The Interstate Multiplier

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Abstract

By considering the construction of the Interstate Highway System, this paper asks how big, if any, are returns to constructing new highways? In this context, I find that the biggest threats to identification are endogeneity and anticipation. To overcome the first, I note that a state's initial population and area shares played an important role in determining the assignment of interstate highway funds. To overcome the second, I propose using news to identify the timing of shocks. I combine my solutions in an IV local projection framework, as in Ramey & Zubairy (2018), and estimate a relative multiplier of 1.7 at the 15 year horizon. I then extend my specification to allow for spillover effects. Finally, using the neoclassical model in a multi-region setting I study the channels through which highway spending impacts the economy. Both empirical and theoretical results suggest that in the case of highway spending the relative multiplier is a lower bound of the aggregate multiplier.

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1 Introduction

Depending on its category, government spending shocks can have very different effects on output. One important form of government spending is spending on highways, which accounts for 59% of all transportation spending, and 28% of gross government investment.[1] This paper asks how big, if any, are returns to highway spending? To accomplish this I study the creation of the Interstate Highway System (IHS), which as of today accounts for 25% of all distance traveled by vehicles in the U.S.[2]

The federal government started appropriating funds towards the construction of the IHS in 1953. However, these funds only became significant after the Federal-Aid Highway Act of 1956 was passed. The 1956 Act envisioned a 41 thousand mile system connecting the principal routes, metropolitan areas, industrial centers and border points within the U.S. Back then, funding of the IHS was estimated to last until 1969. However, both the cost and the construction time of the IHS were greatly underestimated. The system continued receiving funding until 1996 and cost 2.2 times its initial cost-estimate (inflation adjusted).[3]

There are two main challenges to overcome when studying the effects of government spending: endogeneity and anticipation. Until recently, applied research has mainly focused on the first issue and ignored the second one. This paper is the first to study the impact of the IHS, while taking both of these challenges into consideration. To deal with endogeneity in government spending the traditional approach of the literature has been to use SVARs with contemporaneous restrictions. The basic assumption of this method is that spending does not respond within the period to shocks in output. The motivation for this restriction relies on lags in measuring output and delays from policy-makers in making decisions (Blanchard & Perotti, 2002). Unfor-

[1] For 2014, the CBO estimates that highways spending was $165 billion & all transportation spending was $279 billion (CBO, 2015). For that same year, "Table 3.1. Government Current Receipts and Expenditures" from the BEA indicates that gross government spending was $594 billion.

[2] According to Table VM-1 of Highway Statistics this share was 24.83% in 2014 and 25.10% in 2015.

[3] Own calculation using Table FA-3 of the Highway Statistics series from 1953 to 2006.

tunately, recent literature notes that for the case of anticipated spending this method will be inadequate (Ramey & Shapiro, 1998; Ramey, 2011A; Leeper et al., 2013).

Regarding anticipation, one should notice that government spending on several categories can usually be foreseen by agents in advance. This is especially true in the case of infrastructure spending, and it complicates any analysis wishing to claim causality. In the U.S., the federal government typically announces the total amounts to be appropriated for different types of federal-aid, as well as formulas to decide how these funds will be apportioned across states, a few fiscal years in advance. For example, to construct the IHS the Federal Highway Act of 1956 announced amounts to be appropriated for the following 13 fiscal years. Subsequent laws modified the amounts of 10 of these years and added 27 more years into the program.

Table 1 illustrates how IHS appropriations for fiscal years 1957 to 1969 changed as years went by. Spaces left blank in the table correspond to no changes taking place at the time. There are two main takeaways from this table. First, note that the amounts outlined in the 1956 Act provide reasonable estimates of the realized appropriation amounts for, at least, the 8 years that followed.[4] Second, notice that each Act is a news-shock; by 1962 nobody will be surprised to find an appropriation of \$2,200 million USD because it was announced in 1956. While highway spending is only going to affect the structure of the economy until the highways are built, economic agents can clearly use information to react and re-optimize their behavior even before spending takes place. This suggests that in this setting it is more appropriate to study news-shocks.

To study the returns to highway spending I use panel data at the state-level with state and time fixed effects. My specification and level of aggregation imply that I estimate the "open economy relative output multiplier" derived from the construction of the IHS. It is important to note that such multiplier differs conceptually from the "closed economy aggregate output multiplier" (Ramey 2011B; Nakamura & Steinson 2014):

[4]Realized appropriations being $\pm 20\%$ around the amount in the 1956 Act.

- The aggregate output multiplier measures the USD change in aggregate output from increasing spending by 1 USD in a union.
- The relative multiplier measures the USD change in local output from increasing spending by 1 USD in one state of the union, relative to another.

There are several important differences between these two objects. Some of the most important are: (1) Regions that receive spending may not need to pay for it. (2) By purchasing local output, government spending can cause the price of local output to rise. Chodorow-Reich (2017) refers to this as expenditure switching. (3) Monetary policy will not react to higher spending in a single region (Nakamura & Steinson, 2014). (4) Spending might make one region more productive (Leduc & Wilson, 2013). (5) Spending might lower transportation costs across regions, affecting prices faced by consumers.

My empirical results suggest that the relative output multiplier is 1.7 at a 15-year horizon. The external validity of this estimate has important limitations, so I simply refer to it as ”the interstate multiplier”. There are not too many investment projects that can boost productivity as much as building an initial system of highways that connects a country. Today, with only 1% of the nation's road mileage, the IHS accounts for 25% of all distance traveled by vehicles in the U.S. A second interstate, or any other highway built today in the U.S., is likely to generate fewer productivity gains. Therefore, I expect my estimate of the multiplier to be more relevant for developing countries in the initial stages of building transportation infrastructure.

Across the leading estimation methods, most multiplier estimates in the literature lie in a range of 0.6 to 0.8 (Ramey, 2018B). Therefore, it is imperative to ask why my estimate of the multiplier is bigger than most. (1) I find evidence, both theoretically and empirically, that this is not a consequence of the conceptual difference between the relative and aggregate multiplier. If anything, results suggest that for the case of IHS spending the relative multiplier is in fact a lower bound, and very close, to the aggregate multiplier. (2) I argue that the higher than average estimate is a consequence of the type of spending used in the identification. Most research exploits shocks to military spending since it easier to claim exogeneity. While military spending can be thought of as having no effect in the structure of the economy, the same can not be assumed of highway spending. For example, the model by Baxter & King (1993) finds a benchmark long-run multiplier of 1.16 for unproductive spending, and a range of 1.45 to 13.02 for productive spending (Table 4 of Baxter & King, 1993).

Recent research by Donaldson (2018) suggests that transportation spending lowers transportation costs. I use this relation in a multi-region neoclassical model to study the mechanisms through which highway spending raises output. Moreover, I use this model to study the link between the relative and aggregate multiplier. As mentioned, results from this exercise suggest that, for highway spending, the relative multiplier is a lower bound on the aggregate multiplier. When all the economy increases its highway stock, each state faces higher external demand, which is met by increasing private capital.

The rest of the paper is divided as follows. Section 2 goes over relevant literature on highway spending, the anticipation of shocks and multipliers. Section 3 provides background information on the IHS. Section 4 creates a measure of news-shocks that takes into account changes in the present discounted value of interstate spending. Section 5 presents the empirical results, along with robustness checks. Section 6 then studies the link between the relative and the aggregate multiplier, for the case of transportation spending, both empirically and theoretically. Finally, Section 7 concludes.

Table 1: The Act of 1956 vs. Actual Appropriations
(In millions of USD)

Fiscal Year	Act of 1956 (6/29/1956)	Act of 1958 (4/16/1958)	Act of 1959 (9/21/1959)	Sec. of Com.[1] (10/8/1959)	Act of 1961 (6/29/1961)	Act of 1965 (8/28/1965)	Act of 1966 (9/13/1966)	Realized Appropriation
1957	1,175							1,175
1958	1,700							1,700
1959	2,000	2,200						2,200
1960	2,200	2,500						2,500
1961	2,200	2,500	2,000	1,800				1,800
1962	2,200							2,200
1963	2,200				2,400			2,400
1964	2,200				2,600			2,600
1965	2,200				2,700			2,700
1966	2,200				2,800			2,800
1967	2,200				2,900	3,000		3,000
1968	1,500				3,000		3,400	3,400
1969	1,025				3,000		3,800	3,800

[1] Due to insufficient funds the Secretary of Commerce apportioned $1,800 million, instead of $2,000, across states on October 8, 1959.

2 Literature Review

This paper is connected to research that touches on the topics of: (1) the anticipation of government spending; (2) the effect of government spending & infrastructure; and (3) the linkage between the relative and the aggregate multiplier. Across the leading estimation methods, most multiplier estimates in the literature lie in a range of 0.6 to 0.8 (Ramey, 2018B). While these estimates usually exploit shocks to military spending, far less is known about the effects of infrastructure spending. However, a few studies suggest that for infrastructure spending the multiplier is likely to be above unity.

2.1 Anticipation of Government Spending

Until recently the anticipation of government spending was not always considered when studying its effects on output. However, recent literature has pointed out how omitting the agents' foresight can lead to incorrect inference. In the empirical side, Ramey (2011A) shows that anticipation of future military spending can lead to an incorrect identification of spending shocks and argues that timing is not only an issue for defense spending. Interestingly, Ramey uses the IHS as a good example of when a VAR would fail. In a more theoretical framework Leeper et al. (2013) show how agents' foresight can generate challenges in recovering structural shocks.

