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Journal of Urban Economics 55 (2004) 398–415
JOURNAL OF Urban Economics
www.elsevier.com/locate/jue

Firm inventory behavior and the returns from highway infrastructure investments

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Received 9 May 2003; revised 7 November 2003

Abstract

The debate in public and macro economics over the returns from infrastructure spending has largely ignored transportation economics, which has documented substantial inefficiencies created by highway policy and motivated researchers to explain how infrastructure spending produces economic benefits. This paper develops a theoretical argument that highway infrastructure investments generate benefits by lowering firms' inventories and provides empirical estimates of returns based on this mechanism. We find that annual returns from highway investments have fallen to less than 5 percent during the 1980s and 1990s and suggest that a partial explanation may be the rising cost of inefficient transportation infrastructure policy.

Keywords: Highway spending; Public capital stock; Inventory behavior

1. Introduction

America's roads and bridges, valued at roughly $1.4 trillion in 2000, are the nation's largest civilian public investment.[1] In accordance with the 1997 Transportation Equity Act for the 21st Century, between 1998 and 2003 the federal government has obligated roughly $160 billion to maintain and expand highway infrastructure.[2] Including state and local government spending on roads triples that figure.

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[1] Bureau of Economic Analysis, Survey of Current Business, September 2000.
[2] United States Department of Transportation, Highway Statistics.

0094-1190/$ – see front matter
doi:10.1016/j.jue.2003.11.001

Given these enormous sums, it is important to know whether the amount of highway capital is optimal and whether additions to the capital stock are efficient. Public economists and macroeconomists have used cost and production functions to estimate rates of return from transportation infrastructure investments and have at times made dramatic claims about their economic benefits. For instance, using national time series data, Aschauer [1] and Munnell [2] found that infrastructure spending generated returns exceeding 100 percent. However, most studies in the United States and elsewhere suggest more modest returns. Studies using state data and focusing on specific industries (for example, Munnell [3], Nadiri and Mamuneas [4]) found returns to road and highway investments as low as 8 percent, and a few researchers (Hulten and Schwab [5], Holtz-Eakin [6]) even found that returns were negligible. Recently, Nadiri [7], Fernald [8], and Demetriades and Mamuneas [9] have supported the middle ground, finding that by the late 1980s returns were roughly 15 percent to 30 percent.

Although recent studies appear to produce plausible rate of return estimates, production and cost function approaches tend to gloss over the mechanism whereby infrastructure spending produces economic benefits. It is therefore difficult to reconcile their estimates with other evidence on the matter. For example, Winston [10] documents that government policy has created large deadweight losses that compromise the returns from highway spending by designing roads inefficiently and maintaining them at excessive cost, charging automobiles and trucks inefficient prices for road use, and preventing highway projects from being optimally managed. Recent research, however, has failed to explain *why* highway infrastructure investments have yielded a healthy return in the face of significant inefficiencies in highway provision, pricing, and use.

In theory, highway infrastructure investments produce economic benefits in two ways: first, by affecting firms' logistics—that is, the way they move and store finished goods and materials through all stages of the production process—and, second, by improving the speed and reliability of households' work and nonwork trips. US logistics costs exceeded $1 trillion in 2000, comprising 10 percent of GDP (Delaney [11]). Highway investments could reduce these costs by lowering freight rates and improving delivery times and reliability. Households' benefits, measured by their value of travel time savings, are not included in GDP and traditional productivity measures; thus, they have not been included in previous studies. As noted later, these benefits are also likely to be much smaller than the benefits to shippers.

This paper departs from the traditional cost and production function approach and estimates the returns from highway infrastructure spending based on logistics cost savings accrued by US industry. [3] We outline a theoretical framework to link the cost, speed, and reliability of highway transportation with a firm's cost-minimizing inventory levels and logistics costs. We use the framework to develop an econometric model that draws on the US Census Bureau's Longitudinal Research Database of plants' inventory behavior to estimate the effect of highway infrastructure investments on inventory costs. We find that during the 1970s highway investments generated rates of return that exceeded 15 percent,

[3] Haughwout [12] argues that aggregate production functions may not accurately capture the productivity of public infrastructure stocks because infrastructure investments may affect land prices and industrial location. Our approach, however, will not treat plants' locations as fixed.

but that returns fell to less than 5 percent during the 1980s and 1990s. We suggest that returns may have declined in part because of the growing cost of inefficient transportation infrastructure policies.

2. Inventory behavior and highway performance

For many years the economics literature viewed inventories as the result of production-smoothing behavior by manufacturers. Firms were assumed to face decreasing returns to scale (increasing marginal costs) at their normal output levels and to minimize total production costs by holding inventories to avoid bunching production.[4] In the production-smoothing model, improvements in the speed or reliability of transportation have no effect on inventory behavior.

But some of the model's theoretical results conflict with stylized facts about inventories. For instance, output is generally observed to be more variable than sales. Theoretically, production smoothing implies that sales should fluctuate much more than (smoothed) production. Sales and inventory investment are also observed to be positively correlated—firms add more inventory when sales are high, expecting greater sales in the future and fearing lost sales if inventory is not on hand. But if production were smoothed, sales and inventories would have a negative correlation because high sales would lead to depleted inventories, and low sales would lead to accumulations.

Blinder and Maccini [14] came to terms with these contradictions by pointing out that inventories of manufactured finished goods account for less than one-sixth of total manufacturing and trade inventories. Retail inventories, wholesale inventories, and manufacturers' holdings of materials and supplies are larger than finished goods inventories. Moreover, Blinder and Maccini argued that the productive activities associated with accumulating materials and supplies inventories consist of transporting goods, not making them; hence, the presumption that production is subject to increasing marginal costs is not persuasive.

