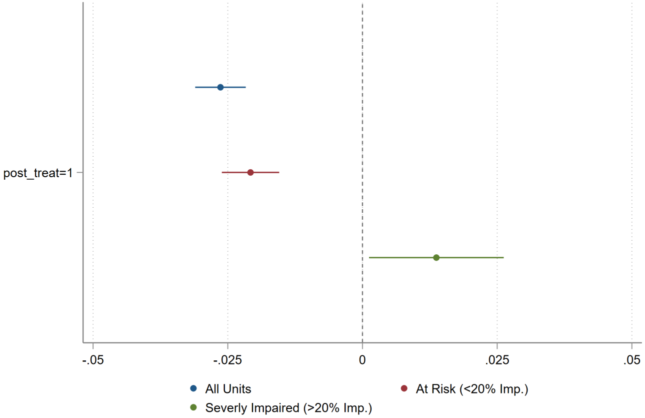


Figure: Treatment Effect with State-Year Fixed Effects, by 2001 watershed imperviousness.

Interpretation

- Relatively less impervious surface in watersheds with low-baseline imperviousness
- Possible increase in high-baseline areas
- Suggests that reductions occur in marginal watersheds rather than severely impaired ones
  - i.e., reductions in places where they may be most meaningful
- Mechanism not obvious:
  - Could be prioritizing from local policy makers
  - Could be that high-baseline areas are too built up for change

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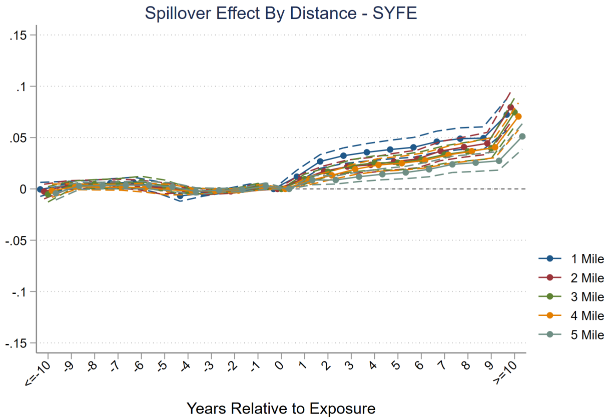
Spillover Effects By Distance

- How do spillover effect sizes change with distance from the boundary?
- If distance to city center is the major location driver, then effects should be strongest close to the boundary
  - May help localities think about reducing spillovers
- Compare 1-mile rings around treated cities to 1-mile rings around control cities

Spillover Event Study By Distance

HUC2 SY FE | HUC4 SY FE | Table



Brief Discussion

- Effects decay with distance
  - Consistent with distance to city center being of first-order importance in location decision
  - Large effects right on the border suggest that Rural Census blocks in MS4 localities are not treated in the same way as the Urbanized Areas

Roadmap

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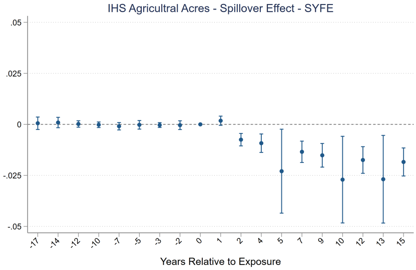
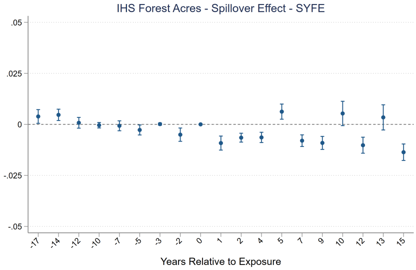
What happens to other land uses in spillover areas?

- If developed land increases in the spillover regions, what is decreasing?
- Pre-exposure land use splits were 34% developed, 30% forested, and 31% agricultural
- These land use changes matter for understanding net water quality effects
  - High-fertilizer agriculture yields runoff with a lot of pollution
- I use NLCD data to estimate changes in agricultural and forested land in the spillover areas

Rural Spillover - Agriculture

Table





LHS: Agricultural land; RHS: Forested Land. NLCD is not yearly so data is sparser temporally.

