

The Costs of Housing Regulation: Evidence From Generative Regulatory Measurement

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We Measure Housing Regulations through Novel AI Methods

Research Question: What are the key features and determinants of municipal zoning regulations, and how do they influence housing production and prices?

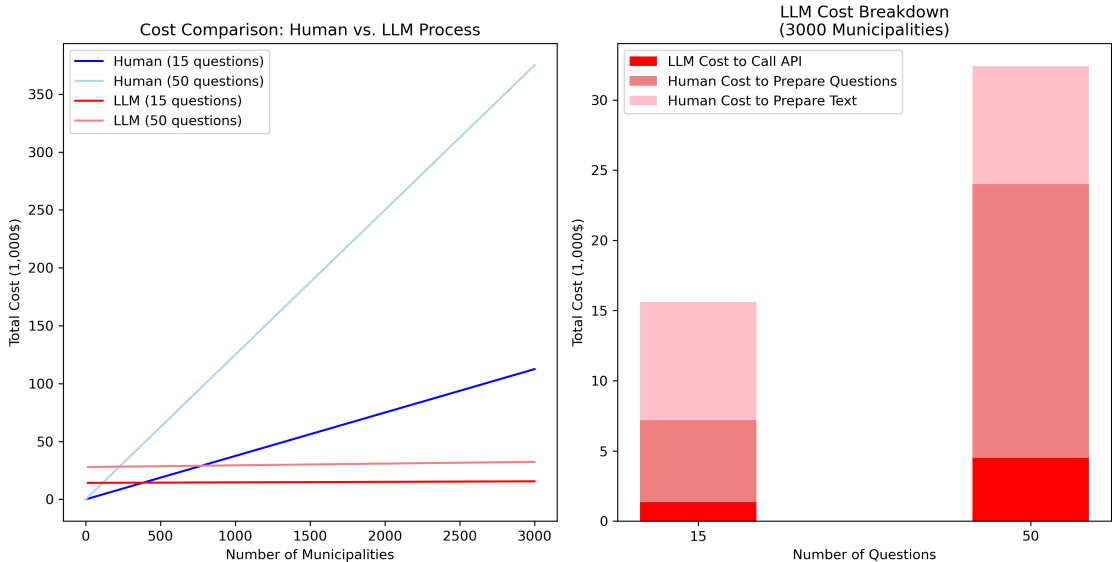
We Measure Housing Regulations through Novel AI Methods

Research Question: What are the key features and determinants of municipal zoning regulations, and how do they influence housing production and prices?

- We propose a novel general purpose method to parse and understand these rules at scale: *generative regulatory measurement*
 - Takes advantage of recent developments in Large Language Models (LLMs) and embedding algorithms applied to ~6,000 zoning codes covering 63% of municipal population
 - Cross-validated against existing hand-classification (MA Pioneer Data, Glaeser Ward 09) and surveys (Wharton Regulatory Index, Gyourko Saiz Summers 08, Gyourko Hartley Kimmel 21)
 - We assess LLM performance in dataset creation for complex laws: accuracy 96% (binary), 0.87 correlation (continuous)

Data, Methodology, and Model Validation

LLM vs Human Cost Analysis



LLM Advantages and Disadvantages For Regulatory Analysis

Advantages

- Advantage 1: Substantially cheaper and faster than human analysis
- Advantage 2: Consistent interpretation of regulation - One LLM vs a team of human analysis