An appropriate inventory model when marginal costs are constant or decreasing is the Economic Order Quantity (EOQ) model, also known as a Fixed Order Quantity model, or an (S, s) model.[5] Because this model captures the costs of holding inventories (such as warehousing costs and the costs of capital) and the costs of not having inventories when they are needed (such as backorder costs and the costs of lost sales), the characteristics of the transportation system play an important role.

Firms are assumed to monitor inventory levels continuously and to select the target inventory level, S, and a reorder point, s, to minimize costs. Product demand is assumed to

[4] For a discussion of the resulting linear–quadratic inventory model, see, for example, West [13].

[5] The EOQ model is widely accepted in the business and logistics literature and has been used in transportation economics studies. For example, it formed the basis for Meyer et al. [15] accounting of inventory costs and for McFadden et al. [16] model of freight transportation demand. Although product demand is typically thought of as the demand for retail, wholesale, or manufactured finished goods, the EOQ model also applies to the demand for semi-finished goods and raw materials.

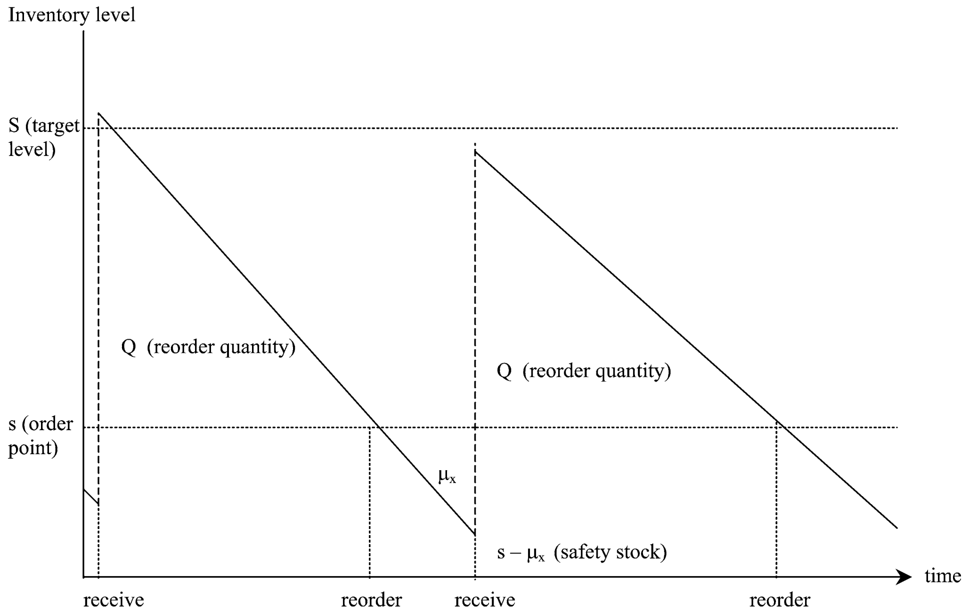

Fig. 1. EOQ model of inventory behavior.

be independent over time. An (S, s) rule specifies the level of order, Q, depending on the level of inventory at the beginning of the period, N, and sales during that period, x,

$$Q = \begin{cases} S - s & \text{if } N - x < s, \\ 0 & \text{if } N - x > s. \end{cases}$$

When inventories fall below the reorder point $(N - x < s)$, an order is placed. As long as inventories remain above the reorder point $(N - x > s)$, they continue to be depleted without being replenished. Firms also recognize that they will not instantaneously receive goods that they order. Inventories continue to drop by μ_x, the expected demand, between the time an order is placed and the goods are received. This ordering policy (and the safety stock) generates inventories whose behavior over time is characterized by a familiar saw-tooth shape (Fig. 1).

Firms accrue several costs from holding and replenishing inventories that can be reduced by improvements in highway transportation. The target inventory level is influenced by a firm's expectations of future sales and the costs of holding larger inventories. Obviously, the more sales that are expected the larger the desired inventory. Firms, however, incur capital costs from goods tied up in inventory and must pay for physical space to store them, insurance, and taxes, and absorb the loss in the value of their goods depending on the depreciation rate. A firm's reorder point protects against shortages or stockouts that arise when demand for the product exists but none is in inventory. The costs created by stockouts include expedited delivery costs (backorder costs) and possibly lost sales. If the good is an input, production delays may result in additional costs. Firms that expect greater sales and variability in sales will raise the reorder point to prevent stockouts.

Faster and more reliable highway transportation enables firms to lower their reorder point because orders will be received more quickly with less uncertainty. Firms will therefore reduce inventory levels and inventory holding costs.[6] At the extreme, if orders could be received instantaneously, then firms would not have to keep any inventory and could eliminate inventory holding costs.

In addition to inventory costs, logistics costs comprise order costs and transportation costs. Because frequent orders increase costs, firms have an incentive to place fewer orders and hold larger inventories. By doing so, firms also may be able to arrange for full truckload shipments and obtain discounts on their transportation rates.

Subject to the costs of holding larger inventories, firms choose S and s to minimize the costs associated with placing orders, stockouts, and the (possibly declining) unit costs of transportation. In practice, firms must choose an order quantity Q that is expected to achieve the target inventory level S once the shipment is received. Firms determine an optimal cost minimizing inventory policy by trading off the higher order costs, transportation costs, and stockout costs that are associated with smaller, more frequent orders against the lower inventory holding costs. Improvements in the highway system that lower transportation costs (rates) directly lower logistics costs and may enable firms to substitute transportation for inventory holdings to reduce logistics costs even further. As noted, improvements that facilitate faster and more reliable transportation reduce stockout and inventory holding costs.

