Does the US have an Infrastructure Cost Problem? Evidence from the Interstate Highway System

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Introduction

We would like to answer the following questions,

- ▶ Did the cost of construction, resurfacing and other maintenance of interstate highways change from 1984-2008?
- ▶ Why?
- ▶ Did the total cost of capital per vehicle mile travelled change?
- ▶ Is there a problem?

Introduction

We would like to answer the following questions,

- ▶ Did the cost of construction, resurfacing and other maintenance of interstate highways change from 1984-2008? From 1990-2008, construction×5.5, resurfacing×2, other×1.

- ▶ Why? Construction: ??? Resurfacing: input prices, decreasing returns.

- ▶ Did the total cost of capital per vehicle mile travelled change? Increased usage, falling interest rates and capital accumulation mean that user cost per mile stays steady in spite of increases in construction and resurfacing costs. (Model dependent)

- ▶ Is there a problem? Not a crisis? Increases in expenditure are about proportional to increases in usage. The 1/3 of expenditure for new construction faces much higher price and no compelling explanation. Does this expenditure pass a Cost-Benefit test?

Introduction II.

Answering these questions will contribute to our understanding of the following issues:

- ▶ Is US infrastructure construction subject to some sort of 'cost disease'?
- ▶ Infrastructure policy is the subject of current debate. Documenting quantities and prices informs this debate.
- ▶ Many studies of the benefits of the interstate, costs are usually an afterthought.

Literature

- ▶ Brooks and Liscow, unpublished, (2018). Estimate cost of miles 1950-1993. Find 4-fold increase mostly from 1970-1993. They suggest 'citizen's voice'. We overlap 1984-1993 and find a 7(5.5)-fold increase 1984(1990)-2008.

- ▶ Small and Winston AER (1978). The only other analysis of roughness. Much higher cost of resurfacing than we find.

- ▶ Smith et al. (1999a), Smith et al. (1999b), environmental regulation associated with higher costs per mile constructed (1990-1994)

- ▶ Keeler and Small, JPE (1978). Similar model, SF bay area, only. Less interested in dynamics.

- ▶ Allen and Arkolakis QJE (2014), Duranton and Turner RES (2012). 'Steady state' cost estimates.

Data

We rely on three main data sources:

- *Highway Statistics*, state-year data on expenditure for construction, resurfacing and maintenance (1984–).
  - Construction: 'ROW', 'New Construction', 'Major Widening'.
  - Resurfacing: 'Reconstruction', 'Rehabilitation, Restoration and Resurfacing'.
  - Maintenance: signage, emergency services, snow removal, etc.
  - Bridges are excluded
- *HPMS Universe* data, state-year data on lane miles for ALL interstate segments (1980-2008).
- *HPMS Sample* data, segment-year level data on roughness, resurfacing and traffic for a SAMPLE of interstate segments. (1980-2008)

Various other, mostly GIS data sets, to track system characteristics over time, e.g., proximity to water.

Definitions

Highway engineering 1.0

- ▶ *International Roughness Index* (IRI).
- ▶ Pavement types: *Flexible* = asphaltic concrete, *Rigid* = (Portland cement) concrete, *Composite* = layers of gravel, concrete, asphaltic concrete.
- ▶ *Structural Number*: Index of road strength. 1" asphaltic concrete is 0.4 units. 1" concrete is 1.
- ▶ *Average Annual Daily Travel*(AADT): Cars passing over a given segment in an average day. (Sample and Universe)
- ▶ *Vehicle Miles Traveled* (VMT): AADT $\times$ segment length $\times$ 365. Sum over segments.
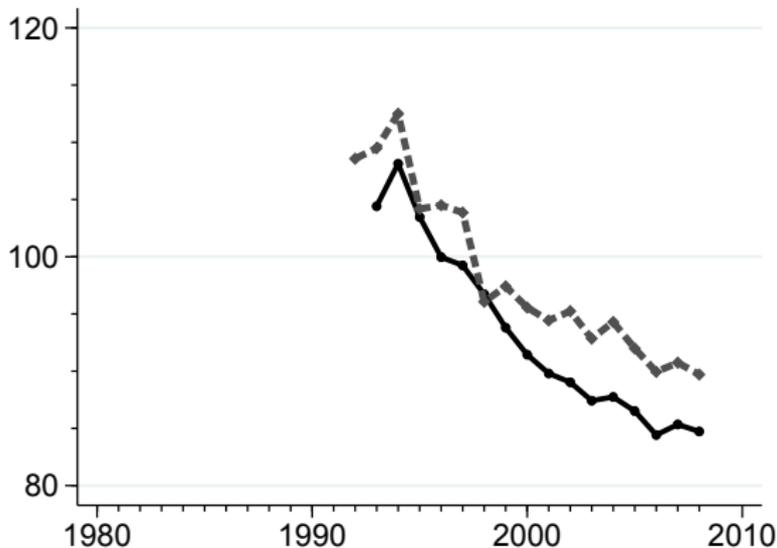
Basic facts