The realization of how important anticipation of government spending actually is has lead new applied research to employ methods that take this issue into consideration (see e.g. Leduc & Wilson, 2013; Arezki et al., 2017; Ramey & Zubairy, 2018A)

2.2 Effects of Government Spending & Infrastructure

Most research focusing on the effects of government spending has used military spending fluctuations (Barro, 1981; Hall, 1986; Rotemberg-Woodford, 1992; Ramey & Shapiro, 1998; Hall, 2009; Ramey 2011A; Barro & Redlick, 2011; Nakamura & Steinsson, 2014). This type of spending has the advantage of being driven by major political events that are unrelated to the state of the economy. However, as Ramey (2011B) notes, there is a possibility that the events leading to military buildups may have influences on the economy apart from the effects on government spending (e.g. increased patriotism could rise labor supply). Moreover, it is very likely for different types of spending to have different effects on output, suggesting the importance of studying fluctuations in non-military spending as well.

Blanchard & Perotti (2002) & Pereira (2000) are examples of papers that use a SVAR with contemporaneous restrictions to study the effects of non-defense spending on output. Their identification relies on the assumption that spending does not respond within the period to shocks in output. Blanchard & Perotti (2002), who use ”Purchases of Goods and Services, both current and capital” as their measure of government spending, find an aggregate output multiplier between 0.9 and 1.3. Meanwhile, Pereira (2000) studies the impact of different types of public investment on output. For the category of ”investment on all highways and streets” Pereira finds an aggregate multiplier of 1.97. The identification method used by these papers has two major drawbacks. First, not taking into account anticipation means that the VAR structural shock can probably be predicted a few quarters in advance; which renders any inference invalid. Second, by using time-series data this method can't take into account time fixed effects which can result in a bias.[5]

This paper is similar in spirit to Leduc & Wilson (2013), who ask a similar question but use the total appropriation amounts from Federal-Aid Highway funds from 1993 to 2010 instead. The authors construct a measure of highway spending news-shocks that captures revisions in expectations about future government spending and study how these shocks affect output using Jordà's local projection method (Section 4 in this paper follows a similar methodology). Their results suggest that news-shocks positively affect output on impact and after six to eight years.

Unfortunately, the estimate of the multiplier is not one of the most impor-

[5]As pointed out by Leduc & Wilson (2013): ”time fixed effects are potentially important when estimating the impact of government spending as it allows one to control for other national macroeconomic factors, particularly monetary policy and federal tax policy, that are likely to be correlated over time (but not over states) with government spending”.

tant contributions in Leduc & Wilson (2013), meaning that their estimates have a few shortcomings: (1) their method follows a 2-step approach so they don't provide standard errors for their estimates of the multiplier; (2) further analysis of their data reveals a problem of weak instruments; (3) they use a log-log specification which is known to bias the estimate of the multiplier upward (see Ramey & Zubairy, 2018A); and (4) they use an unconventional formula of the multiplier which considers all the spending to occur in the 10 years following the shock but only 1 year output gains. Applying the conventional multiplier formula[6] to their results gives estimates of the relative output multiplier that lie between 6.6 and 18.1 (depending on the measure of spending they use).[7]

It is likely that Leduc & Wilson's selected initial year of 1993 was the result of data availability; state-level data before this year has not yet been captured electronically even though it is available in the Highway Statistics Series, a set of annual reports published by the Federal Highway Administration since 1945. For this paper I capture and use such data. In contrast to Leduc & Wilson, by using historical data I can analyze the construction of the IHS. Being the most important highway system in the U.S., studying the IHS is important in its own right. Moreover, the likely existence of decreasing returns to scale in infrastructure spending makes this analysis even more interesting. Back when the construction of the IHS started, both the quantity and quality of roads in the U.S. was not what it is today. Therefore, it seems logical to expect a much stronger effect from building the first set of high-quality highways that connects a country compared to constructing substitute highways with the purpose of alleviating traffic congestion. The time period considered in this paper renders much more interesting results for developing countries lacking good infrastructure.

[6]Such a formula considers all the output gains and spending that occur in the 10 years following the shock

[7]Leduc & Wilson (2013) use 3 measures of highway spending: ”FHWA Grants”, ”State Government Outlays on Highway Construction”, & ”Government Spending for all road related activities”. For each measure they provide a multiplier which they refer to as the ”Mean Multiplier”. The conventional 10-year cumulative multiplier can be obtained by multiplying such multiplier by 11 (the number of time periods they consider)

Based on a cost-benefit analysis, a study by Cox & Love (1996) claims that the interstate has returned between \$6.4 and \$7.7 in economic productivity for each \$1 it cost. While their estimate is not directly comparable to the concept of the multiplier, it does suggest very high returns to highway spending. Another study that considers the IHS is by Chandra & Thompo-son (2000), who focus solely on non-metropolitan counties. They argue that non-metropolitan counties generally receive an interstate just because they fall between cities, so they are less prone to endogeneity bias. Their analysis, which neglects any effects that may arise from agents' foresight, suggests that construction of highways affects the spatial allocation of economic activity: it raises the economic activity in the counties that they pass directly through, but draws activity away from adjacent counties. Moreover, they find that certain industries grow as a results of reduced transportation costs.

This paper is also related to Donaldson (2012), who estimates the impact of railroads using data from colonial India. Donaldson obtains 3 empirical findings: (1) railroads decreased trade costs and interregional price gaps, (2) railroads increased interregional and international trade; and (3) when a district is connected to the railroad network its real income rises by 16%. Using an extension of the Eaton & Kortum (2002) model, Donaldson concludes that railroads raised real income in India because they reduced the cost of trading, and enabled India's heterogeneous districts to enjoy previously unexploited gains from trade due to comparative advantage. Consistent with Donaldson's findings, the model presented in section 6.2 features a reduction in trade costs due to the construction of highways.

2.3 Relative vs. Aggregate Multipliers

As many other recent papers, I will be estimating the "relative output multiplier". As discussed in section 1, such multiplier differs conceptually from the "aggregate output multiplier" for several reasons. Even though the relative multiplier might not be the usual object we are used to thinking about it is interesting in itself as it informs about the effect on a state's output we would observe if we were to increase spending in that state alone. Moreover, recent research by Dupor & Guerrero (2017) on military spending suggest that local multiplier estimates may be reliable indicators of fiscal policy's aggregate effects.

The relative and aggregate multipliers are only indirectly related. Nakamura & Steinsson (2014) study how monetary policy affects the relationship between the two. They argue that monetary policy will not respond to government spending in one region of the union, while it will respond to spending increasing in the whole union. Using this reasoning and a counter-cyclical monetary policy, they conclude that the relative multiplier is an upper bound of the aggregate multiplier.

Recently, Chodorow-Reich (2017) works on a model that attempts to translate the relative multiplier to an aggregate multiplier when monetary policy is not responsive (i.e. at the zero-lower bound). His main finding is that by purchasing local output, government spending causes the relative price of local output to rise (which they refer to as expenditure switching). For the special zero lower bound case, Chodorow-Reich concludes that the relative multiplier is a lower bound of the aggregate multiplier.

3 The IHS

Each of the annual issues of the Highway Statistics Series from 1956 to 1996 provide excellent summaries of the IHS. Supplementing this series with the Federal-Aid Highway Acts, as well as with the cost-estimate reports of finishing the IHS, one can obtain detailed information on the funding and year-to-year changes in the IHS plans. In this section I present a summary on the evolution of the IHS.

The Federal-Aid Highway Act of 1944 gave birth to the IHS, back then called the National System of Interstate Highways. The Act called for the designation of a highway system of 40,000 miles to connect metropolitan areas, cities and industrial centers, as well as to connect the U.S. with Canada and Mexico at key border points. In 1947 the selection of the first 37,700 miles was announced; the remaining miles were reserved for additional urban routes. However, at the time there was no plan on how to fund the system, nor an estimate of how much it would cost; so its construction was uncertain.

In 1952, legislation approved some small funding towards what can be called a pilot stage in the program. The Act of 1952 devoted $25 million of federal funds for the fiscal year 1954 and a similar amount for the fiscal year 1955. States were required to match the federal funds with a 50% Federal - 50% State rule. Moreover, the funds were apportioned across states with a formula[8] that that assigned a weight of one-third to each of the following factors:

(1) Relative Population: the ratio which the population of each state bears to the total population of all the states (as shown by the latest available Federal census).

(2) Relative Area: The ratio which the area of each state bears to the total area of all the states.

(3) Relative Rural Delivery and Star Routes (RDSR) Mileage: the ratio which the mileage of rural delivery routes and star routes in each state bears to

[8] Formula set forth by Section 21 of the Federal Highway Act of 1921.

> the total mileage of rural delivery and star routes in all the states at the close of the preceding fiscal year.

Two years later the Act of 1954, which expanded the pilot stage of the interstate program, was approved. It designated an appropriation of $175 million of federal funds for the fiscal year 1956 and a similar amount for the fiscal year 1957. For these years the apportionment formulas for the states were modified to give more weight to the state's population: (1) a weight of 2/3 on relative population, (2) 1/6 on relative area, and (3) 1/6 on relative RDSR. Moreover, the matching funds rule changed to 60% Federal - 40% State.