Brief Discussion

- Spillover areas experience a decrease in agricultural land
- Effects for forested land are more mixed
- Water quality implications unclear
    - Depends on pollution from urban vs. agriculture

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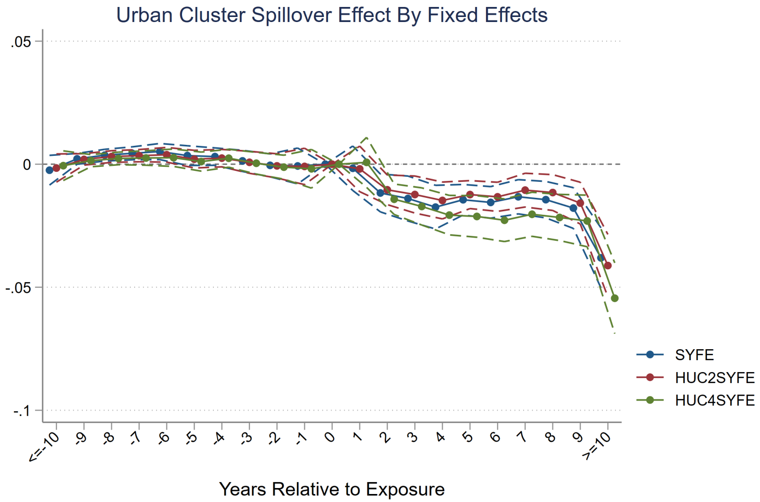
What about Urban Clusters?

- Spillover effects thus far have been for rural areas
- Urban clusters are not necessarily covered by MS4 permits, and so it is unclear how development there may be affected
  - Developers seeking an urban location might relocate there
  - Developers may avoid Urban parts of regulated localities altogether
  - Localities may enforce permit requirements here by choice
- I compare Urban Clusters in MS4 localities to Urban Areas in unregulated localities

Spillover effect to Urban Clusters

Table



Brief Discussion

- Spillover effects are negative
  - There is less development in these areas relative to Urban Areas in unregulated localities
- Urban Clusters in regulated localities are not recipients of development leaving regulated Urbanized Areas
- Mechanism unclear
  - Localities may implement broad strategies
  - Could be anticipation of Urbanized Area expansion
    - Developers avoid future risks

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Calculating Magnitudes

- I perform a back-of-the-envelope calculation to convert effects into areas of impervious surface
  - I use estimates from the by-distance analysis to gain precision
  - I scale developed area by the average imperviousness of developed area using NLCD data
- Across the treated sample, I estimate 6,437 acres of impervious surface prevented
- Across the Rural spillover sample, I estimate 1,554 acres of impervious surface induced
  - 696 acres (45%) occurs within 1 mile of the regulatory boundary
- Total "leakage" of 24%

Calculation Table

Conclusions

- I find evidence consistent with land developers moving beyond regulatory boundaries as a response to costs from MS4 regulation
- Back-of-the-envelope calculations suggest that for every 1 acre of impervious surface averted, 0.24 acres were induced in Rural spillover areas
  - About half of all of the induced imperviousness occurs within one mile of the regulatory boundary
- Some caveats
  - Spillovers to Urban Areas (within and beyond MS4 localities) could amplify or diminish the effect
  - Effects are relative to respective control groups and do not account for general trends

Implications

- What are the implications for water quality? Multiple factors
  - More impervious surface is reduced than relocated
  - Treatment effects are concentrated in at-risk watersheds
  - Spillovers also reduce agricultural land, with unclear effects
  - Water quality improvements can come through other MS4 channels, not just construction regulation

Thank you for your time!