Lane miles
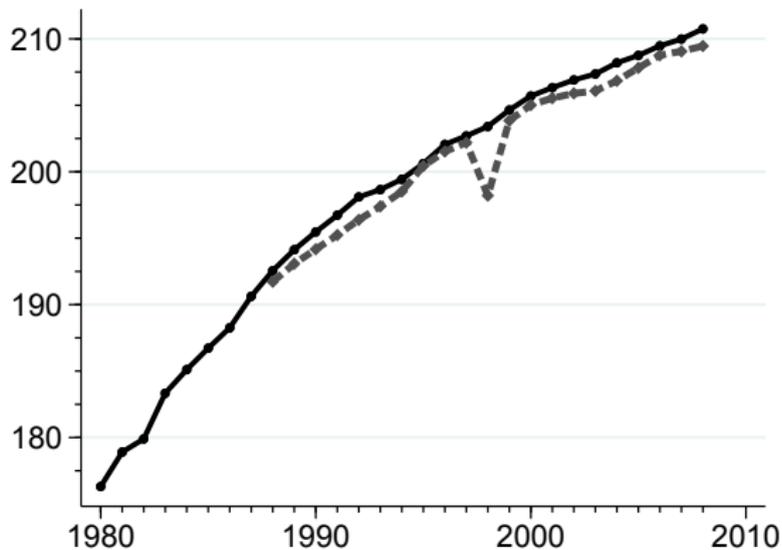
Dashed line,

HPMS Sample; Solid line, HPMS Universe.

The extent of the network increased by about 20% from 1980-2008.

Basic facts
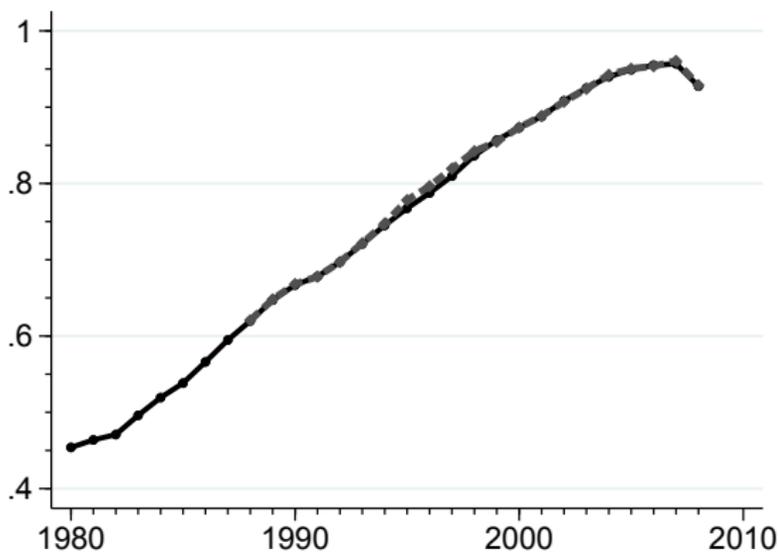
IRI - inches per mile

Dashed line, HPMS Sample; Solid line, HPMS Universe.