Shortly after the Act of 1954 was passed, President Eisenhower started a campaign towards expanding the highway program with a speech given to the Governors' Conference.[9] After the speech, President Eisenhower asked General Clay to head a committee to propose a plan for constructing the interstate. At that time there was a consensus that there was a need for the IHS; however, there was no agreement on how to pay for it.[10] Using information on a report that was currently being developed by the Bureau of Public Roads, the Clay committee estimated the program would cost $27.2 billion (January 1955). They suggested for the Federal Government to cover $25 billion and to finance it with a 30-year bond. The financial plan set forth by the Clay committee had very little support and was rejected from Congress.

After legislation failed in 1955, it was predicted that in 1956 (a presidential election year) the Democratic Congress would not approve such an important plan sought by a Republican president. However, Eisenhower continued to urge approval and worked with Congress to reach compromises. New legislation in 1956 proposed to finance the interstate with the creation of a Highway Trust Fund (HTF), which would collect a tax of 3 cents per gallon tax on gasoline and diesel, along with other excise taxes on highway users.[11] The idea was for the HTF to be modeled after the Social Security Trust Fund; revenue would go

[9] Since the President's mother was seriously ill the speech was delivered by Vice President Nixon, who read from the President's notes.

[10] See https://www.fhwa.dot.gov/infrastructure/originalintent.cfm

[11] The HTF was also to be funded with taxes on tire rubber, tube rubber, new trucks, buses, and trailers. Today the HTF still exists, however it now collects a fuel tax of 18.4 cents per gallon on gasoline and 24.4 cents per gallon on diesel.

into the general treasury, but credited directly to the Fund. The HTF was a successful compromise which lead to the approval of the Federal-Aid Highway Act of 1956.[12]

The Act of 1956 is sometimes referred to as the IHS Act as it set forth a plan for completing the IHS. First, it created the HTF to finance highway federal-aid; at the time this included the IHS and the ABC program.[13] Second, it envisioned that the IHS would be completed in the following 13 years. Third, it provided more substantial federal-aid funds than its predecessors; totaling \$25 billion to be spent during the 13 year period considered. Fourth, it changed the matching funds rule to 90% Federal - 10% State, which provided more incentives for states to invest in the IHS.[14] This matching rule prevailed until the last federal-aid appropriations took place in 1996. The state matching funds rule together with the \$25 billion appropriation meant total funds equal to 6.2% of GDP.

For 1957 to 1959 the apportionment formula was the same as the one provided by the Act of 1954. For the subsequent years, the 1956 Act provided a different formula, solely based on the relative costs of completing the IHS. That is, the formula was equal to the ratio of the estimated cost of completing the system in each state compared with the cost in all states.[15] To keep this formula up to date, the cost-estimate of completing the IHS was to be updated periodically by the Secretary of Commerce.[16] The logic behind this method was for all states to finish construction of the IHS around the same time.

Even though subsequent acts, amendments and resolutions shaped the fu-

[12]The 1956 Act passed congress with 89 in favor and only 1 against, and was signed by President Eisenhower on June 29, 1956.

[13]The ABC program is a Federal-aid program that provides funds for Primary and Secondary Highway System, as well as for extensions of these systems within urban areas.

[14]The federal government actually covered 90.4% of the funds as section 108(e) of the Act of 1956 specified that the federal government would cover a percentage of the remaining 10% in any state where the ratio between the area of Federal lands and nontaxable Indian lands to the total area of the state exceeded 5%. The additional percentage was equal to 10% times such ratio and was capped at 5%. This rule affected only 12 states.

[15]The Federal-Aid Highway Act of 1963 slightly changed the formula starting in fiscal year 1967. The new formula considered the ratio of the federal share of the estimated cost of completing the system in each state compared to the federal share if the estimated cost of completing the system in all states.

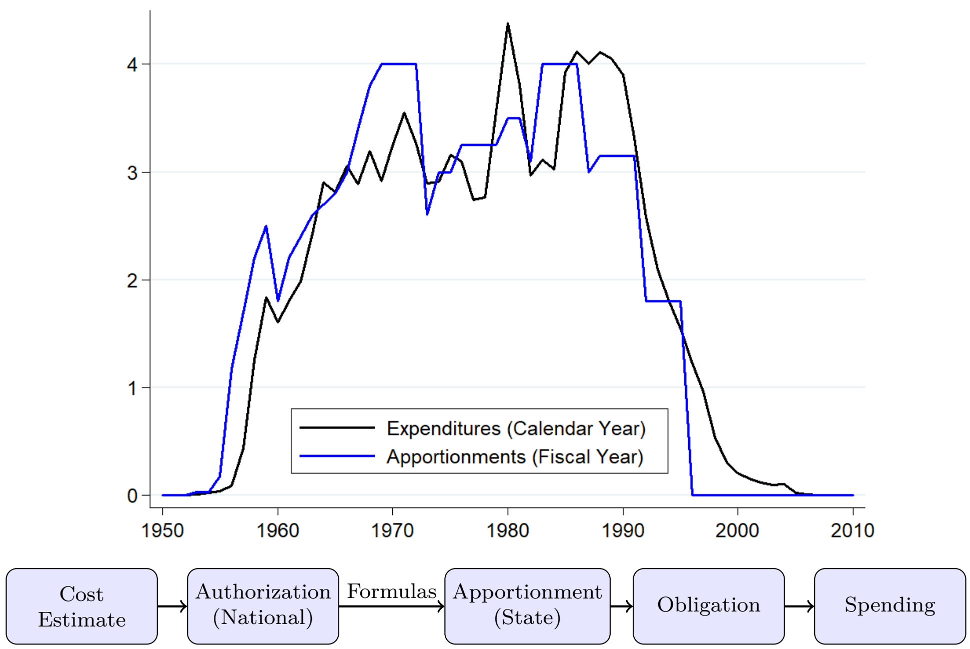
[16]This responsibility was later transferred to the Secretary of Transportation.

ture years of the IHS, its essence remained linked to the Act of 1956. The most important changes were triggered by the rising estimated cost of the system, which delayed the end of its construction until 1996 and required considerably more appropriations than what the original plan considered.

Figure 1 shows how appropriations and expenditures of federal funds evolved from the beginning of the program. While the final appropriation took place in fiscal year 1996, expenditure continued in the 2000's because funds had been obligated but not yet spent. The procedure by which spending took place is also illustrated in Figure 1: (1) First, an estimate of the cost of completing the interstate was released. (2) Then, an authorization took place in a Federal Highway Act. These authorizations outline the amounts that would be available at the national level for the following couple of fiscal years. (3) Funds were then apportioned across stated using formulas provided by legislation. The share each state receives is called the apportionment factor (AF). For each fiscal year apportionment factors were usually announced between 1 and 2 years in advance; however they could be predicted with accuracy many years in advance using the formulas set forth by legislation. (4) Once the fiscal year of the appropriation was reached, states obligated funds in interstate highway projects. (5) Finally, as highways were built, spending took place. Payments to contractors for work completed were initially made from state funds[17] and the federal share was paid as reimbursements.

[17] Sometimes from funds transferred to the state by cities, counties, or other local governments

Figure 1: Federal Government Funds to Construct the IHS
(Billions of Nominal USD)



4 Methodology

In this section I construct a measure of interstate news-shocks that takes into account agents' knowledge of future IHS spending and explain how it can be used in a Local IV projection, as in Ramey & Zubairy (2018A), to estimate the relative interstate multiplier. I also explain how estimation of the multiplier may be decomposed in a three-step method, via which the exact same multiplier may be estimated.

4.1 Specification

Throughout the paper i indexes states and t indexes time periods. Let $y_{i,t+h} = \dfrac{Y_{i,t+h} - Y_{i,t-1}}{Y_{i,t-1}}$ and $g_{i,t+h} = \dfrac{G_{i,t+h} - G_{i,t-1}}{Y_{i,t-1}}$, where Y_{it} is output and G_{it} is a measure of spending at the state level, both real and per capita. In the simplest case G_{it} would be IHS spending. However, an increase in IHS spending is likely to induce other government spending categories to rise. The spending measure used, G_{it}, should capture this spillover effect.

To estimate the relative multiplier consider the following specification for every horizon $H \in \{0, \ldots, \bar{H}\}$:

$$\sum_{h=0}^{H} y_{i,t+h} = \mu_H \sum_{h=0}^{H} g_{i,t+h} + \boldsymbol{\psi_H x_{it}} + \varepsilon_{it}^{(H)} \tag{1}$$

For each horizon the parameter of interest is μ_H, the relative interstate multiplier at horizon H. $\boldsymbol{x}$ is a column vector of control variables discussed in subsection 4.4, and $\varepsilon_{i,t}^{(H)}$ is a residual. The control variables include both state and time fixed effects. In this context the inclusion of time fixed effects is extremely important as it controls for aggregate shocks and policy that affect all states at a particular point in time.

The definitions of $y_{i,t+h}$ and $g_{i,t+h}$ used are now common in the literature (see Hall, 2009; Barro & Redlick, 2011; Owyang et al., 2013; and Nakamura & Steinsson, 2014). As noted by Hall (2009), by using the same denominator this transformation preserves the normal definition of the multiplier as the dollar change in output per dollar of government purchases.[18]

Estimating equation 1 using Jordà's local projection method (2005) would deliver biased estimates of $\{\mu_H\}_{H=0}^{\bar{H}}$ due to the endogeneity of IHS spending. To overcome this issue one can use Local IV projection (Ramey & Zubairy, 2018A), which requires an instrumental variable that is both valid and relevant.