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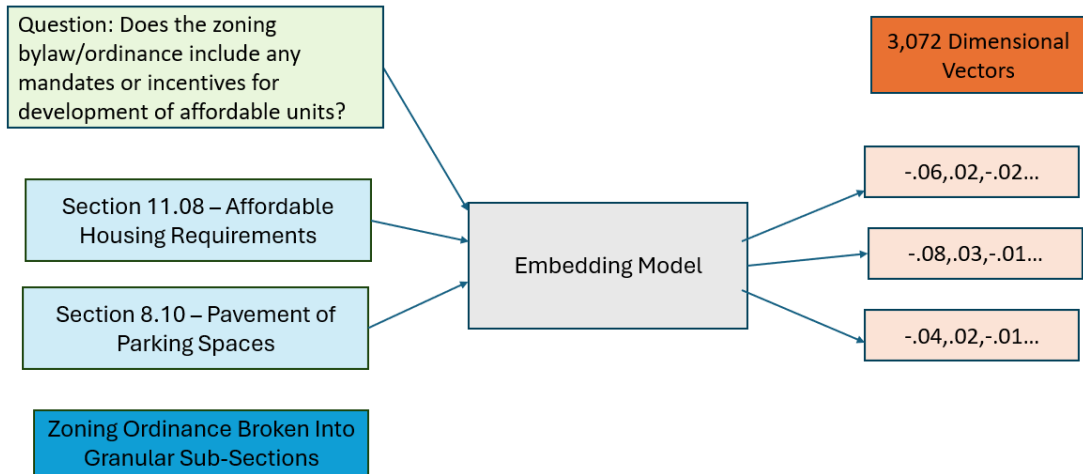
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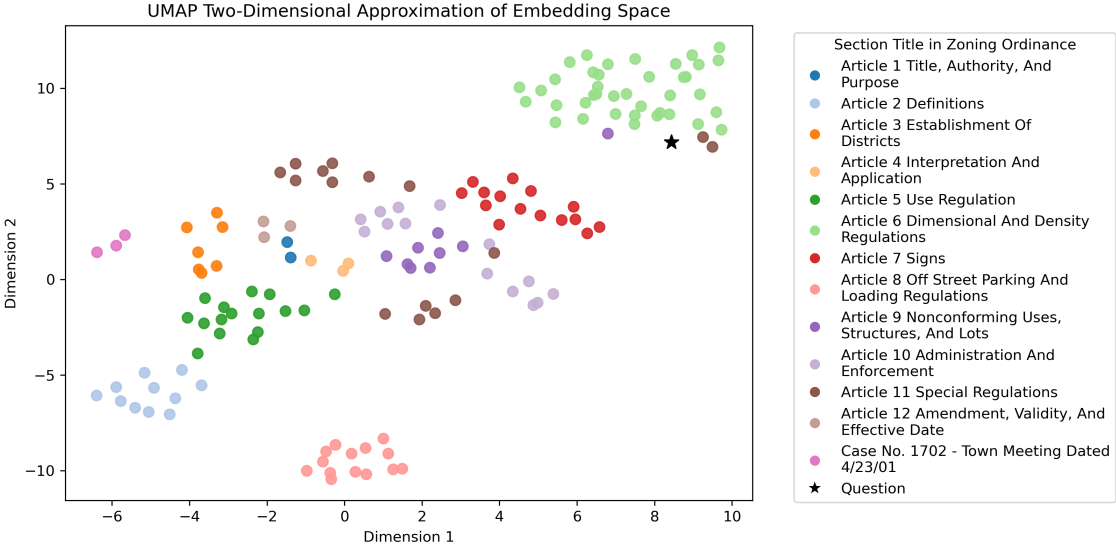
Challenges

- Challenge 1: Hallucinations and inaccurate classifications
 - Solution: Train and validate against human classified data
- Challenge 2: Limited effective LLM context window
 - Use Retrieval Augmented Generation (RAG) [Details:](#)

Example: First, We Embed Text and a Question For Arlington, MA

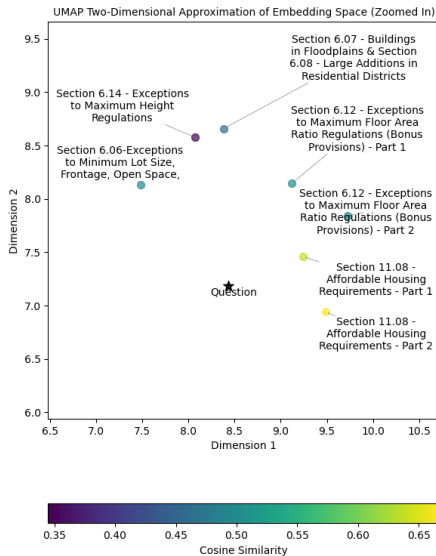


Embedding Space Clusters Similar Text



Relevant Text Close in Space to Question

- We measure the distance from the question vector to the text vector using normalized cosine-similarity (in n-dimensional space)
- Relevant sections on affordable housing and exceptions to lot size and floor area requirements are near the question vector
- We also use a **re-ranking** algorithm on high cosine-similarity text



We Provide the LLM With Question Background Information

Background Information: Inclusionary zoning requires or encourages developers to include affordable dwelling units within new developments of market rate homes. Some municipalities call it “incentive zoning” ... (omitted for brevity)

Assumptions: Do not include provisions for entirely affordable, subsidized housing development by public or non-profit corporations. Also do not include provisions under “rate of development” headings that exempt affordable units from project phasing and growth caps.