International Roughness Index (IRI) decreased from about 110 inches/lane mile to 90 from 1990-2008. ($< 90 =$ 'good').
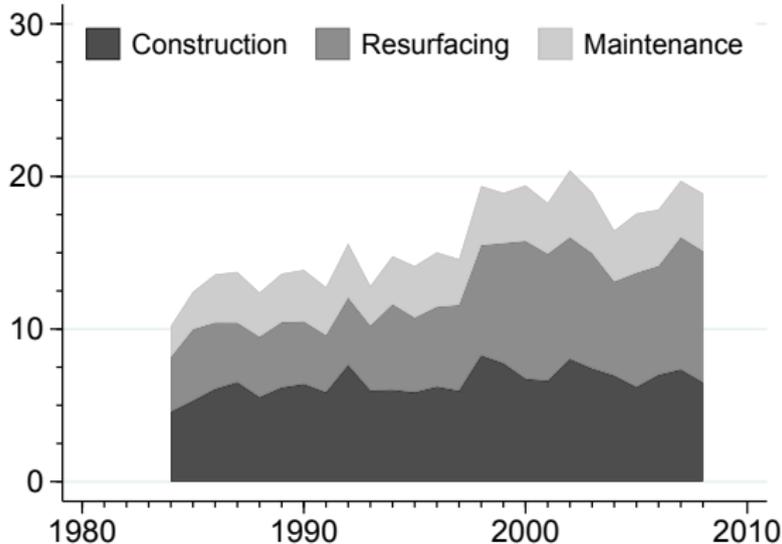
Basic facts
AADT

Dashed line, HPMS Sample; Solid line, HPMS Universe.

Annual Average Daily Traffic (AADT)about doubled from
1980-2008.

Basic facts

Expenditure USD2010b

From bottom, construction, resurfacing, maintenance. Total
expenditure about doubles 1984-2008 from about 10-20b,
resurfacing shows biggest increases.

Basic facts

Summary

- ▶ Lane miles increase about 20% 1980-2008.
- ▶ Pavement condition improves dramatically 1990-2008.
- ▶ Traffic per lane mile about doubles 1980-2008.
- ▶ Expenditure about doubles 1994-2008.

Trends in system composition

It is natural to suspect that these trends in composition at least partly explain the increasing average price of construction and resurfacing (this turns out to be mostly wrong).

- ▶ Share segments urban 0.28 ↑ 0.42 (1984-2008).
- ▶ Share segments near water ↑ (no units) (1984-2008).
- ▶ Mean grade, mean elevation ↓ (1984-2008).
- ▶ Union exposure ↓ (1984-2008).
- ▶ Share expansion lanes 0.88 ↑ 0.98 (1984-2008).
- ▶ Structural number 6.65 ↑ 6.9 ∼ 0.75 inches of asphaltic concrete. (1990-2008)
- ▶ Share rigid pavement 0.4 ↓ 0.25.(1990-2008)

Resurfacing costs I.

1. Inches per lane mile per resurfacing. $i \sim$ segment, $s \sim$ state, $t \sim$ year. $q \sim$ IRI. $\mathbb{1}_{ist}(q) = 1$ iff is resurfaced in t.

   $$\Delta q_{ist} = C_0 + C_1 \mathbb{1}_{ist}(q) + C_2[\mathbb{1}_{ist}(q)t] + \text{Controls}_{ist} + \epsilon_{ist}.$$

   C_1 is inches per lane mile per resurfacing. C_2 is trend.

2. Inches per lane million 2010USD per lane mile of resurfacing expenditure. $\imath_{st}^Q$ millions of dollars per resurfaced lane mile of expenditure in s, t.

   $$\Delta q_{ist} = A_0 + A_1[\mathbb{1}_{ist}(q)\imath_{st}] + A_2[\mathbb{1}_{ist}(q)\imath_{st}t] + \text{Controls}_{ist} + \epsilon_{ist}.$$

   LHS is inches. $\imath_{st}$ is $m/resurfaced\ miles \implies A_1$ is inches per million dollars of expenditure per resurfaced lane mile. That is, $A_1 = 1/p^Q$, the inverse price of roughness.