As an instrumental variable I propose using a measure of the unexpected change in the Present Discounted Value (PDV) of IHS funds, that are unrelated to future growth prospects. My instrument falls into the news-shock category as it uses news to identify the timing of shocks. The use of news-shocks is now common in the applied macroeconomics literature; for example, Ramey & Zubairy (2018A) use them to study fiscal policy, Leduc & Wilson (2013) for highway spending, and Kuttner (2001) for monetary policy.

Let $\Phi_{i,t}$ be the news-shock of state i at time t, in real and per capita terms. Then:

$$\phi_{it} = \frac{\mathbb{E}_t[PDV_{it}] - \mathbb{E}_{t-1}[PDV_{it}]}{Y_{i,t-1}} \tag{2}$$

where

$$PDV_{it} = \sum_{\tau=0}^{\infty} \beta_t^{\tau} \hat{e}_i A_{t+\tau} \tag{3}$$

β is the discount factor, $\hat{e}_i$ is an estimate of an exogenous measure of the apportionment factor (AF) received by each state, and A_t is the real appropriation amount and real state-matching funds (all per capita) of time t. The news shock stems from agents having more information available at date t than at date $t-1$. It is expressed as a fraction of lagged output for consistency with the specification of equation 1. The following subsection discusses the estimation of the news-shock, as well as the intuition behind the exogenous apportionment factor e_i.

[18]Several papers studying fiscal policy have employed log-transformations instead. I depart from this convention because of three reasons. First, government spending in the IHS is zero in many entries of my data set; and by using logarithms I would be forced to drop these observations. Secondly, when using logarithms one needs to transform the estimated elasticities to dollar equivalents using the sample average of output to IHS spending (Y/G) to obtain an estimate the multiplier. Ramey & Zubairy (2018A) note that when Y/G is volatile across time this transformation biases the estimated multiplier upwards. In my sample Y/G fluctuates a lot because G happens to be zero, or close to zero, in many observations. Third, the transformation used in this paper permits obtaining standard errors of the estimate of the multiplier directly; which is not possible when employing logarithms.

4.2 Constructing the News-Shock

The goal of this subsection is to estimate an instrument, at the state-level, to be used in a Local IV projection framework. The instrument must overcome two challenges:

1. Anticipation: as with other forms of government spending, IHS spending was highly anticipated.

2. Endogeneity: growth prospects of a state might influence its apportionment factors (AFs) of federal-aid in highways.

The anticipation issue is tackled by using a measure of the unexpected change in the present discounted value in interstate funding (see equation 2). The news-shocks stem from 20 public laws I identify between 1952 and 1991. These public laws gave birth to the IHS, modified appropriations and extended its construction time. I use these acts as nationwide news-shocks that affect all states simultaneously by affecting appropriation amounts (and required state-matching funds) for each fiscal year.

Calculation of the PDVs of equation 3 also requires knowledge of the AFs. However, fluctuations in the AFs starting in 1960 pose a threat to identification as these are likely to be endogenous to a state's own economic condition and future growth prospects. As mentioned in Section 3, the formula for AFs in 1960 started to consider the relative estimated cost of finishing the interstate; while before 1960 it gave weights to relative population, area and mileage. The change in the formula in 1960 can create an upward or downward bias depending on which of these effects is bigger: (1) If a state suddenly has a higher growth potential it might receive a higher AF as more highways are likely to be needed there. (2) If a state suddenly has a lower growth perspective, then counter-cyclical fiscal policy might cause its AF to increase in order to promote economic activity.

To overcome the endogeneity issue, I propose substituting the observed AFs, with initial population and area shares. Figure 2 plots the cross-sectional correlation between the variable $0.5s_i^{(P)} + 0.5s_i^{(A)}$ and the observed AFs (where $s_i^{(P)}$ is the share of population of state i in 1947 and $s_i^{(A)}$ is the area share).

As illustrated in the plot, the weighted correlation between exogenous and observed AFs is 79%. Correlation is relatively high in the beginning of the program and remains high at least until 1985. Up until 1959 a high correlation is to be expected, as AFs were constructed by weighting relative population, area and RDSR mileage. It is satisfactory to see that such correlation continues even after 1959, when the formula changed to consider relative costs instead. As time passed correlations begin to grow weaker as some states made more progress in their segments of the interstate than others. In the last 10 years of the program we find the weakest correlations; however in these years appropriations were also very small as not that much money was needed to finish the interstate at the time.

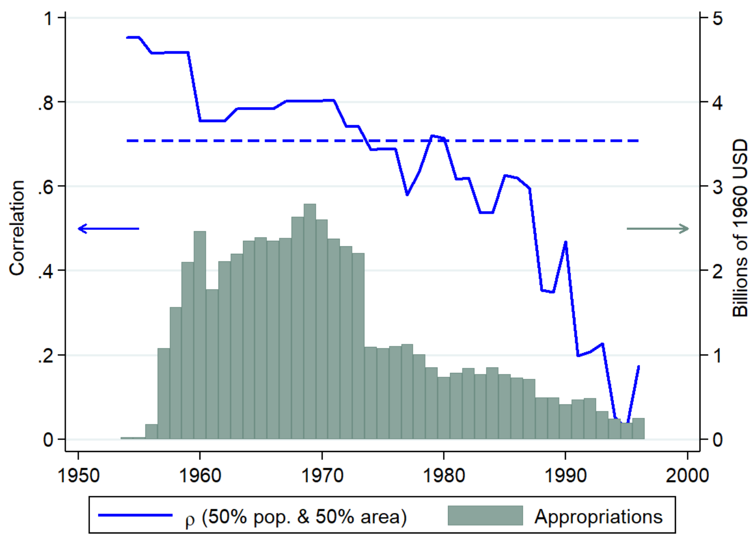
Since initial population and area shares influenced apportionment factors all throughout the program, any convex combination of these can be used as a valid instrument. It is also possible to use initial population and area shares individually and obtain two instruments instead. This approach is preferred as one does not have to arbitrarily set weights. I refer to the news-shock based on initial population as $\phi_{it}^{(P)}$ and to the one based on area as $\phi_{it}^{(A)}$. In fact, the IV estimation automatically assigns weights to each of these instruments, and these weights can be backed out. For convenience, I let $z_{itH} = p_H\phi_{it}^{(P)} + (1 - p_H)\phi_{it}^{(A)}$ (note that different horizons (H) will results in different weights), where p_H is the weight assigned by the IV estimator to the initial population weight. For the baseline 15-year multiplier estimation, the assigned weights are in fact 50% to initial population and 50% to area.

Figure 3 shows scatter plots for selected years between the exogenous AF and the observed ones. This figure permits tracking states that might be of interest, and reaffirms the previous findings regarding the relationship between the exogenous and observed AFs. Even though the relation between these variables becomes weaker over time, by 1980 it is still quite strong.

Finally, to estimate the news-shock a few choices must be made on: (1) the time frequency of the variables; (2) the timing of shocks; and (3) the estimation of β_t.

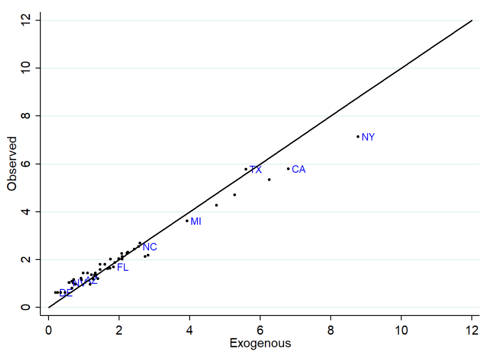
Quarterly frequency: Since shocks can potentially be dated at a daily

Figure 2: Apportionment Factor Correlations & IHS Appropriations

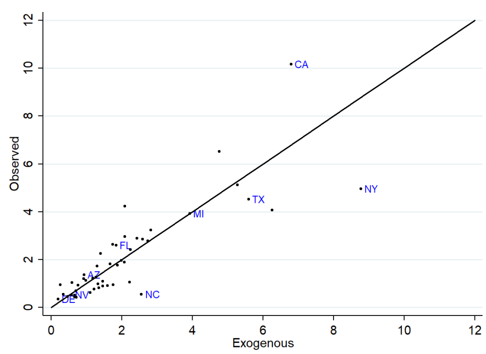


Note: Dashed lines represent average correlations weighted by real appropriation amounts.