3. An econometric model of inventories and infrastructure investments

Based on the preceding discussion, we develop an econometric model of the determinants of plants' inventories and use it to calculate the rate of return from highway infrastructure investments. The central influences on a plant's expected inventory level, I, for a given product can be summarized as

$$I = f(\text{expectations of and variation in demand, order/holding/stockout costs,}\\ \text{and transportation system attributes}).$$

We account for these influences empirically using the best measures available.

Firms' current inventory decisions are affected by their expectations of demand for their product. Because quantitative information on plant expectations is unavailable, the current-year demand, *annual demand*, serves as a proxy for the expectation of next-year's demand. We also interact annual demand with year dummies to capture the formation of expectations associated with a given year and to control for other unmeasured phenomena that may affect the relationship between inventories and demand across all industries. We also specify the *variability* in annual demand to indicate how firms' inventories are likely to respond to potentially significant shifts in demand. We expect that, all else equal, an increase in expected demand and the variability of demand will increase inventories.

[6] Tyworth and Zeng [17] present a formal demonstration of this effect.

Warehousing costs, stockout costs, and order processing information for individual plants are not publicly available. These variables, however, are likely to vary by commodity and geography; thus, *industry* and *location* dummies can be used to capture their effects on inventory levels. Other unobserved influences on plants' inventories that vary over time are captured by *year* dummies.

Inventory holding costs are also likely to be affected by interest rates, *interest*, and firms' inventory strategies such as their adoption of just-in-time (JIT) inventory policies. Higher interest rates increase holding costs and should, therefore, cause inventories to fall. JIT inventory practices enable firms to reduce waste in the manufacturing process and operate with "lean" inventories. Under this system, orders are placed only as stocks are depleted—in contrast with systems that move batches into and through production in pre-determined quantities. Plants benefit from JIT systems because they operate with lower inventories and are better able to detect product quality throughout production, which reduces work-in-progress arising from errors that must be corrected. Companies that have adopted JIT should have lower work-in-progress inventories than their less-diligent counterparts; thus, we control for the presence of these practices by including the ratio of work-in-progress inventories to final inventories, *work*, in our specification. An increase in this ratio should have a positive effect on inventories.

Ideally, the cost, speed, and reliability of transporting freight between city-pairs would be included as explanatory variables, and a separate model would link these measures of transportation performance to investments in highway infrastructure. Unfortunately, disaggregate highway performance data for a wide range of commodities and locations are unavailable; thus, the effects of these variables will be subsumed by the highway capital stock variable, *infra*, which enters directly into the specification.[7] An increase in the value of the highway capital stock should reduce inventories.

The speed and reliability of highway transportation are also likely to be affected by public policies such as deregulation of the trucking industry and the level of highway congestion. Trucking deregulation, *dereg*, is captured with two dummy variables. One corresponds to the start of interstate deregulation and takes on a value of 1 for 1980 and years beyond, 0 for years before 1980. The second dummy captures the advent of *intrastate* trucking deregulation and takes on a value of 1 for 1990 and beyond, 0 for years before 1990.[8] We expect that deregulation has reduced inventories by stimulating rate reductions and service improvements in truck transportation.[9] Highway congestion, *congest*, reduces travel speeds and reliability, thus causing plants to increase inventories. Congestion in a given area can be measured by vehicle-miles-traveled divided by miles of road. It is not clear, however, whether congestion should be held constant in our analysis because

[7] A handful of disaggregate freight demand models specify truck transit times and reliability for individual city-pairs. In theory, shippers' value of transit time and reliability reflects the impact of these service quality variables on logistics costs. It is difficult, however, to get disaggregate shipper data for a wide range of commodities because of confidentiality constraints.

[8] Federal legislation deregulated intrastate trucking in 1994. But several states had already deregulated rates and entry before that date; thus, we "turn on" the dummy in 1990 to capture the incipient effects of intrastate deregulation.

[9] Another potentially relevant policy is the adoption and subsequent elimination of a national 55-mph speed limit. However, this limit was in effect for virtually the entire period covered by our sample (see below).

infrastructure investments may affect road mileage. If so, we could reduce the impact of infrastructure spending on inventories by not allowing congestion to vary. Therefore, we present a model that includes congestion and one that omits it to assess how the rate-of-return calculations are affected by the treatment of this variable.

Given these measures, our econometric model of the determinants of plant inventory levels can be expressed as

$$I = f(\text{annual demand, annual demand year interaction, variability of demand,} \\ \text{industry, location, year, interest, work, infra, dereg, and congest}).$$

The empirical literature has not identified a preferred functional form to estimate inventory levels. Theoretical EOQ inventory models find that reorder size is a function of the square root of demand interacted with other influences. Thus, we specify a plant's inventory and its primary determinant, the (square root) of annual demand, in logarithms to allow demand to interact with other variables in the model, which enter in a linear manner. This specification maintains consistency with theory and is easy to interpret.[10] Estimation takes place on the following equation:

$$\begin{aligned}\log(I) = {} & \beta_1 * \log\bigl(\text{annual demand}^{1/2}\bigr) + \beta_2 * \text{year} * \log\bigl(\text{annual demand}^{1/2}\bigr) \\ & + \beta_3 * \text{variability in demand} + \beta_4 * \text{industry} + \beta_5 * \text{location} + \beta_6 * \text{year} \\ & + \beta_7 * \text{interest} + \beta_8 * \text{work} + \beta_9 * \text{infra} + \beta_{10} * \text{dereg} + \beta_{11} * \text{congest} + \varepsilon,\end{aligned}$$

where ε is a disturbance term.