Relevant Text Enables A Correct Answer

GPT-4 Turbo Output: The zoning bylaw/ordinance provided does indeed include mandates and incentives for the development of affordable units. Here's a breakdown of the evidence supporting this conclusion:

1. ****Mandates for Affordable Housing Development**:** The ordinance mandates that 15% of the residential units in new projects be affordable units (Section 11.08, Part_1, d. REQUIREMENTS, 1.). This requirement applies to all new residential projects, including phased or segmented developments, with six or more units subject to Environmental Design Review (Section 11.08, Part_1, b. APPLICATION). The affordable units must conform to specific affordability criteria, ensuring they are accessible to households earning no more than 60% of the median income for rental units and no more than 70% of the median income for homeownership units (Section 11.08, Part_1, c. DEFINITIONS).

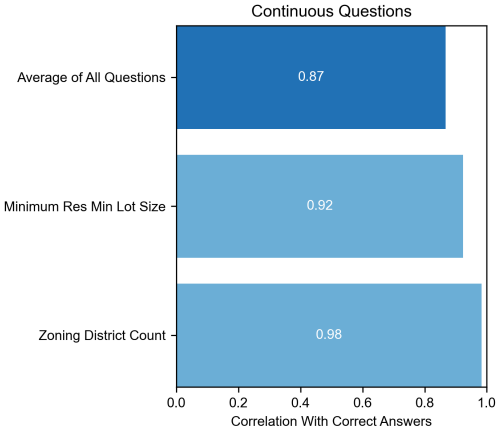
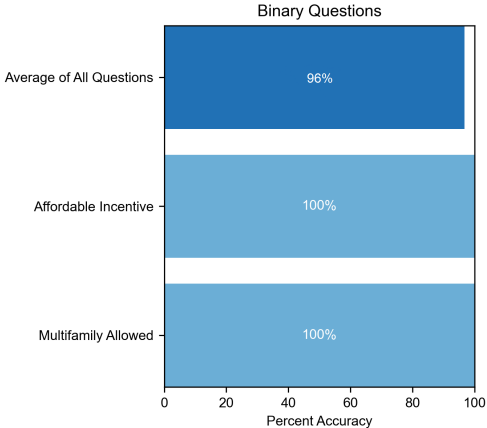
(other evidence omitted for brevity)

Given the evidence from the zoning bylaw/ordinance, it is clear that the town has both mandates and incentives in place for the development of affordable housing units.

ANSWER: YES

High Accuracy on Binary Questions and Continuous Measures

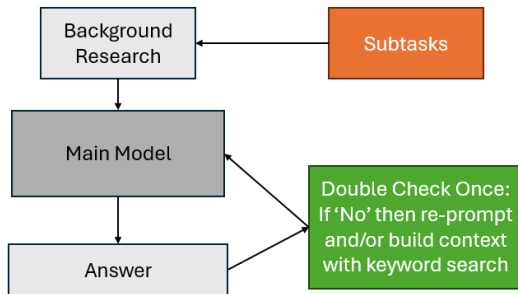
Measuring model accuracy: AI vs. Pioneer hand-classification



Model Training Process Overview

Training Components

- Prompt engineering for consistent responses
- Question-specific background and assumptions
- Multi-step processing to handle complex queries:
 - Subtasks break down complex questions
 - Double-checking validates negative responses



Multi-Step Processing: Example Cases

Example 1: Minimum Lot Size

- Question: "What is the lowest minimum lot size for single family homes?"
- Challenge: Information spread across different sections
- : Solution: Use two questions
 - Question 1: "List all single family districts"
 - Question 2: "Given these districts, what is the minimum lot size in each?"

Example 2: ADU Regulations

- Question: "Are Accessory Dwelling Units (ADUs) allowed?"
- Challenge: Limited context window makes 'No' answer ambiguous
- Solution: Double check 'No' answer with keyword search context

Challenges in Standardizing Regulatory Measurement

Core Challenge

- Map high-dimensional, heterogeneous zoning regulations into standardized, low-dimensional dataset

Key Issues

- Handling unexpected edge cases
 - Example: Lot size exceptions beyond common cases
- Question relevance
 - Provide default assumptions (e.g., no mention of ADUs → not allowed)

Solutions

- Utilize previous studies' standardized regulatory questions
 - Pioneer Institute, Wharton Index
- Allow model to opt-out of truly ambiguous cases
 - Model can say "I don't know"
- Human training to prompt LLM for common exceptions