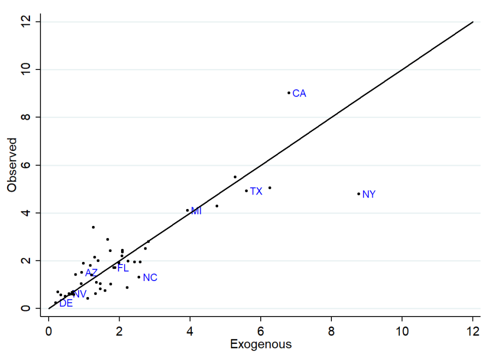
Figure 3: Observed vs. Exogenous AF for Different Fiscal Years



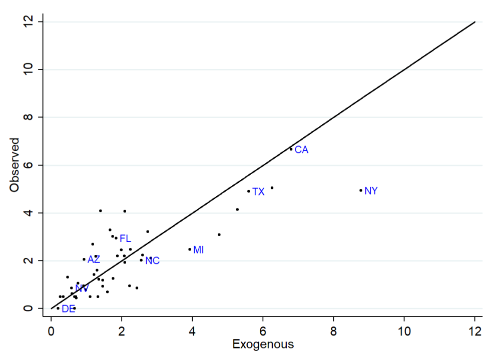
(a) 1959



(b) 1960



(c) 1970



(d) 1980

frequency and output can be observed at a quarterly frequency, I use a quarterly frequency for all variables. This poses a few challenges: **(1)** Appropriations are for fiscal years. A simple way to deal with this is to divide each fiscal year's expected spending by four. This assumption is harmless as the PDV formula will aggregate these quantities back together with a discount factor that is close to 1. **(2)** Expenditure on the IHS is observed in calendar years until 1991, and in fiscal years starting in 1992. I use the proportional Denton method (see Bloem, et al., 2001) to estimate this variable at a quarterly frequency.

The Timing of Shocks: For years before 1958, I set the timing of the news-shocks to the quarter that the Highway Acts passed Congress. Starting in 1958, I set the timing of the news-shocks to the quarter the interstate cost-estimate became available. It is important to note that the first cost estimate at the state level was released in 1958. Since the approval of the Highway Act if 1956 was unexpected, for that authorization I set the time of the news-shock to the quarter that the Act was approved by Congress.

The Discount Factor: To estimate β_t I use an approach similar to Leduc & Wilson (2013). I let $\beta_t = \dfrac{1}{1+i_t}$, where i_t is the quarterly discount rate at quarter t, which I estimate using a 5 year rolling average of the 3-month T-Bill rate. To avoid having movements in interest rates generate news-shocks, I assume that they can be anticipated fully one quarter ahead, so $\mathbb{E}_{t-1}[i_t] = i_t$.

Figure 4 plots summary statistics of the estimated news-shock at $H = 60$, where lagged per capita GDP has been annualized for ease of interpretation. For each quarter a national shock is defined as $\sum_i [z_{itH} Y_{i,t-1}] / \sum_i [4Y_{i,t-1}]$, while the average state shock is given by $\sum_i [z_{itH}/4]/N$, where $N = 48$ (Alaska, Hawaii, and the District of Columbia are not considered). The cross sectional standard deviations presented are based on $z_{itH}/4$. As may be noted, the news-shock is different than zero in 18 occasions.[19] The plot makes clear that the most important news-shocks were triggered by the Act of 1956, the cost estimate of 1961, and the cost estimate of 1977. The news-shock derived

[19]There are 20 public laws in the sample, but 2 of them overlap in 1959 Q3 and the other two overlap in 1976 Q1.

from the Act of 1956 was equal to about 9% of GDP. A closer look of the 1956 shock is shown in figure 5, which illustrates the distribution of the shock across states. While most states (39) received a shock between 3 and 12% of their GDP, the distribution is quite uneven and there are 9 states in the upper tail (above 12%).

4.3 Three-Step Method

Ramey & Zubairy (2018A) explain how the Local IV Projection method from above is equivalent to the following three-step method:

1. Reduced from regression: For every H regress $\sum_{h=0}^{H} y_{i,t+h}$ on z_{itH} and all exogenous covariates from equation 1. For each horizon, let β_y^H denote the coefficient on z_{itH}. Then $\{\beta_y^H\}_{H=0}^{\bar{H}}$ is the integral of the impulse response function (IIRF) of a news-shock on output.

2. First-stage regression: For every H regress $\sum_{h=0}^{H} g_{i,t+h}$ on z_{itH} and all exogenous covariates from equation 1. For each horizon, let β_g^H denote the coefficient on z_{itH}. Then $\{\beta_g^H\}_{H=0}^{\bar{H}}$ is the IIRF of a news-shock on spending.

3. Multiplier computation: the multiplier at horizon H is defined as $\mu_H = \beta_y^H / \beta_g^H$.

The 3-step approach is quite informative of how the shock affects the economy, as it involves estimating IRFs that track the effect of the news-shock on both output and actual spending. Estimation can be done by using Jordà's (2005) direct projections approach. However, unlike Local IV Projection, the three-step method does not deliver standard errors for the estimate of the multiplier. It is therefore important to complement the analysis and use each method when convenient.

4.4 Control Variables

The controls $\boldsymbol{x}$ included in the baseline specification are:

Figure 4: News-Shock as Fraction of Annualized Lagged GDP (%)

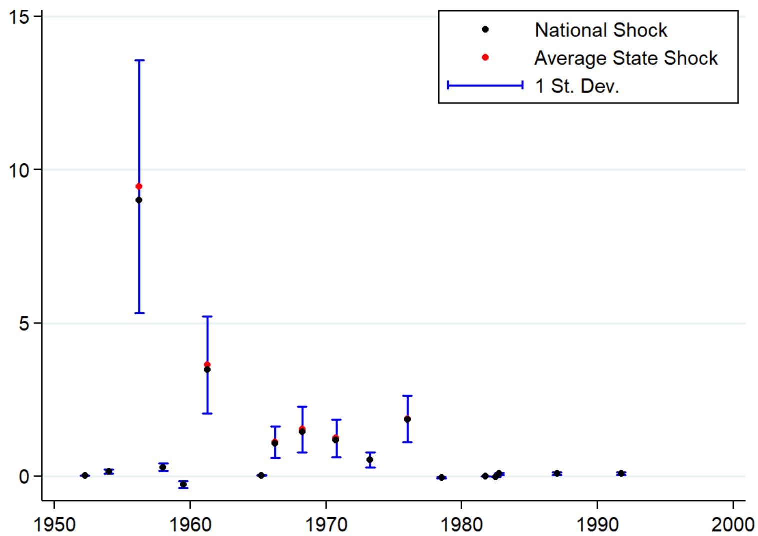
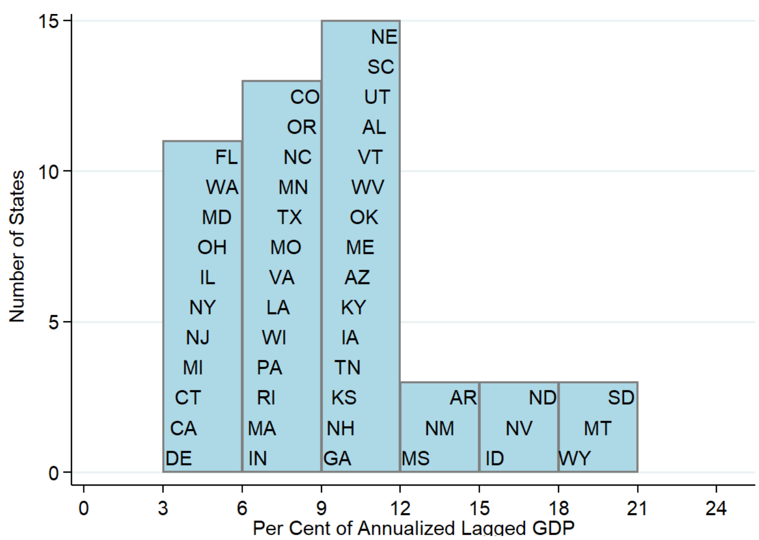


Figure 5: The Shock of 1956



Note: States whose codes are placed further to the right received a higher shock.

- Short term lags of the endogenous variables: $\dfrac{Y_{i,t-p} - Y_{i,t-1-p}}{Y_{i,t-1-p}}$ and also $\dfrac{G_{i,t-p} - G_{i,t-1-p}}{Y_{i,t-1-p}}$ for $p = 1$ to 4. These terms are meant to capture business cycle movements and short term dynamics.

- Long term growth (5 years) of the endogenous variables: $\dfrac{Y_{i,t-1} - Y_{i,t-21}}{Y_{i,t-21}}$ and $\dfrac{G_{i,t-1} - G_{i,t-21}}{Y_{t-21}}$. The first term is of special importance as it can be used to proxy the future growth potential of states.

- Lagged variables: Y_{t-1}, G_{t-1} and P_{t-1}. These control for relations between growth rates and levels; the first term is especially important as it can capture economic convergence.

- Short term lags on population growth: $\dfrac{P_{i,t-p} - P_{i,t-1-p}}{P_{i,t-1-p}}$ for $p = 1$ to 4 (where $P_{i,t}$ denotes population).

- Long term growth (5 years) of population: $\dfrac{P_{i,t-1} - P_{i,t-21}}{P_{i,t-21}}$.

5 Empirical Results

This section presents the empirical results. First, I show the baseline results, and then I proceed by going over robustness checks.

I let $\bar{H} = 60$, meaning that I will estimate the multiplier up until a 15 year horizon following the news-shock. Data covers the 48 contiguous states from 1948:Q1 to 2008:Q3.[20] For estimation purposes, serial correlation and heteroskedasticity in the error term are taken into consideration by estimating Newey-West (1994) standard errors.[21] Additionally, to obtain a nationally representative relative multiplier, equation 1 is weighted by the population of each state.[22]

The preferred estimation method is IV-GMM, which is more efficient than 2SLS given that there are more instruments than endogenous variables. While the multiplier is estimated for different horizons, the preferred horizon is the one that uses all 15 years. Being the farthest away from the shock, the 15-year multiplier is less likely to be contaminated by anticipation effects. Moreover, it uses the most information on spending and output changes, and has one of the highest first-stage F-statistics.