4. Construction of the sample and data sources

The US Census Bureau provides data on establishment-level inventories through its Longitudinal Research Database (LRD).[11] Between 50,000 and 75,000 plants were surveyed annually during our period of analysis, 1973 to 1996.[12] The LRD inventory data are broken down into three components: raw materials, work-in-progress, and finished goods inventories. This distinction is important and often overlooked. Given that the primary cost of accumulating raw materials is transportation, raw materials are characterized by constant or decreasing marginal costs of production, which is consistent with the theoretical inventory model. Finished goods are likely to be subject to increasing costs of production and production smoothing, which is inconsistent with the model. Work-in-progress inventories are governed by no clear theoretical considerations, being determined by management strategies, and so it is inappropriate to treat them in the same

[10] We recognize that otherwise the use of the square root of demand is superfluous with a logarithmic specification (because the coefficient for the log of a square root is simply twice the coefficient for a log of a linear term in such a model).

[11] An establishment is a specific physical location engaged in industrial activity, also commonly referred to as a plant.

[12] The LRD is actually a combination of two Census Bureau data sources, the Census of Manufactures (CM) and the Annual Survey of Manufactures (ASM). For more information on the LRD, see McGuckin and Pascoe [18].

way as raw materials. The econometric analysis therefore confines its attention to the determinants of plant-level raw materials inventories.[13] In the rate-of-return calculations, we will account for wholesale and retail inventories and use sensitivity analysis to analyze how final goods inventories affect our findings.

The LRD contains the value of raw materials demanded by plants. We use this as our primary demand variable and form an estimate of the variability of a plant's materials demand by calculating the variance of its demand over time divided by its mean demand. Nominal values for raw materials inventories and the demand for raw materials are converted to real (1987) values with industry-level price deflators taken from the NBER-CES/Census Manufacturing Industry Productivity Database (Bartelsman et al. [19]).

Real (1987) public highway capital stock data come from Bell and McGuire [20].[14] That study used Federal Highway Administration data to develop a highway capital stock series at the state level, starting in 1931 and updated to 1996 for our use.[15] The estimated changes in the public highway capital stock between 1973 and 1996 for different regions in the United States are shown in Fig. 2. Real highway capital is greatest in the East North Central and South Atlantic regions and lowest in New England, a credible finding because highway allocations are biased in favor of faster-growing regions and rural states (Johnson and Libecap [21]). Some regions, such as the Mid-Atlantic and New England, experienced increases and decreases in their highway stock over the period. (Decreases occurred when depreciation and discards were greater than new investment.) Other regions experienced steady increases (e.g., South Atlantic, West North Central) or alternate periods of increasing and no growth (e.g., the Pacific).

It is also useful to summarize real spending on roads and highways (Fig. 3). Infrastructure spending generally decreased during the 1970s but increased during the 1980s and 1990s. A surge in spending at the beginning of each decade preceded major legislation that provided additional highway funding. Namely, the 1982 Surface Transportation Assistance Act instituted a 5 cents/gallon increase in the federal gasoline tax that enlarged the Highway Trust Fund, and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) increased support for highway demonstration projects and other road-related activities.

Inventory levels are likely to be affected by infrastructure investments that improve urban and intercity truck transportation. Although the LRD data identifies the county in which plants are located, it is appropriate to account for changes in the capital stock beyond the county. Because improvements in state and out-of-state capital stocks could reduce

[13] The value of beginning-of-year and end-of-year inventory stocks is reported. Little difference was found between the two when we used them in estimation, thus end-of-year values are used.

[14] A physical measure of infrastructure, lane mileage, could not be used because it is not available for the entire period covered by our sample.

[15] We are grateful to Michael Bell for updating the highway capital stock series. The capital stock was estimated using the perpetual inventory method, in which the value of the capital stock in a given year is based on the current capital investment plus the sum of previous investments that have been adjusted for depreciation and discards. Discards were assumed to follow a truncated normal distribution, and the depreciation schedule was taken with a parameter of 0.9. (Straight-line depreciation would take a value of 0.) The results were then deflated to 1982 dollars using the FHWA composite price index. The full data set used here, which extends to 1996, was converted to 1987 dollars. Bell and McGuire provide further discussion of the methods used to construct the capital stock.

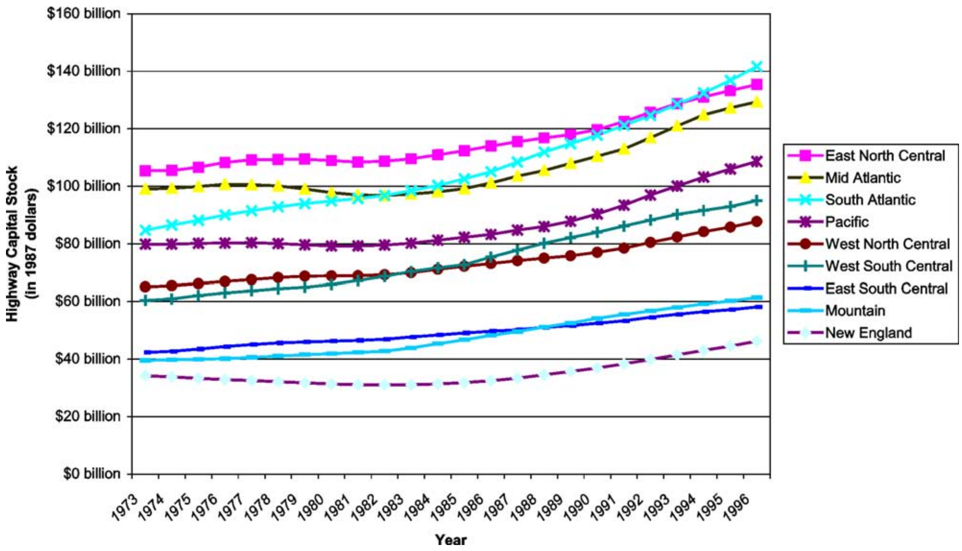

Fig. 2. Real highway capital stock by region (in 1987 dollars).