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Appendix

Stormwater At Different Levels of Imperviousness

Back

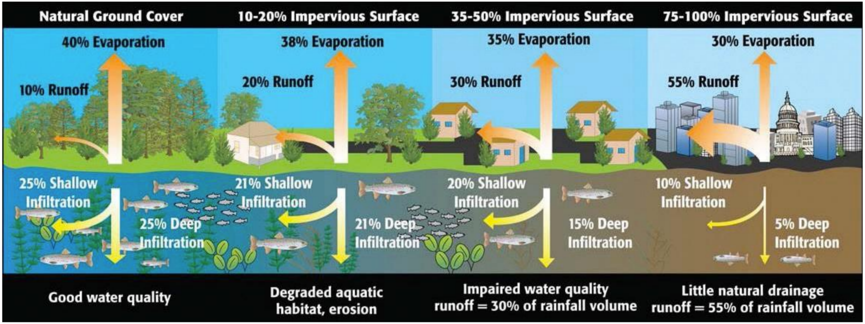


Figure: From Potomac Conservancy State of the Nation's River (2008).

Damages over Imperviousness levels

Back

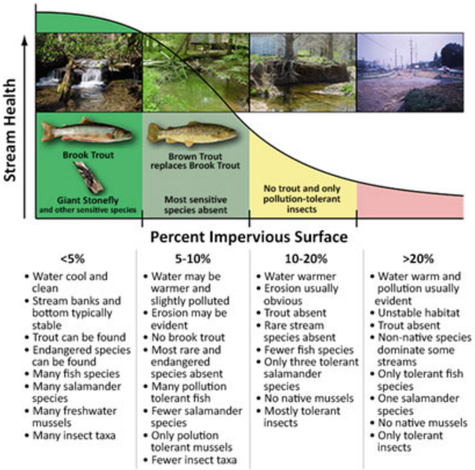


Figure: Waterbody health w/ impervious surfaces. From Gaithersburg, Maryland.

Imperviousness Damages Examples- Threshold

Back

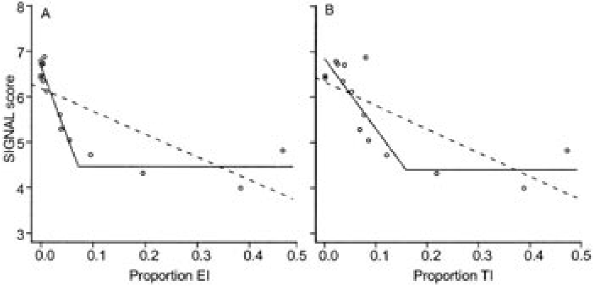


Figure: Macro-invertebrate Health Score (Walsh et al 2005). Example of "threshold" level of impervious surfaces for ecological health.

Six Minimum Control Measures

1. Public education and outreach
2. Public involvement and participation
3. Illicit discharge detection and elimination
4. Construction site stormwater runoff control
5. Post-construction management in new development and redevelopment
6. Pollution prevention and good housekeeping in municipal operations

Back

MS4 MCM 4

- Construction site stormwater runoff control (40 CFR § 122.34 (b) (4))
  - (A) An ordinance or other regulatory mechanism to require erosion and sediment controls, as well as sanctions to ensure compliance...
  - (B) Requirements for construction site operators to implement appropriate erosion and sediment control best management practices;
  - (C) Requirements for construction site operators to control waste [...] that may cause adverse impacts to water quality;
  - (D) Procedures for site plan review which incorporate consideration of potential water quality impacts;
  - (E) Procedures for receipt and consideration of information submitted by the public, and
  - (F) Procedures for site inspection and enforcement of control measures.

Back

MS4 MCM 5

- Post-construction management in new development and redevelopment (40 CFR § 122.34 (b) (4))
  - (A) Develop and implement strategies which include a combination of structural and/or non-structural best management practices (BMPs) appropriate for the community;
  - (B) Use an ordinance or other regulatory mechanism to address post-construction runoff from new development and redevelopment [...] and
  - (C) Ensure adequate long-term operation and maintenance of BMPs.