5.1 Baseline Results

Under the presence of spending crowd-in, using a narrow definition of spending, such as IHS spending, can bias the multiplier because the spillover would be captured by the IIRF on output, but not by the IIRF on spending. Therefore, to allow for the possibility that expenditure in the IHS may have an impact in other government spending categories, three different measures of spending are used for the baseline results: (1) IHS spending, (2) All state spending, and

[20]Due to the use of lags in the control variables and leads in the dependent variables, the regression sample is fixed for all horizons between 1953:Q2 and 1993:Q3. So each regression sample contains 7,776 observations.

[21]In appendix A I show that residuals exhibit autocorrelation but do not exhibit cross-sectional correlation. In the case of cross-sectional independence it has been shown by Hoechle (2007) that Newey-West standard errors outperform Driscoll-Kraay standard errors.

[22]Analytic weights were used. To avoid population growth giving a higher weight to later cross sections in the sample for every year each state receives a weight based on its 2008 population.

(3) All local and state spending at the state level. Note that by recognizing the presence of spillovers in other spending categories, the estimated multiplier reflects the returns from spending in a basket of goods and services, and not only in the interstate. In the following subsection I estimate the components of such basket.

Figure 6 plots the fraction that IHS spending represents of all state spending (black line), and all local plus state spending (blue line) at the national level. The fractions started at zero, since the first appropriation toward constructing the IHS was done in fiscal year 1954. Both fractions increased rapidly and reached their peaks in the 1960s. Then, the fractions slowly went back to zero.

Figure 6: IHS Spending

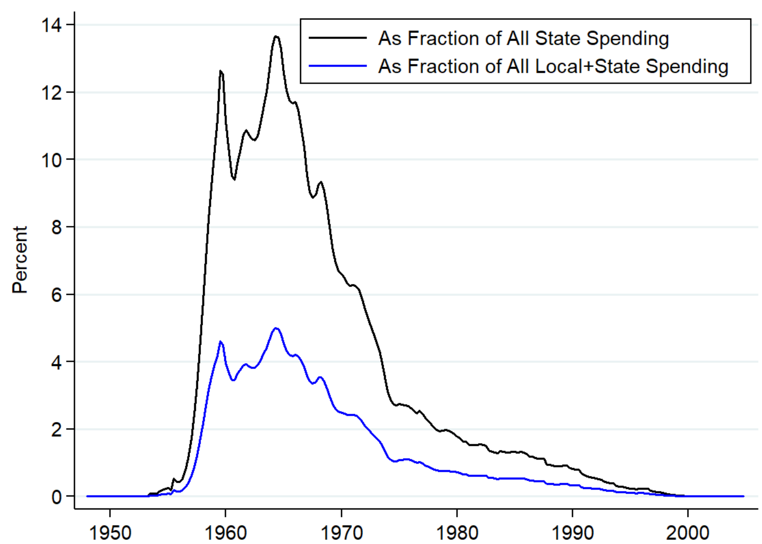


Table 2 provides estimates of the 15-year multiplier with and without population weights, for different spending measures. The results illustrate both the importance of weighting and of using a broad measure of spending. If one only uses IHS spending, and does not weight by population, the estimate is equal to 10.5, the estimate decreases to 6.8 if all state spending is considered, and to 4.2 if all local and state spending is taken into account. Moreover, when population weights are employed the estimate decreases considerably, suggesting that states with less population gain more from highway construction. For the IHS spending measure the multiplier is equal to 7.3, for state spending 2.5, and for local and state spending 1.7. Since the interest lies in a nationally representative multiplier the weighted version is preferred. Moreover, the fact that the multiplier estimate decreases as broader spending measures are considered is a clear indication of the presence of spending crowd-in. Therefore the 1.7 multiplier estimate is the preferred one.

Table 2: IV-GMM estimates of the 15-year multiplier

Spending Measure		**Without Weights**	**With Weights**
IHS	$\hat{\mu}$	10.52***	7.30***
	$\hat{se}(\hat{\mu})$	(1.15)	(0.89)
	Hansen's J	{0.16}	{0.85}
	R^2	[0.59]	[0.68]
State	$\hat{\mu}$	6.76***	2.52***
	$\hat{se}(\hat{\mu})$	(0.58)	(0.56)
	Hansen's J	{0.08}	{0.49}
	R^2	[0.58]	[0.72]
Local + State	$\hat{\mu}$	4.20***	1.70***
	$\hat{se}(\hat{\mu})$	(0.39)	(0.32)
	Hansen's J	{0.83}	{0.89}
	R^2	[0.66]	[0.74]

Notes: Robust SEs in parentheses, Hansen's J overidentification test P-Value in braces, R^2 in brackets. SEs are robust with respect to heteroskedasticity and autocorrelation. Each estimate is based on a regression with a sample size of 7,776 observations.

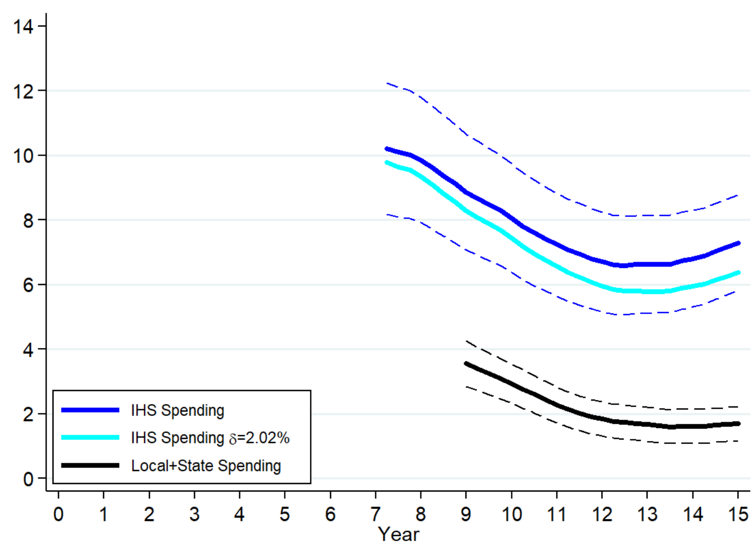
Figure 7 shows the estimated relative multiplier at different horizons for the IHS and the state and local spending measures. For the IHS spending measure, an additional estimate that takes into account a 2.02% depreciation rate of highways is estimated (BEA, 2003).[23] The figure only shows the multiplier starting at the quarter when the 10% level threshold for weak instruments is reached (see figure 8).

Figure 7 suggests a downward sloping behavior of the multiplier until year 12. This may be a consequence of agents anticipating future spending, and

[23]An advantage of the other spending measures is that depreciation is already taken into account by the estimate. As suggested by the IIRFs, considering broader measures of spending decreases the estimate of the multiplier considerably.

taking advantage of business opportunities. For example, by opening a motel or restaurant where a highway is supposed to go through. Starting in year 12 the broader spending measure delivers a fairly constant estimate of the multiplier, whereas the IHS spending measure begins to increase. This suggests that starting around year 12 IHS spending is not increasing too much, but other local and state spending is.

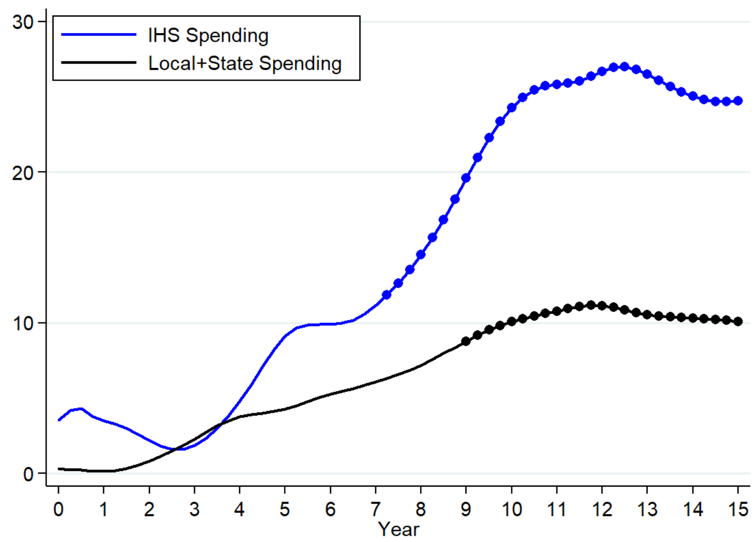
Figure 7: Estimated Multiplier with Different Spending Measures



Notes: Dashed lines correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,776.