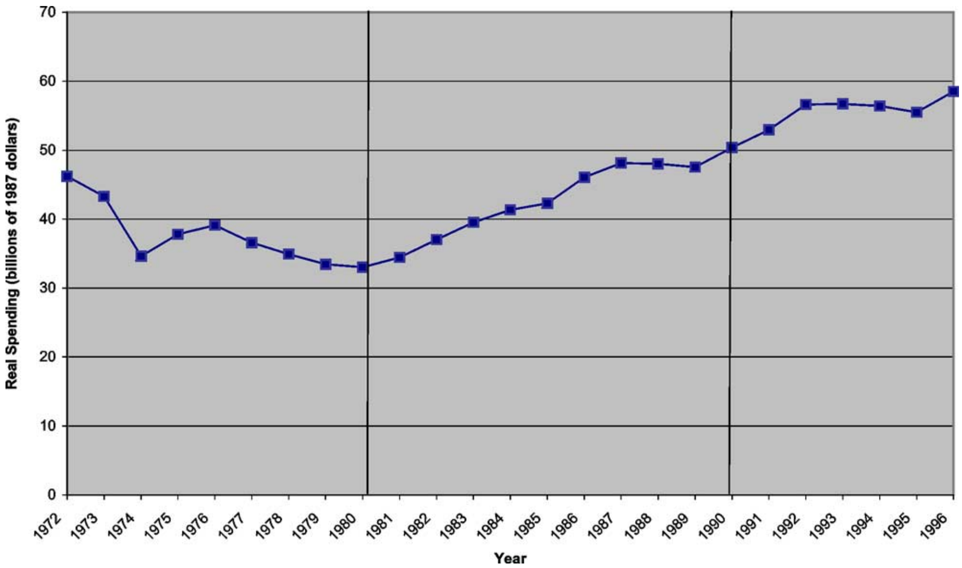

Fig. 3. Real spending on roads and highways in the continental United States (in 1987 dollars).

rates, transit times, and unreliability for shipments and help lower a plant's inventories, state and national capital stocks are included in the specification. To avoid double-counting, the national capital stock covers the rest of the country outside of a given state.

Raw materials can be transported by several alternative modes to the plants at which they are used. Although a large share of freight is transported by truck, some is carried by water, rail, or air. Raw materials inventories comprised of goods shipped primarily by non-highway modes are less likely to be affected by improvements in highway infrastructure than raw materials inventories that are dependent on truck transportation. Thus, we weighted the highway infrastructure data to reflect the extent to which a plant, based on its industry classification, uses truck transportation. The weights are formed from data contained in US Department of Transportation Bureau of Transportation Statistics [22] satellite accounts which provide detailed industry and commodity breakdowns of transportation use by mode, including trucking, relative to other inputs in the production process. The more important trucking is to an industry's production, the greater the weight that is placed on the highway infrastructure measure.

Turning to the data sources of the remaining variables, we use the real prime interest rate from the Federal Reserve Bank of St. Louis. Work-in-progress inventory is included in the LRD data set. Finally, congestion, measured at the state level by vehicle-miles-traveled (VMT) divided by highway miles, is constructed from data contained in the US Department of Transportation's Highway Statistics. Given that highway system mileage did not expand much from the mid-1970s to mid-1990s, the congestion variable is primarily capturing changes in VMT.[16]

5. Estimation results

It is not clear how long it takes plants to respond to investments in highway capital that may improve truck transportation. Preliminary estimations revealed little empirical difference between specifying the capital stock contemporaneously with inventories or with a one- or two-year lag. As shown in Fig. 2, changes in the capital stock are typically small over any two or three year period. Thus, we report results using the current-year infrastructure. We did find that the marginal effect of the highway capital stock on inventories was not stable over time. Consistent with the major trends in highway spending presented in Fig. 3, we interacted the state and national capital stock variables with dummy variables for each decade in our sample.

Parameter estimates of the inventory model based on a fixed effects specification that includes congestion are presented in the first column of Table 1.[17] Generally, the parameters are precisely estimated. Our central finding is that plants reduce their inventories in response to investments in the highway capital stock that improve local and intercity transportation within their state and that improve transportation between their state and other states. Because intrastate infrastructure is closer to plants than interstate

[16] Highway mileage grew 1.9 percent and interstate mileage grew 14.4 percent during 1975–1995 (USDOT, Highway Statistics). Lane mileage was not available for this period.

[17] Estimations were also performed using random effects, but this specification was rejected on statistical grounds. Space precludes presentation of the state (location) and industry fixed effects, but we can report that many of them were statistically significant. We considered the use of firm dummies to capture inventory policies that are possibly in common among plants owned by the same firm. Unfortunately, we were not able to estimate these dummies because there were too many to include. On the other hand, it is likely that the most important characteristic that is shared by plants owned by the same firm is reflected in their work-in-progress inventory, which is included in the specification.