Conclusion

Novel approach to systematically categorize regulatory standards, contact: dm4766@stern.nyu.edu

- *Generative regulatory measurement*, through LLMs/RAGs enables interpretation of a large text corpus, opening up a new research frontier
 - Cost-effective and scalable approach to classification of regulatory statutes
 - High accuracy in classifying zoning regulations
 - Code and data available at <https://github.com/dmilo75/ai-zoning>

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- *Generative regulatory measurement*, through LLMs/RAGs enables interpretation of a large text corpus, opening up a new research frontier
- We use generated data to find: Zoning restricts housing production and density through rent extraction and exclusion Five Facts

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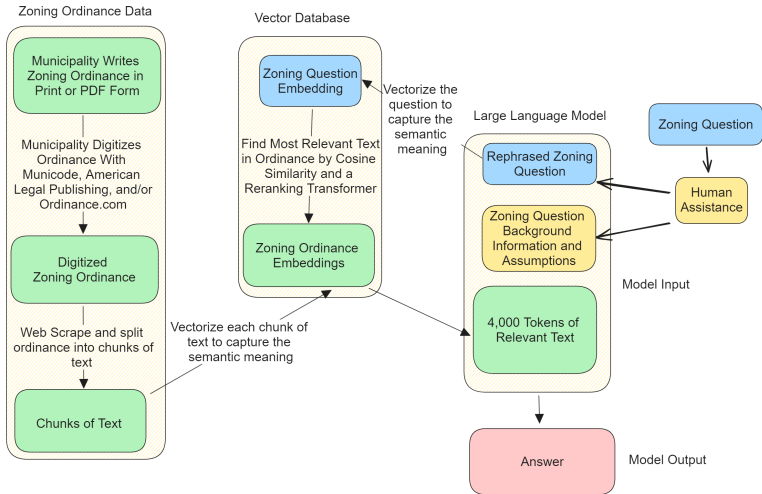
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- Further Research:
 - Ambiguity: How can we better measure ambiguous regulation?
 - Complexity: How can we measure regulatory complexity?
 - Inference: LLM generated data in regressions/models

Thanks!

Appendix

Processing Municipal Codes Using LLMs [Back](#)

Retrieval Augmented Generation (RAG)



Related Literature in Regulatory and Textual Interpretation

- **Existing Nationwide Approaches:** Wharton Regulatory Index (Gyourko Saiz Summers 08, Gyourko Hartley Kimmel 21); Huang and Tang 12; Mayer Somerville 00, Saks 08
More comprehensive, detailed, and broader scope of regulatory measurement
- **Narrower Local Approaches:** MA Pioneer Data (Glaeser Ward 09), Shanks 21, Quigley Raphael 05, Jackson 16, Ihlanfeldt 07, CA Turner Housing Data
We automate and scale this approach nationally
- **Existing AI Research:** Sentiment extraction (Hassan et al. 19, Romer Romer 04, Tetlock 07, Lopez-Lira Tang 23), LLMs to textual or regulatory documents (Jha et al. 23, Yang 23, Hansen Kazinnik 23), contractual interpretation (“generative interpretation” Hoffman Arbel 23)
Show LLMs can be used to parse understanding of complicated regulatory documents

Overall Population Coverage

	National	Northeast	Midwest	South	West
Coverage Metrics					
Total Munis	19,488	2,101	8,481	6,587	2,319
% of Munis in Sample	25	32	19	22	48
Total Townships	16,213	4,111	12,102	0	0
% of Townships in Sample	6	23	0	-	-
Total Pop. (Millions)	331	57	69	127	77
% of Pop. Under Local Gov.	76	100	95	55	78

Percent of Population Coverage by Source

	National	Northeast	Midwest	South	West
Ordinance Aggregator					
American Legal Publishing	11	15	15	6	8
Municode	23	1	19	54	12
Ordinance.com	30	52	12	1	60
Total	63	68	46	61	80

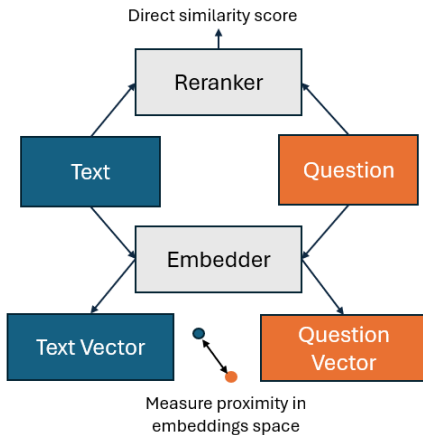
Pioneer Institute Classification of Massachusetts Zoning Codes