Gardner (2021) Overview

Back

- A standard TWFE estimation yields a weighted treatment effect, some of the weights of which can be negative and bias the estimate
- Gardner proposes a two-stage difference-in-differences estimator
  - First stage estimates fixed effects using untreated units

$$Y_{it} = \lambda_i + \gamma_t + \epsilon_{it} \tag{1}$$

  - Then, using the full sample, regress the residualized outcome, $\tilde{Y}_{it}$ on the treatment indicator

$$\tilde{Y}_{it} = \beta TREAT_{it} + \varepsilon_{it} \tag{2}$$

- By estimating and then removing the fixed effects, the estimated average treatment effect will not be biased from heterogeneity across groups and periods that would otherwise be projected onto the estimate

Estimating Equation

Back

- First stage uses only untreated/un-spillover-ed part of the sample

$$asinh(Y_{ist}) = \alpha_i + \alpha_{st} + \epsilon_{ist}$$

- Second stage uses the full sample, regressing residualized outcome on *TREAT* or *SPILL* indicator

$$asinh(Y_{ist}) - \hat{\alpha}_i - \hat{\alpha}_{st} \equiv \tilde{Y}_{ist} = \beta \times TREAT_{ist} + \nu_{ist}$$

- Y_{ist} is the acreage of land in a Census block with impervious surfaces
- α_i is a Census block fixed effect (baseline local and municipal characteristics)
- α_{st} is a state-year fixed effect (state-level temporal shocks). Robust to HUC 2,4 by state by year alternatives.
- Standard errors clustered at the HUC-12 level and bootstrapped

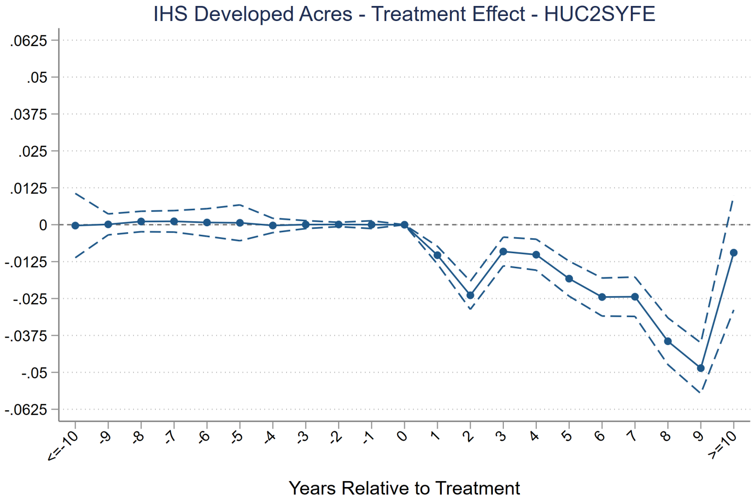
Intuition of Butts (2021)

- If a researcher is willing to assume the extent of spillovers, and that some units are unaffected by spillovers, all components can be identified.
- This partitions the sample into four groups
  - Treated with no spillovers (1) $D = 1, S = 0$
  - Control with no spillovers (2) $D = 0, S = 0$
  - Treated with spillovers (3) $D = 1, S = 1$
  - Control with spillovers (4) $D = 0, S = 1$
- Direct effect compares (1) and (2)
- Control spillover compares (2) and (4)
- Treated spillover compares (1) and (3)

Back

Treatment Effect Event Study - Robustness

Back



Treatment Effect Event Study - Robustness

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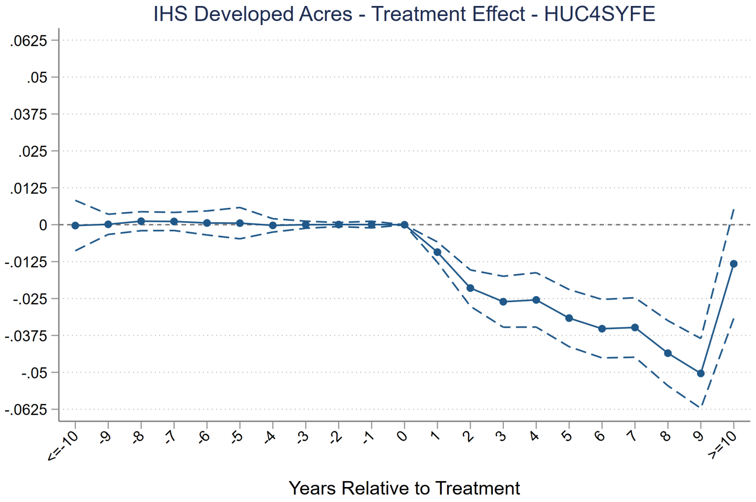