Table 1
Inventory model parameter estimates* (Dependent variable: natural log of raw materials inventories)

Variable (in 1987 dollars as appropriate)	Model 1 coefficient**	Model 2 coefficient**
State Highway Capital Stock	−8.93E−08	−9.94E−08
	(1.35E−08)	(1.35E−08)
State Highway Capital Stock interacted with dummy for the 1980s	3.80E−08	4.88E−08
(1 if year is 1980–1989, 0 otherwise)	(1.41E−08)	(1.40E−08)
State Highway Capital Stock interacted with dummy for the 1990s	7.34E−08	9.06E−08
(1 if year is 1990–1996, 0 otherwise)	(1.39E−08)	(1.37E−08)
National Highway Capital Stock	−5.54E−08	−5.46E−08
	(1.29E−08)	(1.24E−08)
National Highway Capital Stock interacted with dummy for the 1980s	3.81E−08	3.71E−08
(1 if year is 1980–1989, 0 otherwise)	(1.25E−08)	(1.29E−08)
National Highway Capital Stock interacted with dummy for the 1990s	5.27E−08	5.15E−08
(1 if year is 1990–1996, 0 otherwise)	(1.28E−08)	(1.27E−08)
Natural log of square root of materials demand	1.7103	1.7122
	(0.0033)	(0.0033)
State-level congestion	0.1086	Omitted
	(0.0167)	
Variability of materials demand (variance of demand/mean demand)	0.0373	0.0375
	(0.0121)	(0.0122)
Work-in progress inventory ratio	0.1424	0.1424
	(0.0051)	(0.0051)
Prime interest rate	−2.7945	−2.8455
	(0.2459)	(0.2453)
Deregulation dummy (1 for 1980–1996, 0 otherwise)	−23.349	−22.9882
	(8.1330)	(8.1189)
Deregulation dummy (1 for 1990–1996, 0 otherwise)	−10.265	−10.2629
	(3.1846)	(3.1819)
Year trend	0.0174	0.0197
	(0.0011)	(0.0011)
R^2	0.69	0.69
Number of observations	941,844	941,844

* State dummies, year dummies, industry fixed effects, and materials demand year interaction parameter coefficients are not shown.
** Huber–White robust standard errors in parentheses.

infrastructure, it is not surprising that improvements in the former decrease inventories more than improvements in the latter.[18] Changes in both the state and national capital

[18] We attempted to obtain greater precision of the effect of infrastructure investments on plants' inventories in two ways. First, we divided each state's highway capital stock by its square miles to capture the possibility that a plant in a smaller state may be closer to roads that are improved than a plant in a larger state and thus benefit more from a given increase in the capital stock. However, this specification did not lead to statistical improvements in the model or have a material effect on the parameter estimates. Second, we explored the impact of highway investments measured at a smaller geographic level than a state. Boarnet [23] created a data set for California road and highway infrastructure disaggregated to the county level. But estimations based on these data indicated that the effect on inventories of infrastructure at the county-level was virtually the same as the effect of infrastructure in the rest of the state.

stock had a larger effect on inventories during the 1970s than in subsequent decades when highway spending increased substantially. (Quantitative effects will be discussed shortly.)

Turning to the other parameter estimates, the coefficient of the square root of materials demand lies above 1 but less than 2, indicating that plants do not adhere strictly to the square root rule but that their inventories increase less than proportionately with demand, which is reasonable. It is worth noting that many of the individual-year dummies that control for expectations of materials demand were negative, statistically significant, and tended to grow over time, suggesting that firms' demand forecasts helped them follow the square root rule more closely. Increases in congestion, the variability of materials demand, and the work-in-progress inventory cause raw materials inventories to rise, while higher interest rates and inter- and intrastate trucking deregulation cause inventories to fall. We noted that the work-in-progress inventory ratio is a reasonable proxy for the adoption of just-in-time inventory practices. This phenomenon could also be picked up by the deregulation dummies because deregulation spurred trucking firms to offer service improvements, such as prompt pick up and delivery, that facilitate JIT management. Finally, the time trend indicates that raw materials inventories have been increasing over time *ceteris paribus*, which could reflect growing product variety in the economy (Bils and Klenow [24]).[19]

The second column of Table 1 presents the parameter estimates for a model that does not include congestion. Comparing the two columns in the table shows that the impact of the state and national capital stock variables on inventories is not particularly affected when we allow congestion to vary, which confirms that this variable is primarily capturing changes in VMT that are unrelated to infrastructure investments.

5.1. Rates of return

We use the econometric estimates in the first column of Table 1 to calculate rates of return based on logistics cost savings. We first convert the capital stock coefficients into the annual effect of an additional dollar of highway spending on inventory levels. We determine the effect of highway spending in a single state on firm inventories throughout the country, thus taking national impacts into account, and average effects over all states. We find that investing an additional dollar in the highway capital stock generated, on average, a modest 7 cent annual reduction in raw materials inventories during the 1970s, but much smaller reductions of 2 cents and 0.33 cent during the 1980s and 1990s. Cost reductions for the sample are obtained by multiplying these figures by the net investment in the road system and the holding costs of inventories. Net investments in highways (i.e.,

[19] An examination of our data did not indicate, however, that raw materials inventories were growing as a function of time. To understand the potential impact of product variety on inventories, consider a firm that makes tortilla chips. Suppose this firm's raw materials demand increases by 100 bushels of corn for a given period. If the relationship between the inventory cycle stock and demand were linear, and the firm used a single raw material (say yellow corn), then following the "square root rule" the optimal reorder quantity would increase by 10 bushels of corn. However, if the firm used two raw materials (yellow corn and blue corn to make different color tortilla chips), then the sum of the optimal reorder quantities would increase by approximately 14 (two times the square root of fifty). We attempted to quantify this effect explicitly with a proxy for product proliferation, but it was found to be statistically insignificant.

increases in the value of the capital stock) amounted to $25 billion during 1973–1979, $91 billion during 1980–1989, and $137 billion during 1990–1996. Thus, assuming a standard 25 percent holding cost for materials inventories yields annual cost savings to plants in the sample of $0.4 billion, $0.42 billion, and $0.1 billion during these periods.