- We use the [Housing Regulation Database](#) which is an initiative of the Pioneer Institute for Public Policy Research and Harvard's Rappaport Institute for Greater Boston
- Covers: zoning, subdivision, wetlands, and septic regulations for each municipality in 50 miles of Boston (187 municipalities; half of state)
- Research staff went through municipal zoning documents through Dec 2004
- Data used on research (ie Glaeser Ward 09) on connection between zoning and housing outcomes

[Return](#)

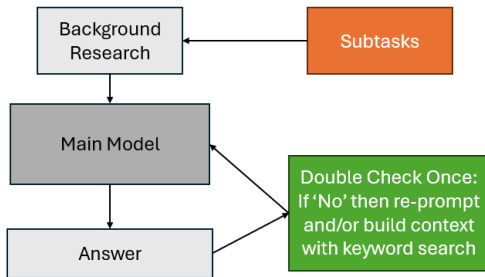
Reranking Algorithm

- Rerankers: jointly encode query-document pairs for accurate, but expensive, similarity scores.
- Two-stage retrieval: first, retrieve the nearest 50 text vectors to the question vector using embeddings; then, apply a reranker.
- Final ranking: convert cosine similarity and reranker scores to z-scores, sum them, and rank the text passages based on the combined score.



Multi-Step Processing

- Subtasks: Some questions require context that is scattered throughout the embedding space. For this, we use subtasks to summarize the necessary context for the LLM.
- Double Checking: A negative answer may mean a lack of context or strong evidence for 'No'. For some questions, we re-prompt the LLM with different context containing highly relevant keywords.

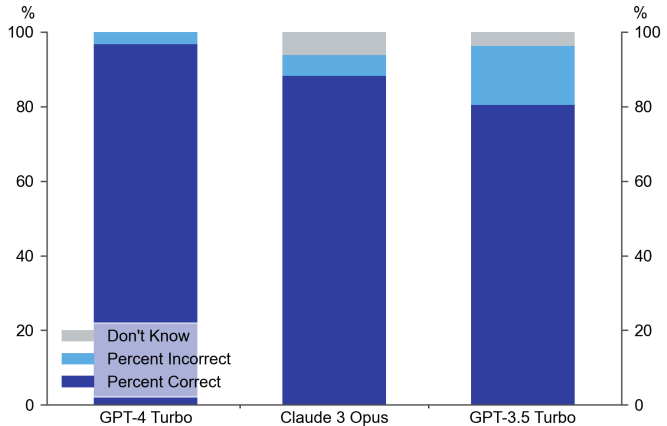


We Estimate High Accuracy on Binary Questions [Return](#)

Question	RSE	% Accuracy
Is multifamily housing allowed, either by right or special permit (including through overlays or cluster zoning)?	0.00	100%
Are apartments above commercial properties (mixed-use) allowed in any district?	0.07	96%
Is multifamily housing listed as allowed through conversion (of either single-family houses or nonresidential buildings)?	0.08	96%
Are attached single-family houses (townhouses, 3+ units) listed as an allowed use (by right or special permit)?	0.30	90%
Does the zoning include any provisions for housing that is restricted by age?	0.14	96%
Are accessory or in-law apartments allowed (by right or special permit) in any district?	0.09	96%
Is cluster development, planned unit development, open-space residential design, or another type of flexible zoning allowed by right?	0.00	100%
Is cluster development, planned unit development, open-space residential design, or another type of flexible zoning allowed by special permit?	0.00	100%
Does the zoning bylaw/ordinance include any mandates or incentives for development of affordable units?	0.00	100%
Is there a town-wide annual or biannual cap on residential permits issued, and/or is project phasing required?	0.33	90%
Are there restrictions on counting wetlands, sloped land or easements in lot-size calculations?	0.14	96%
Cumulative Average	0.11	96%
Cumulative Median	0.09	96%