Rural Spillover Event Study - Robustness

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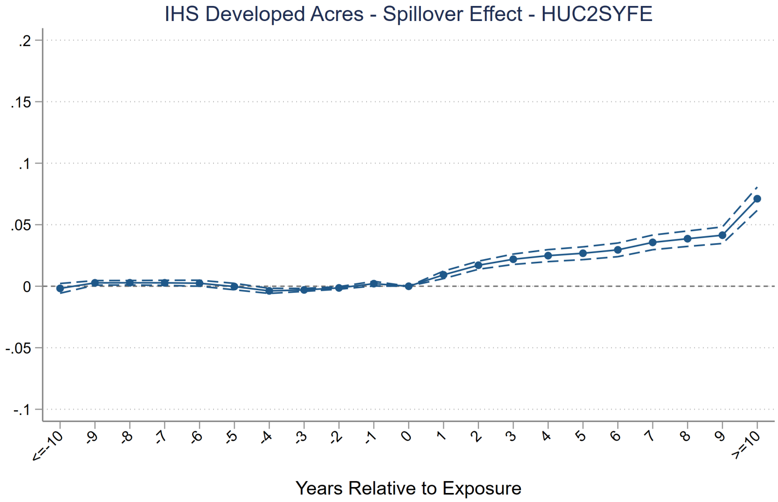

Rural Spillover Event Study - Robustness

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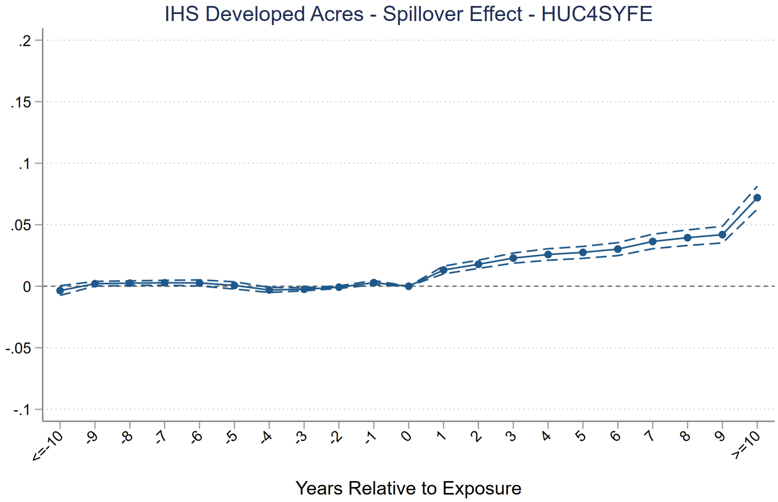