By definition, the news-shock only informs about future funding taking place, and does not assign any funds immediately. Even after time passes, and funds are assigned, it still takes time between a state obligates funds and the highway is constructed (which is when expenditure takes place). This situation means that the multiplier can't be accurately estimated during the first few quarters that follow the shock due to the instrument irrelevance. However, as the horizon increases the instrument goes from irrelevant to weak, and then from weak to strong. This dynamic can be seen in figure 8, which plots the Kleibergen-Paap Wald F-statistic for the IHS spending and state and local spending measures. Given the serial correlation of the error term, the statistic is compared to thresholds derived by work from Montiel Olea and Pflueger

Figure 8: Instrument Relevance: Kleibergen-Paap Wald F-statistic



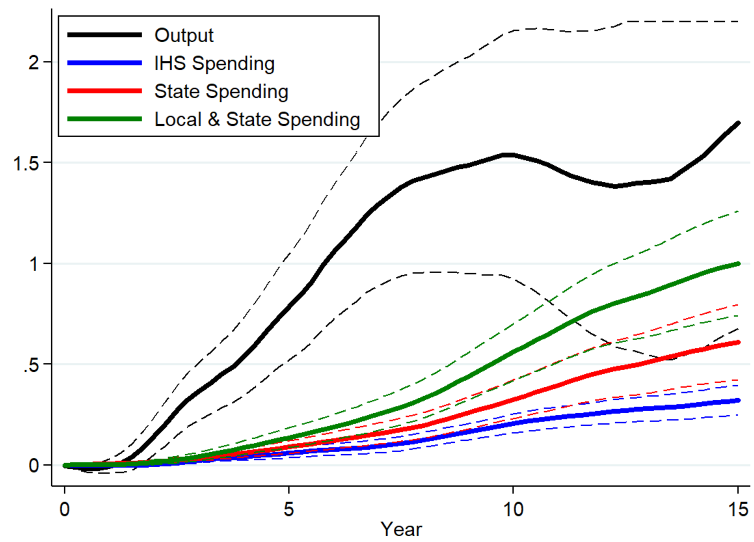
Note: First stage F-statistic computed using Newey-West standard errors. Round dots denote horizons where weak instruments are rejected at the 10% level using the Montiel-Olea & Pflueger (2013) test.

(2013). As can be noted from the figure, at the 10% level the instrument stops being weak starting at year 9 (for local and state spending).

Figure 9 shows the IIRFs of a news-shock on output[24] and the three measures of spending. The figure is normalized such that state and local spending increases by 1 USD 15 year after the shock. For each of the three spending measures, and each horizon, an estimate of the multiplier may be calculated by dividing the point estimate of the IIRF of output over that of spending. For example, at the 15 year horizon the estimate of the multiplier based on local and state spending is 1.7. Moreover, the plot suggests that for each USD spent in the IHS: (1) State expenditures increased \$0.90 more, and (2) Local expenditures increased \$1.20 more. These results are evidence of high spending crowd-in originating from highway construction, and illustrate how by not considering other spending one may overestimate the returns to highway spending.

[24]Control variables change for each spending measure, therefore the IIRF on output marginally changes as well. All IIRFs on output are not statistically different, and they are visually very similar. Therefore, I only plot one of these IIRF for simplicity. I plot the one that uses all local and state spending controls.

Figure 9: Integral of IRFs



Notes: Dashed lines correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,776. The IIRF on output is from the regression with all local and state spending controls.

5.2 The spending basket and how it is financed

So far the results suggest large crowd-in effects from the IHS on other spending categories. This raises the question of what other types of spending are increasing? Let $w_{i,t}$ denote the spending category of interest. To study the effect of the news-shock on $w_{i,t}$ I include it as an endogenous variable in my baseline specification (one category at a time).[25] Then, I look into the coefficient on z_{itH} when $\sum_{h=0}^{H} w_{i,t+h}$ is the dependent variable (this is a new first-stage regression). The results, which are normalized by having spending increase 1 USD 15 years after the shock, are plotted in figures 10, and 11.

Figure 10 shows the spending categories that are more impacted by the news-shock. Panel A shows their evolution over the 15 year period, and panel B shows the cumulative effect over a 15 year period. After 15 years, I find that a 1 USD increase in local and state spending is explained: (1) 35% by spending in education; (2) 32% by spending in the IHS; (3) 18% by spending in other

[25] I also include any relevant control variables based on lags of $w_{i,t}$ in the specification.

highways and roads; (4) 8% by spending in financial administration; (5) 5% by spending in health and hospitals; and 2% by spending in other categories. In contrast, figure 11 shows spending categories that do not seem to be affected by the news-shock: police, sewerage, fire protection, libraries, and parks and recreation.

To finance the 1 USD increase in spending, state and local revenue also must have increased by 1 USD following the news-shock. The effect of the news-shock on income categories is explored in figures 12, and 13.

Figure 12 shows the revenue categories that are more impacted by the news-shock. Panel A shows their evolution over the 15 year period, and panel B shows the cumulative effect over a 15 year period. After 15 years, I find that a 1 USD increase in local and state spending is explained: (1) 28% by intergovernmental revenue from the federal government for IHS construction; (2) 14% by other types of intergovernmental revenue; (3) 19% by an increase in property taxes; (4) 14% by income taxes; (5) 12% by other types of taxes; and (6) 13% by other sources. In contrast, figure 13 shows a couple of categories that do not seem to be affected by the news-shock: motor fuels tax (collected by the state or local governments), liquor revenue, license taxes, and sales taxes. The increase in property taxes suggests that home values increase due to the increased spending.[26]

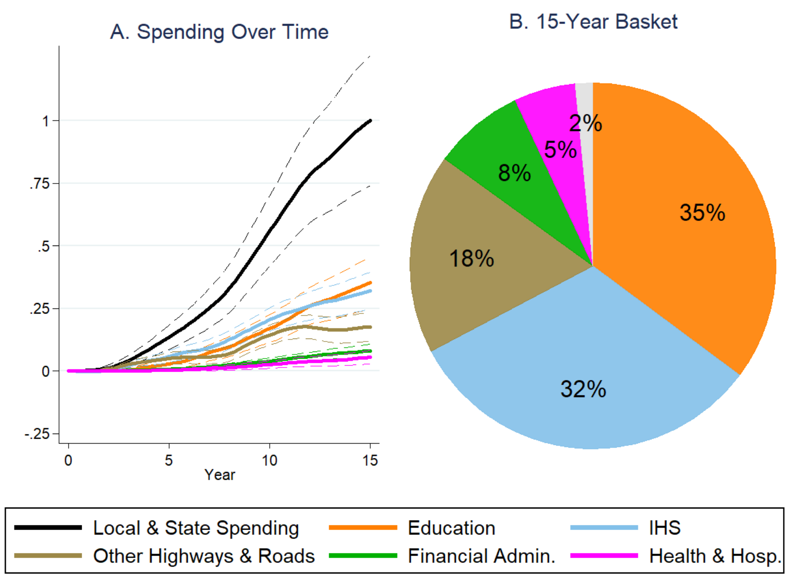
5.3 Robustness Checks

5.3.1 Testing Shock Anticipation

To confirm whether the proposed timing of the shock is adequate, I test anticipation effects by checking if the news-shock has any impact on lagged output, or lagged spending. To do this, I run the reduced form and first stage regressions (steps 1 and 2 of the three-step method of subsection 4.3) using $\frac{Y_{i,t-p} - Y_{i,t-4}}{Y_{i,t-4}}$ and $\frac{G_{i,t-p} - G_{i,t-4}}{Y_{i,t-4}}$ for $p = 0$ to 3 as dependent variables. Control variables are lagged 3 quarters for consistency. As in the preferred spec-

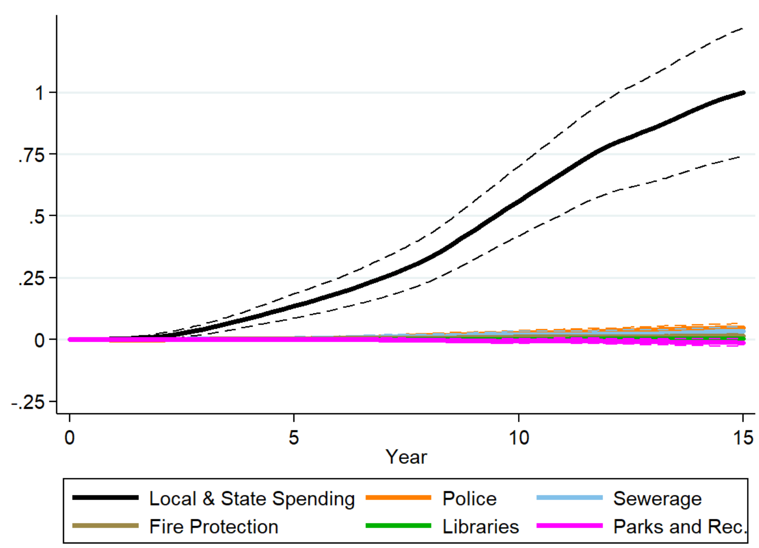
[26]In a recent study, McIntosh et al. (2018) finds that infrastructure investment in poor low-income urban neighborhoods in Mexico lead to real estate value to increase in 2 USD for every USD invested.

Figure 10: Integral of IRFs



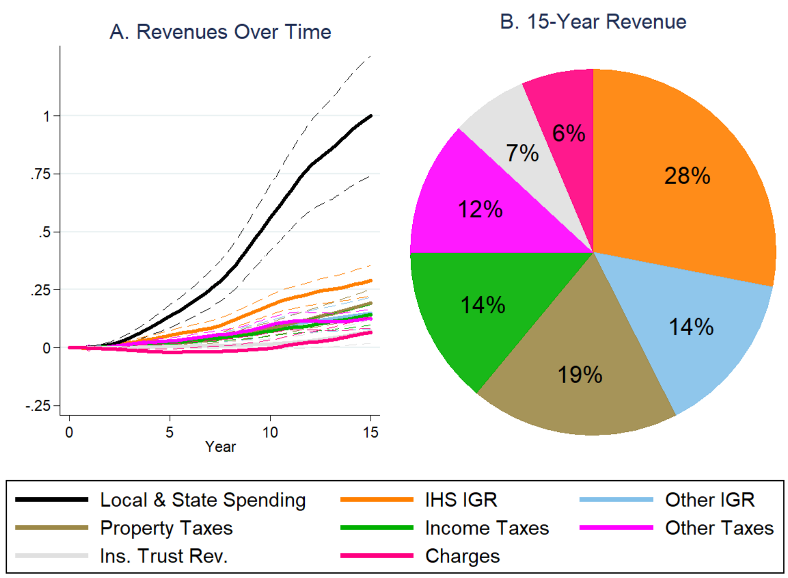
Notes: Dashed lines correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,776.