We Estimate High Accuracy on Binary Questions

Adjusted Percent Accuracy of Each Model on Testing Sample of 30 Municipalities

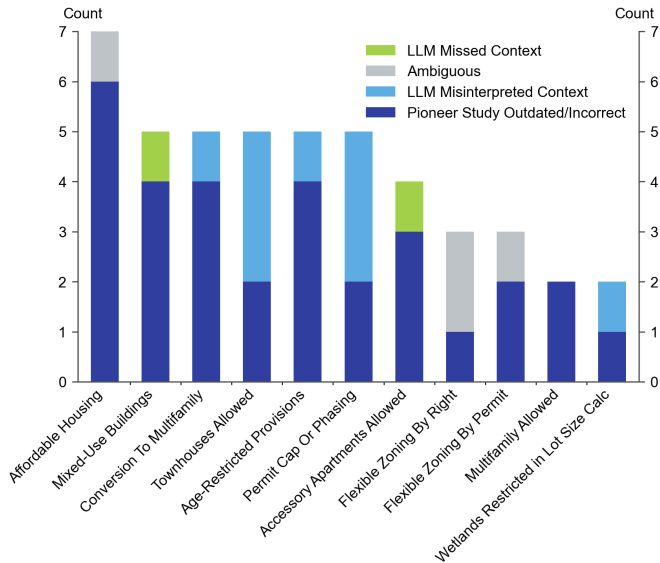


Also High Associations on Continuous Measures

Question	RSE	Correlation
How many zoning districts, including overlays, are in the municipality?	0.06	0.98
What is the longest frontage requirement for single-family residential development in any district?	1.16	0.70
Minimum of Min Lot Sizes (Square Feet)	0.73	0.61
Mean of Min Lot Sizes (Square Feet)	14.77	0.39
Minimum of Residential Min Lot Sizes (Square Feet)	0.16	0.92
Mean of Residential Min Lot Sizes (Square Feet)	11.80	0.44
Cumulative Average	4.78	0.67
Cumulative Median	1.16	0.67

Reasons for Errors

[Return](#)



Balance between False Positives and False negatives

Question	True Positive	False Positive	True Negative	False Negative	True Positive Rate	False Positive Rate	Precision
Multifamily Allowed	28	0	2	0	1.00	0.00	1.00
Mixed-Use Buildings	15	0	14	1	0.94	0.00	1.00
Conversion to Multifamily	12	1	17	0	1.00	0.06	0.92
Townhouses Allowed	18	1	9	2	0.90	0.10	0.95
Age-Restricted Provisions	22	0	7	1	0.96	0.00	1.00
Accessory Apartments Allowed	18	0	11	1	0.95	0.00	1.00
Flexible Zoning by Right	1	1	27	0	1.00	0.04	0.50
Flexible Zoning by Permit	26	0	3	0	1.00	0.00	1.00
Affordable Housing	22	0	7	0	1.00	0.00	1.00
Permit Cap or Phasing	8	2	19	1	0.89	0.10	0.80
Wetlands Restricted in Lot-Size Calc	23	1	6	0	1.00	0.14	0.96
Total	193	6	122	6	0.97	0.05	0.97

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Questions from Wharton Regulatory Index [Return](#)

7. Do you have a minimum lot size requirement? ☐ a. Yes 1 ☐ b. No 2 (If “No,” skip to question 8.)

7A. If “Yes,” do you have the same minimum lot size requirement across the entire jurisdiction?

☐ a. Yes 1 ☐ b. No 2

7B. If you have any minimum size requirement, what is the largest minimum requirement? (Check only one.)

☐ Less than ½ acre 1 ☐ ½ to 1 acre 2 ☐ 1 to under 2 acres 3 ☐ 2 acres or more 4

9. Do developers have to comply with any of the following requirements to build in your jurisdiction?

	Yes	No
a. Include affordable housing, however defined, in their projects	☐ 1	☐ 2
b. Supply mandatory dedication of space or open space (or fee in lieu of dedication)	☐ 1	☐ 2
c. Pay impact fees (allocable share of costs of infrastructure improvement)	☐ 1	☐ 2

Correlation Against Wharton Regulatory Responses

		Wharton Average	Our Average	Correlation
Affordable Housing		0.20	0.06	0.34
Minimum Lot Size	Less than 1/2 acre	0.48	0.47	0.38
	1/2 to 1 acre	0.16	0.12	0.17
	1 to under 2 acres	0.13	0.17	0.25
	2 acres or more	0.23	0.18	0.31

Five Facts About Zoning

- Create dataset on US zoning regulations to establish 5 facts:
 1. Housing production disproportionately occurs in unincorporated areas w/o mun. zoning
 2. Density is broadly limited by zoning
 3. Zoning follows monocentric pattern, w/ suburban regulations strict in bulk regulations
 4. Housing regulations cluster into two main principal components, the first corresponds to zoning complexity and can be interpreted as extracting value in high demand environments
 5. The second principal component associates with exclusionary zoning