Treatment Effect by Watershed Imp. - All Fixed Effects

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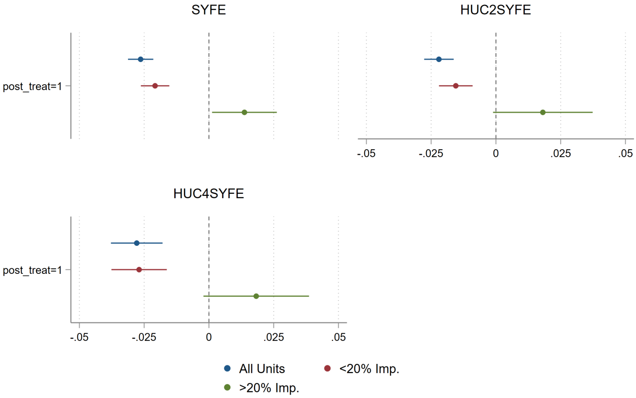
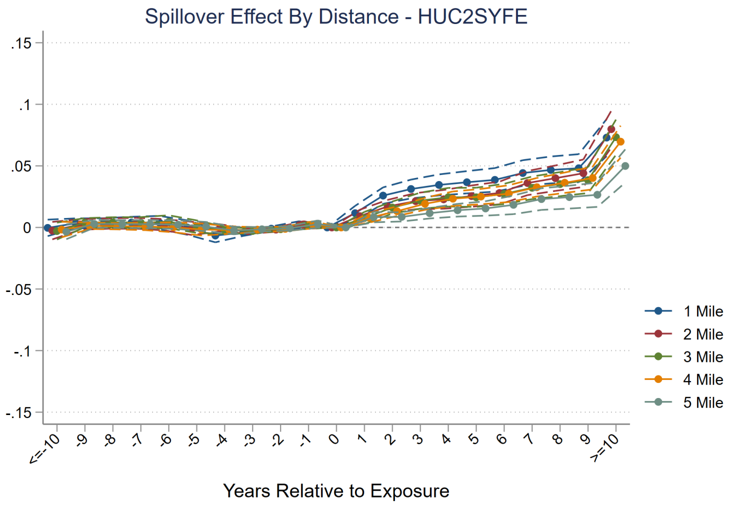


Figure: Treatment Effect by fixed effects and 2001 watershed imperviousness.

Rural Spillover Event Study By Distance - HUC2 SY FE

Back



Rural Spillover Event Study By Distance - HUC4 SY FE

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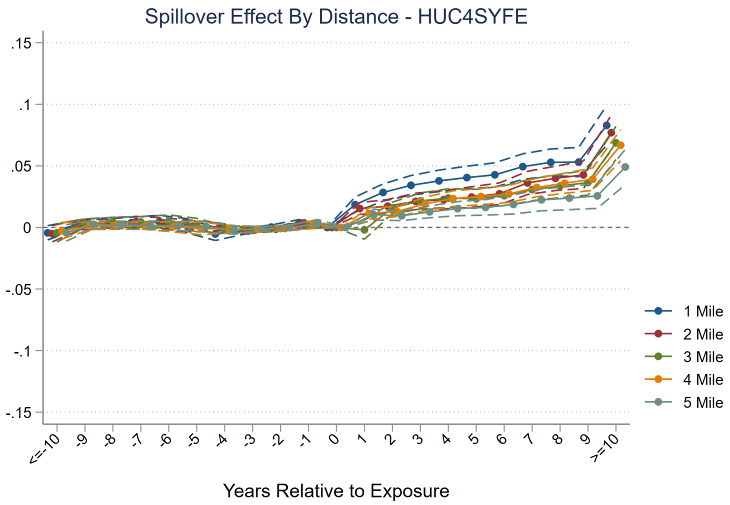