These estimates must be inflated to obtain national logistics cost savings. First, based on the LRD data they are multiplied by 1.5 to account for materials inventories in the economy not included in the sample. Second, raw materials inventories represent roughly a quarter of total inventories in the economy (Blinder and Maccini [14]). In theory, retail and wholesale inventories behave similarly to materials inventories, and they are almost as large.[20] Given that the inventory cost savings in these sectors are additive, the materials inventory cost savings should be multiplied by 2.6 (Blinder and Maccini [14]) to obtain total inventory cost savings. Finally, we obtain national logistics cost savings by multiplying inventory cost savings by the ratio of logistics costs to inventory costs in the economy, 2.7 (Delaney [25]). Dividing these cost savings by each period's annual net investment in the highway capital stock yields an annual rate of return that reaches 17.6 percent during the 1970s but then falls to 4.9 percent during the 1980s and to a meager 1 percent by the 1990s.[21]

The findings are not particularly affected by more liberal assumptions that expand the cost savings from lower inventories. For example, assuming that the holding costs of inventories are 30 percent instead of 25 percent and that final goods inventories are also affected by infrastructure investments (i.e., the materials inventory multiplier is 3.2 instead of 2.6) causes returns to rise to 25 percent during the 1970s, but they are still only 7 percent and 1.3 percent during the 1980s and 1990s.[22]

5.2. Other transportation-related effects on inventories

In contrast to recent highway investments, inter- and intrastate trucking deregulation has had a substantial impact on inventories. Based on the coefficients for the deregulation

[20] Wholesale and retail shipments are as likely to be transported by truck as raw materials shipments and hence be similarly affected by improvements in highways. As noted, it is unclear whether final goods inventories are primarily held as buffer stocks to help smooth the costs of production or whether they behave like retail, wholesale, and material goods inventories and would thus be similarly affected by transportation improvements. Given this uncertainly, we assume in this initial calculation that manufactured final goods inventories are not affected by highway investments.

[21] Using net highway investment understates the amount of government spending on highways and potentially overstates rates of return. Our estimated rates of return, however, are not overstated because we also use net investments to estimate national logistics cost savings.

[22] Our findings are also robust to other areas of potential sensitivity. Bell and McGuire [20] have found that alternative depreciation assumptions that could be used to construct the highway capital stock variables did not lead to perceptible changes in parameter estimates. As we reported, the capital stock coefficients were not particularly affected by our treatment of congestion. We also found that rate-of-return estimates that allow congestion to vary are very similar to those in our base case where we hold congestion constant. Finally, it is noteworthy that rates of return declined during the 1980s and 1990s while inter- and intrastate trucking deregulation was apparently reducing inventories. We explored whether the decline in returns might be spuriously related to our controls for deregulation by fitting a model that excluded the deregulation dummy variables, but we found that rates of return were still below 5 percent during the 1980s and 1990s.

dummy variables, the estimated annual benefits to plants in the sample from lower materials inventories amount to nearly $15 billion by the 1990s.[23] To be sure, this estimate is likely to include other influences besides deregulation, such as the widespread adoption of information technology and just-in-time inventory practices, so it would be misleading to inflate it to estimate national benefits. Nonetheless, the trucking deregulation experience suggests that plants can realize large inventory cost savings from noticeable improvements in shipping costs, times, and reliability.[24]

Highway congestion, which is thought primarily to impose costs on commuters, also raises inventory costs. Based on the estimated coefficient for congestion, a 10 percent increase in vehicle-miles traveled produces roughly a $1 billion increase in annual logistics costs. This estimate understates the true costs of congestion because it reflects uniform increases in traffic throughout all hours of the day and all days of the week, instead of concentrated increases during peak periods. Yet it still indicates that firms are adversely affected by growing vehicle traffic. Unfortunately, increasing highway spending appears to have become an inefficient way to offset these costs.

5.3. Disaggregate specifications

The effect of infrastructure investments on a plant's raw materials inventory could vary with the product it stores and its location. We explored the first possibility by interacting the capital stock variables with 2-digit standard industry classifications. Surprisingly, we were unable to detect many statistically significant differences. Food and tobacco inventories were the exceptions, as they were less affected than other inventories by capital stock investments, possibly because of harvesting or aging considerations.

We investigated whether infrastructure investments had distinct effects on plants in different locations by estimating inventory models that allowed the parameters of the capital stock variables to vary in accordance with the regional classifications given in Fig. 2. We found that the state capital stock parameters increased and the national capital stock parameters decreased as plants' regional classifications moved east to west. This pattern aligns with larger sizes of states as the country expanded; thus, the national capital stock for plants in western states is likely to be further away and improvements less important than for plants in eastern states whose national infrastructure is likely to be closer. These changes in the capital stock parameters, however, had virtually no effect on the rate of return estimates. It is also possible that new plants have made location decisions and/or have used more up-to-date inventory practices that enable them to take better advantage of infrastructure investments than older plants. We therefore formed distinct age ranges and

[23] This estimate is obtained by assuming the deregulation dummies were zero for each plant and calculating the difference in inventories under this scenario and when the dummies took on a value of one signifying that deregulation was in effect. Other variables, such as materials demand, are also likely to be affected by a change in regulatory policy; thus this calculation should be viewed with caution.