Resurfacing costs over time
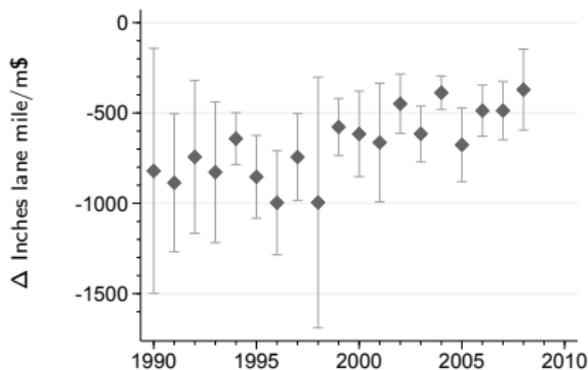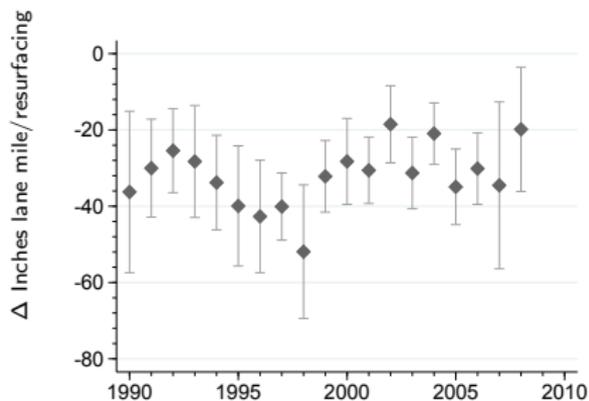
About 40 inches reduction in IRI per resurfacing event in 1984.
Trend up is barely distinguishable $\implies$ effect of resurfacing is not
changing much.

About 820 inches per million dollars in 1990, 490 in 2007.
Inverting, 1,200\$ per inch in 1990, 2,050 \$/inch in 2008.
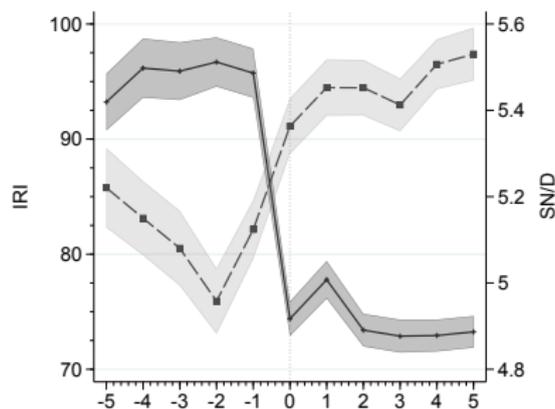
Resurfacing costs and composition.

Inches per lane mile per resurfacing. $i \sim$ segment, $s \sim$ state, $t \sim$ year. $q \sim$ IRI. $\mathbb{1}_{ist}(q) = 1$ iff *is* resurfaced in t. $x \sim$ composition measure.

$$\Delta q_{ist} = A_0 + A_1[\mathbb{1}_{ist}(q)\imath_{st}] + A_2[\mathbb{1}_{ist}(q)\imath_{st}t] + A_3t +$$
$$B_1[\mathbb{1}_{ist}(q)\imath_{st}x_{jst}] + B_2[\mathbb{1}_{ist}(q)\imath_{st}x_{jst}t] + B_3x_{jst} +$$
$$\text{Controls}_{ist} + \epsilon_{ist}.$$

$B_2 \neq 0$ and $A_2 = 0 \implies$ aggregate trend explained by observations with high $|x|$ values. For example, x could be an indicator for urban status of segment. Then B_1 is the urban premium.