Treatment Effect Map

Back

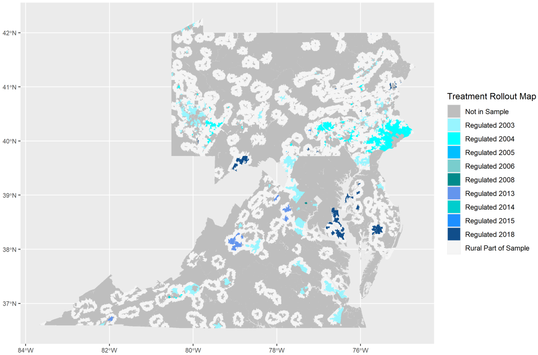

Figure: Map of Census blocks used to estimate the treatment effect

Rural Spillover Map

Back

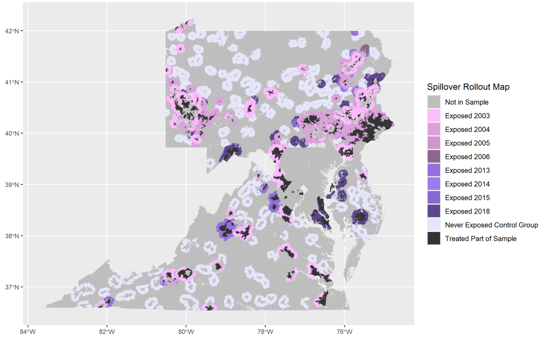

Figure: Map of Census blocks used to estimate the rural spillover effect

Spillover Decay

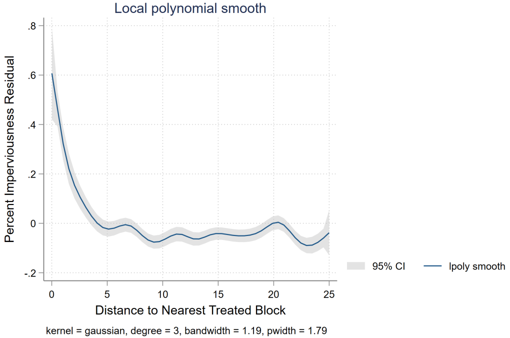

Figure: Local Polynomial regression of the change in percent imperviousness with distance to the nearest treated block

Back

Treatment Effect Table

Back

Table: Treatment Effect onto Regulated Urban Blocks

	(1) IHS Acres Developed	(2) IHS Acres Developed	(3) IHS Acres Developed
Post-MS4 Regulation	-0.0264*** (0.00259)	-0.0220*** (0.00272)	-0.0279*** (0.00486)
Pre-Treatment Outcome Mean	6.00	6.00	6.00
Number of Treated Blocks	94,935	94,935	94,935
Observations	1,377,772	1,184,151	868,206
Time Fixed Effect	State-Year	HUC2-State-Year	HUC4-State-Year

Notes: *$<$0.10 ** p$<$0.05, *** p$<$0.01.

Rural Spillover Effect Table

Back

Table: Spillover Effect onto Rural Blocks: Land Development

	(1) IHS Acres Developed	(2) IHS Acres Developed	(3) IHS Acres Developed
Exposed to Spillovers	0.0454*** (0.00276)	0.0445*** (0.00282)	0.0455*** (0.00305)
Pre-Exposure Outcome Mean	2.92	2.92	2.92
Number of Exposed Blocks	51,476	51,476	51,476
Observations	2,095,600	2,095,600	2,092,364
Time Fixed Effect	State-Year	HUC2-State-Year	HUC4-State-Year

Notes: *<0.10 ** p<0.05, *** p<0.01.

Forest and Ag Table

Back

Table: Spillover Effect onto Rural Blocks: Forests and Agriculture

	(1) IHS Forest Acreage	(2) IHS Agricultural Acreage
Exposed to Spillovers	-0.00885*** (0.00135)	-0.0125*** (0.00234)
Pre-Exposure Outcome Mean	78.89	55.34
Number of Exposed Blocks	47,644	47,644
Observations	627,880	627,880

Notes: *$<$0.10 ** p$<$0.05, *** p$<$0.01.

Treatment Effect by Watershed Imperviousness Table

Back

Table: Treatment Effect by Watershed Imperviousness

	(1) IHS Acres Developed	(2) IHS Acres Developed	(3) IHS Acres Developed
Panel A: HUC12's $<$ 20% Impervious			
Post-MS4 Regulation	-0.0208***	-0.0155***	-0.0269***
	(0.00280)	(0.00331)	(0.00545)
Observations	1,009,236	868,079	675,029
Panel B: HUC12's $>$ 20% Impervious			
Post-MS4 Regulation	0.0137**	0.0181*	0.0183*
	(0.00638)	(0.00981)	(0.0104)
Observations	146,614	139,470	136,600
Time Fixed Effect	State $\times$ Year	HUC2 $\times$ State $\times$ Year	HUC4 $\times$ State $\times$ Year

Notes: *$<$0.10 ** p$<$0.05, *** p$<$0.01.