[24] Based on changes in the inventory/sales ratio, Delaney [26] obtained an upper bound estimate of the annual benefits from trucking deregulation of $96 billion. This estimate is much larger than others that were derived from changes in shippers' demand for freight transportation (for example, Winston et al. [27]), but there is no question that the annual benefits to shippers from inter- and intrastate trucking deregulation have been substantial.

estimated separate inventory models for plants in each range, but these estimations did not lead to changes in our conclusions.

6. Discussion and policy implications

Previous estimates of the rate of return from infrastructure investments have been so diverse that it is not surprising that our findings are consistent with some subset of the literature.[25] Our estimates of modest to trivial returns are aligned with those obtained by Hulten and Schwab [5], Holtz-Eakin [6], and Nadiri and Mamuneas [4]. The decline in returns that we found from the 1970s to the 1980s parallels Nadiri's [7] and Fernald's [8] results, although their level of returns is higher.

In our analysis, highway spending raises productivity by improving the cost, speed, and reliability of highway transportation which reduces inventories. Thus, we depart from the public/macro research programs by focusing on this mechanism to understand why returns have declined. One consideration is that the US network of roads and highways has matured. By the late 1970s, the interstate highway system was substantially completed. During the past two decades, the primary objective of highway spending has shifted from expanding the nation's capital stock to maintaining it. Undoubtedly, the improvements in costs and service from such investments and the concomitant reduction in plants' inventories cannot compare with those produced by the construction of thousands of miles of new roads. Nonetheless, spending on the capital stock has accelerated in the past two decades.

It is also possible that inefficient highway pricing and investment policies have undermined the benefits from government spending. The inefficiencies associated with such policies include but are not limited to wasteful pork barrel spending, poor responses to demographic changes, and suboptimal maintenance of the road system.

Beginning in 1982, the US Congress allowed its members to fund specific roads. These so-called demonstration projects now amount to 5 percent of federal highway funding, not including former House Speaker Tip O'Neill's personal intervention to secure multibillion dollar funding for the "Big Dig" in Boston. A notorious example of wasteful pork barrel spending is the $400 million expenditure on a stretch of I-99 in Pennsylvania that carries less traffic in a year than the Washington, DC, Capital Beltway carries in three days. Although expenditures on such projects may not be large enough to significantly lower

[25] As noted, our estimates and previous estimates of the rate of return do not account for the effect of infrastructure investments on households. The magnitude of these benefits, however, is not clear. Only a small share of highway spending during our sample period has gone toward new construction that would significantly expand highway capacity. Indeed, congestion has increased steadily during the 1980s and early 1990s. It appears to have stabilized in the late 1990s only because people are working and living in outlying suburbs (Winston [10]). As discussed below, road quality has also continued to deteriorate over time, which accelerates the depreciation of households' vehicles. Because plants' locations were not fixed during the period of analysis, our approach is consistent with previous work by capturing any logistics cost savings plants were able to achieve by changing locations in response to infrastructure investments. Finally, we do not include any cost savings from agglomeration economies such as lower labor costs, but the extent of these savings is not clear.

overall returns, they are indicative of the growing political pressures that reduce highway spending efficiency.[26]

The rate of employment decentralization in US metropolitan areas grew substantially during the 1960s and 1970s and then slowed considerably during the 1980s and 1990s.[27] But in a classic policy mismatch, urban/suburban freeway and principal arterial investments *accelerated* as employment decentralization *slowed* (US Department of Transportation, Highway Statistics, 1995). Just as roads were being improved to benefit plants (and households) in the suburbs, suburban job growth slowed, thus reducing the benefits from these investments. Even when highway investments in major urban areas have attempted to keep up with the growth in vehicle traffic, lengthy delays and large cost overruns, such as in Boston and Washington, DC, have postponed service improvements and lowered returns.

Plants' cost savings from improving part of a road network will be offset if other parts are allowed to deteriorate. Indeed, the speed and reliability of highway transportation have been adversely affected by the growing share of freeways and arterials in "fair" or worse condition over the past 20 years (US Department of Transportation, Highway Statistics, Table HM-63, various volumes).[28] As pointed out by Small et al. [30], the condition of US roads would be vastly improved if trucks were charged efficiently for their contribution to pavement damage and if roads were built thicker.

In sum, it appears that large investments in a mature highway system during the 1980s and 1990s may have had only a small positive impact on firms' logistics costs and generated low returns because they were, in part, undermined by suboptimal policies. If we are correct, policy discussions about highway spending should pay greater attention to mitigating current inefficiencies. Unfortunately, policy recommendations that would improve highway pricing and investment continue to go unheeded, suggesting that the problems associated with traditional public ownership and management of the highways may be politically intractable. If so, the time may have come to investigate the benefits of greater involvement of the private sector in highway provision.

Acknowledgments

We are grateful to M. Baily, A. Jacoby, K. Small, referees, and the editor for helpful comments. This paper reports the results of research and analysis undertaken while Shirley was a research affiliate at the US Census Bureau. It has undergone a Census Bureau review more limited in scope than that given to official Census Bureau publications. Research findings and conclusions are those of the authors and do not necessarily indicate

[26] Evans [28] shows that the inclusion of highway (pork barrel) demonstration projects is important to secure passage of legislation authorizing the nation's highway and transit programs.

[27] Watson [29] reports that the share of central city employment within the metropolitan area declined from 0.59 in 1970 to 0.52 in 1980, but then only declined to 0.50 in 1990.

[28] The quality of roads over time can be determined by assessing pavement condition based on present serviceability ratings and the international roughness indicator. We used the "fair" or worse threshold because some roads in this condition have rutting and cracking and had extensive patching that may reduce the speed at which vehicles travel.

concurrence by the Census Bureau. The paper has been screened to ensure that no confidential information is revealed.

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