Busy, urban, rigid roads are more expensive. Roads are more expensive in states with high unionization. Only structural number explains the TREND in the cost of resurfacing. 'Rigid' indicators matter a little.
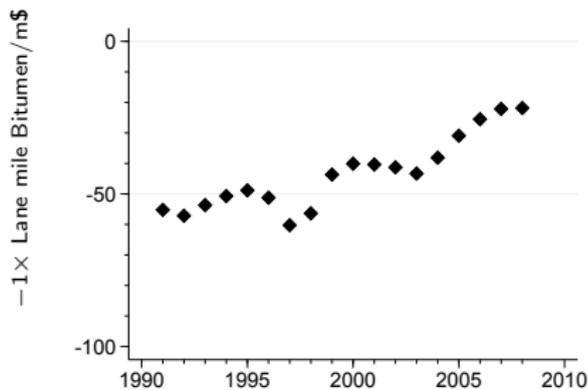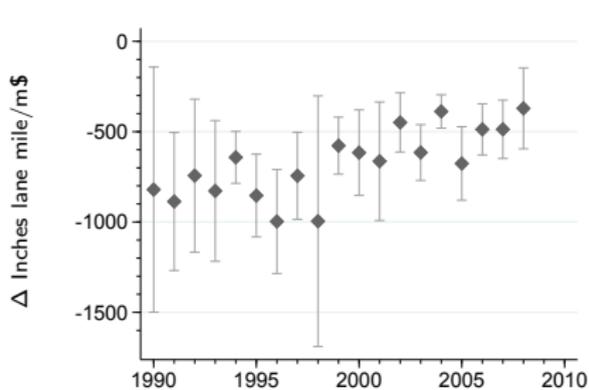
Resurfacing Costs and the Price of Asphaltic Concrete I.

Changes in IRI and structural number around resurfacing events for all segments with flexible pavement.

SN increases by about $0.4 \approx 1$ inch of asphaltic concrete $=$ HPMS definition of 'resurfacing'.

# Resurfacing Costs and the Price of Asphaltic Concrete II.

Left: Inches of roughness per million dollars per lane mile of expenditure $(1/p^Q)$.
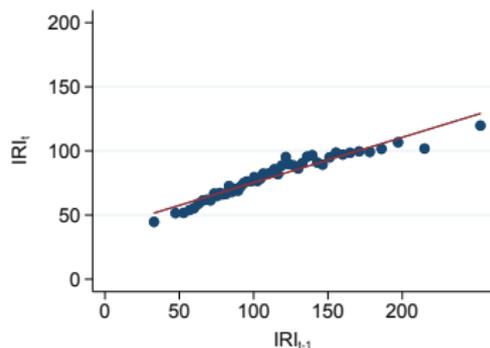
Right: Lane miles of Asphaltic concrete per million \$ $(\times - 1)$.

Increase in price of asphaltic concrete tracks increase in price of roughness and explains about 70% of price increase (at 1 inch of paving material per resurfacing).

Resurfacing Costs and Decreasing Returns
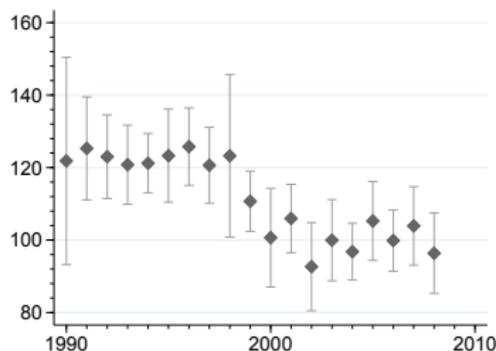
(a) IRI_{t-1} over time

(b) IRI_t vs. IRI_{t-1}

Left: IRI at $t-1$ over time.

Right: Bin scatter plot relating IRI in t and IRI in t-1. The regression coefficient is 0.35 with a SE of 0.03

Each inch of initial IRI increases post resurfacing IRI by 0.35 inches. There are decreasing returns to effort. This explains the slight decrease in the effect of resurfacing on IRI.

Construction costs over time

All data is state-year, not segment-year. Basic regression:

$$\Delta L_{st} = A_0 + A_1 I_{st}^L + A_2[I_{st}^L t] + A_3 t + \epsilon_{st}$$

for $L \sim$ lane miles of interstate in state s yeat t and I_{st}^L expenditure on construction in the same state-year. $A_2 \sim$ lane miles per million 2010USD, $1/p^L$.

Checking for composition effects:

$$\Delta L_{st} = A_0 + A_1 I_{st}^L + A_2[I_{st}^L t] + A_3 t +$$
$$B_1 I_{st}^L x_{st} + B_2[I_{st}^L x_{st} t] + B_3 x_{st} + \epsilon_{st}$$

where x_{st} measures the composition of the network: grade, elevation, proximity to water, urban, unionization, new miles, structural number, share rigid. Find x with $B_2 < 0, A_2 = 0$?