Spillover Effect by Distance Table

Back

Table: Spillover Effect onto Rural Block by Distance

	(1) IHS Acres Developed	(2) IHS Acres Developed	(3) IHS Acres Developed	(4) IHS Acres Developed	(5) IHS Acres Developed
Distance to Urban Edge	One Mile	Two Miles	Three Miles	Four Miles	Five Miles
Exposed to Spillovers	0.0508*** (0.00538)	0.0483*** (0.00521)	0.0456*** (0.00460)	0.0429*** (0.00417)	0.0306*** (0.00447)
Pre-Exposure Outcome Mean	4.61	3.19	2.75	2.19	1.89
Number of Exposed Blocks	11,918	9,339	8,846	9,935	11,438
Observations	452,180	386,320	378,300	429,920	448,880

Notes: *<0.10 ** p<0.05, *** p<0.01.

Urban Cluster Spillover Table

Back

Table: Spillover Effect onto Nearby Urban Cluster Blocks

	(1) IHS Acres Developed	(2) IHS Acres Developed	(3) IHS Acres Developed
Post-MS4 Regulation	-0.0204*** (0.00359)	-0.0203*** (0.00386)	-0.0280*** (0.00465)
Pre-Treatment Outcome Mean	4.23	4.23	4.23
Number of Treated Blocks	7,803	7,803	7,803
Observations	1,400,440	1,400,440	1400440
Time Fixed Effect	State-Year	HUC2-State-Year	HUC4-State-Year

Notes: *<0.1 ** p<0.05, *** p<0.01.

Calculation Table

Back

Table: Calculation Table

	(1) Treated	(2) Average Spillover	(3) 1 Mile Spillover	(4) 2 mile Spillover	(5) 3 Mile Spillover	(6) 4 Mile Spillover	(7) 5 Mile Spillover	(8) Sum over 1 mile rings
Point Estimate	-0.0264	0.0454	0.0508	0.0483	0.0456	0.0429	0.0304	-
Percent Effect (/100)	-0.0261	0.0464	0.0521	0.0495	0.0467	0.0438	0.0309	-
95% Confidence Interval Estimate	(-0.0310, -0.0210)	(0.0400, 0.0508)	(0.0403, 0.0614)	(0.0381, 0.0585)	(0.0366, 0.0547)	(0.0347, 0.0511)	(0.0216, 0.0391)	-
95% Percent Effect (/100)	(-.0320, -0.0215)	(0.0408, 0.0521)	(0.0411, 0.0633)	(0.0388, 0.0602)	(0.0373, 0.0562)	(0.0353, 0.0524)	(0.0218, 0.0399)	-
Pre-Exposure Developed Acres	6.00	2.92	4.61	3.19	2.75	2.19	1.89	-
Mean Imperviousness on Developed Land (2019 NLCD)	0.433	0.210	0.243	0.208	0.203	0.200	0.196	-
Number of Treated/Exposed Blocks	94,935	51,476	11,918	9,339	8,846	9,935	11,438	-
Impervious Acreage Effect	-6,437.33	1,464.62	695.58	306.73	230.62	190.60	130.93	1,554.46
95% CI	(-7,892.52, -5,302.78)	(1,287.86, 1,644.54)	(544.71, 845.11)	(240.43, 373.04)	(184.20, 277.53)	(153.61, 228.02)	(92.37, 169.06)	(1,215.35, 1,892.76)
Leakage	-	22.75%	-	-	-	-	-	24.15%
Leakage (BC, WC)	-	(16.3%, 31.0%)	-	-	-	-	-	(15.4%, 35.7%)

95% confidence intervals are based on standard errors clustered at the county-by-urban-area level. Point estimates are from two-stage difference-in-differences regressions of the inverse hyperbolic sine of acreage of developed land. Percent effects are calculated using $e^{\hat{\beta}} - 1$. (BC, WC) refers to Best Case and Worst Case bounds of leakage, using the upper end of treatment effects and the lower end of leakage effects, or vice versa. Each distance group is mutually exclusive. For instance, column (4) consists of blocks at least one mile from the urban edge and no more than two miles from the urban edge. Pre-treatment outcome mean is the mean across final pre-treatment year levels. Proportion of block developed is calculated by taking the proportion of the block characterized as having impervious surface in a given year. This proportion is then multiplied by the total area of the block to give developed acreage. Imperviousness on developed acreage is taken using the final data year, to account for the fact that the average imperviousness of development may have been affected by MS4 policy.