Construction costs over time
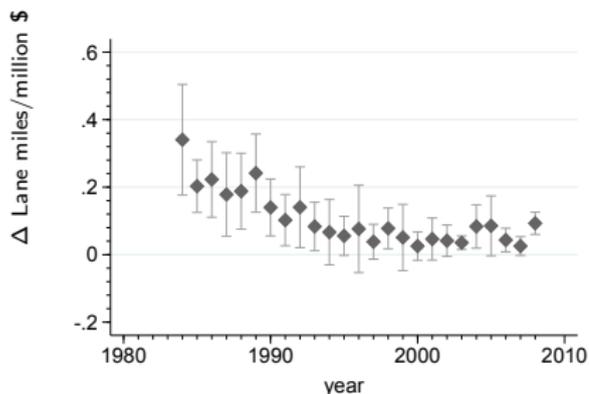
About 0.14 lane miles/million dollars in 1990, 0.025 in 2008. Inverting, 7m dollars per lane mile in 1990, 40m in 2007 (All 2010USD).

None of the composition variables can explain the trend, except maybe share rigid and structural number.

A new flexible road is 12 inches of asphaltic concrete. The increase in the cost of these materials accounts for about 300k of the 33m dollars per lane mile increase in the cost of new construction.

Define and Calculate User Cost of Capital

We can now state the government's perfect foresight dynamic optimization problem,

$$V(L_0, q_0) = \max_{I_t^l, \imath_t^q} \sum_{t=0}^{\infty} \frac{\pi_t}{(1+r)^t}$$

$$\text{subject to} \quad \pi_t = r_t^h A_t q_t^\alpha L_t^{1-\alpha} - p_t^l I_t^l - p_t^q \imath_t^q L_t \quad (1)$$

$$L_{t+1} = L_t + I_t^l \quad (2)$$

$$q_{t+1} = q_t (1 - \delta_t) + \imath_t^q , \quad (3)$$

$A_t q_t^\alpha L_t^{1-\alpha} \sim$ planner objective. Here just VMT.
$A_t \sim$ TFP of L and q
$r^h \sim$ user cost of capital/user fee per vehicle mile.
$r \sim$ time-varying real interest rate.
$q = 180 - \text{IRI}$ (180 is acceptable/poor threshold)
$\alpha \sim$ road quality share in VMT.
$\delta \sim$ depreciation rate of q

Calibrate Planer's problem to get r^h

▶ The planner's problem gives us
1. Steady state FOC.
2. Two Euler conditions, one for each choice variable, q and L.

▶ We can solve each of these three expressions for r^h, the user cost of capital that rationalizes investment behavior.

▶ If we guess at α and δ we can calibrate these three expressions for r^h using data that is easy to observe.

▶ None of the the three r^h series shows a trend (but they are noisy). Why?
   ▶ Decrease in interest rate, increase in usage and capital accumulation all offset price increases.
   ▶ Euler conditions also reflect incentive to accumulate capital early when it is cheap.

▶ Issues: δ not multiplicative. Planner probably cares about ride quality and speed adjusted VMT.

Conclusion I

▶ Between 1990 and 2008, the price of roughness about doubled. This reflects increases in materials prices and decreasing returns. This affects almost half of 2008 interstate expenditure.

▶ Between 1990 and 2008 the price of new construction increased by about a factor of 5.5. This may reflect hard to observe changes in construction or 'citizen's voice' (Brooks and Liscow, 2020).

▶ Composition effects are important for level effects. The urban and union premium decreases.

▶ The user cost of interstate capital does not seem to increase (in a rough calculation).

Conclusion II

Does the US have an infrastructure cost problem?

- ▶ Prices relevant to 35% of the interstate budget are increasing rapidly.
- ▶ This is probably not strictly about 'construction costs'. The cost of resurfacing increases only because of materials costs.
- ▶ Suggestive evidence indicates that new interstates are changing in ways that we can't quite see.
- ▶ Do these (slightly speculative) design changes pass a cost benefit test?
    - ▶ Maybe. p^L increases much faster than p^Q. But...
    - ▶ Early roads probably did not do enough externality mitigation (Brooks Liscow 2020, Brinkman and Lin (2020)).
    - ▶ The interstate carries twice as much traffic through more urban places in 2008 than 1990. More externality mitigation makes sense.