Figure 11: Integral of IRFs



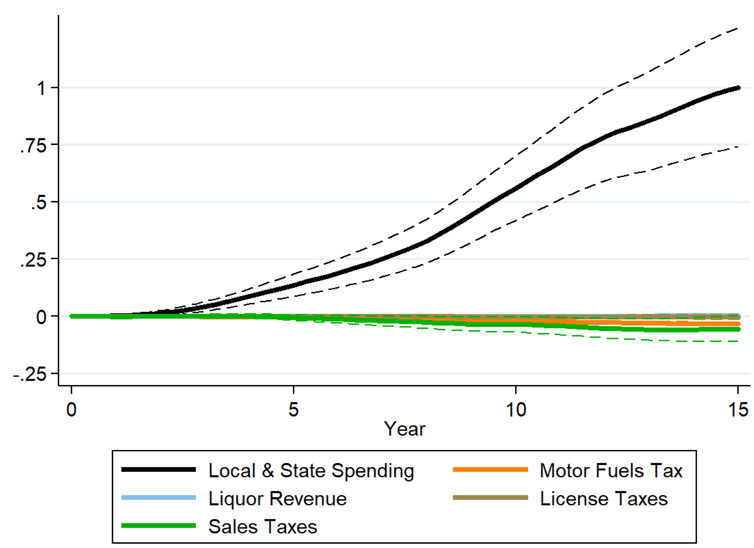
Notes: Dashed lines correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,776.

Figure 12: Integral of IRFs



Notes: Dashed lines correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,776.

Figure 13: Integral of IRFs

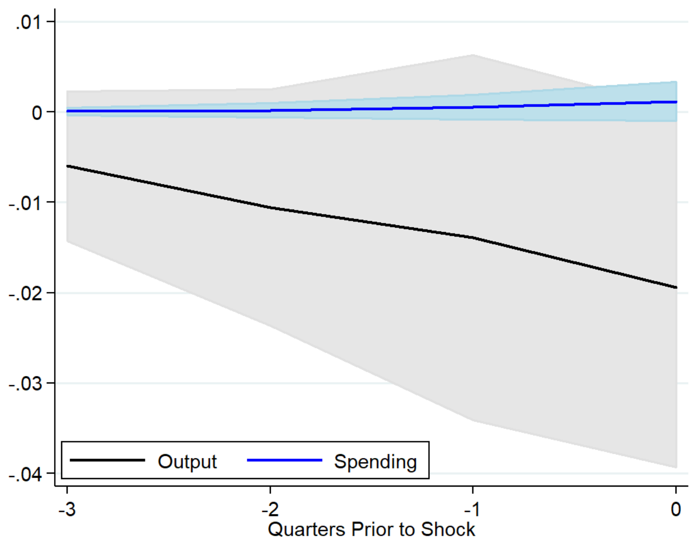


Notes: Dashed lines correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,776.

ification, the measure of G used corresponds to all local and state spending. Notice that for $p = 0$ the specification is similar to the initial horizon of section 5.1 (with the only difference being the additional lags in the controls).[27]

The IRFs, plotted in figure 14, show no significant anticipation effects. Note that for ease of interpretation, the scale of the shock is adjusted just as in the baseline specification.

Figure 14: IRFs Testing Shock Anticipation



Notes: Shaded areas correspond to 90% confidence intervals. Each estimate is based on a regression with a sample size of 7,632: N=48 and T=159 (1954:Q1-1993:Q3).

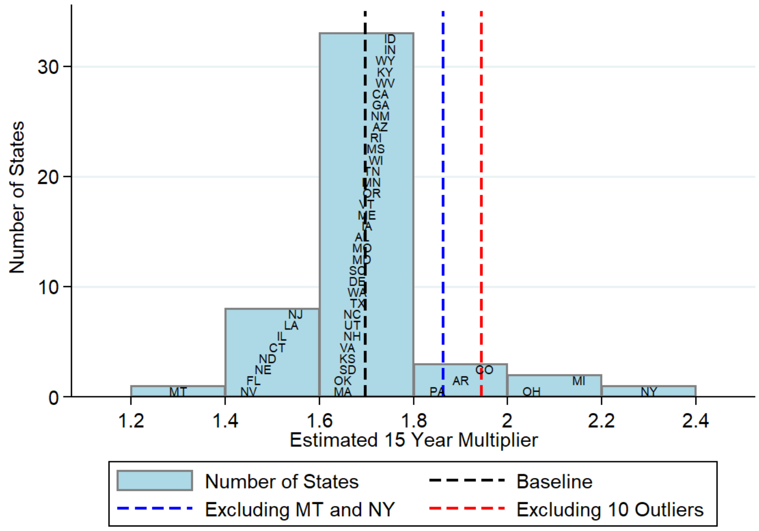
5.3.2 Testing for Outliers

To evaluate whether some state is leading the results, I re-estimate the 15-year multiplier 48 times, each time excluding one of the 48 states. The results presented in Figure 15 suggest a balanced amount of positive and negative outliers. For example, excluding Montana lowers the estimate of the multiplier to 1.34, while excluding New York raises it to 2.26. If both of these states are excluded, then an estimate of 1.88 is obtained. If the five highest positive

[27]In constructing the news-shock, the general rule was to set the timing to 1 quarter before the public law was passed. Therefore looking at $p = 0$ to 3 looks at any possible anticipation starting 1 year before the public law was passed.

outliers and the five highest negative outliers are excluded, then the multiplier jumps to 1.95.

Figure 15: Outlier Analysis



Note: Excluding states whose codes are placed further to the right leads to a higher estimate of the 15-year multiplier.

6 The Aggregate Multiplier

This section presents evidence on the aggregate multiplier, and its relation to the relative multiplier for the case of highway spending. First, empirical evidence is presented. Surprisingly, the results do not suggest significant spillovers across states from increased spending. However, instrument relevance is weak here, so results should be interpreted with caution. Secondly, I use the neoclassical model in a multi-region setting to study the link between the aggregate and the relative multiplier. Here, the results suggest that the relative multiplier is a lower bound on the aggregate multiplier, but that they are actually very similar.

6.1 Estimating spillovers

Following Dupor & Guerrero (2017), this subsection examines whether output in state i can be affected by highway spending from state j. As explained by these authors, by accounting for interstate spillovers one can obtain an estimate of the multiplier that is presumably close to the aggregate effect. The idea is that the aggregate multiplier (μ^A) and the relative multiplier (μ^R) are related by the following formula:

$$\mu^A = \mu^R + \text{Spillovers}$$

Initially, I restrict my attention to the case where states i and j share a border since spillovers should be bigger between neighboring states. Let N_i be the set of states that share a border with i (alternatively one could let it be a set that includes all states except for i). The variables $\lambda_{i,t}^{(A)}$, $\lambda_{i,t}^{(P)}$, and $\Lambda_{i,t}$ are defined as:

$$\lambda_{i,t}^{(P)} = \frac{\sum_{j \in N_i} \left[\phi_{it}^{(P)} Y_{j,t-1}\right]}{Y_{i,t-1}} \tag{4}$$

$$\lambda_{i,t}^{(A)} = \frac{\sum_{j \in N_i} \left[\phi_{it}^{(A)} Y_{j,t-1}\right]}{Y_{i,t-1}} \tag{5}$$

$$\Lambda_{i,t+h} = \frac{\sum_{j \in N_i} [G_{j,t+h} - G_{j,t-1}]}{Y_{i,t-1}} \tag{6}$$

$\lambda_{i,t}^{(P)}$ is the news-shock that informs about future IHS spending increasing in states contiguous to i using population shares, $\lambda_{i,t}^{(A)}$ is similar but uses area shares instead, and $\Lambda_{i,t+h}$ captures the actual change in IHS spending in the same states. The idea is to add $\sum_{h=0}^{H} \Lambda_{i,t+h}$ as an endogenous variable, and use $\lambda_{i,t}^{(P)}$ and $\lambda_{i,t}^{(A)}$ as additional instruments. To be consistent, I also add controls based on lags of $\Lambda_{i,t}$ to the specification (the same set of controls that were added for the endogenous variable $g_{i,t}$, as explained in subsection 4.4). The new second stage equation is:

$$\sum_{h=0}^{H} y_{i,t+h} = \mu_H \sum_{h=0}^{H} g_{i,t+h} + \nu_H \sum_{h=0}^{H} \Lambda_{i,t+h} + \boldsymbol{\psi_H x_{it}} + \varepsilon_{it}^{(H)} \tag{7}$$

where μ_H is the dynamic multiplier and ν_H is the interstate spillover.

Table 3 provides estimates of the 15-year multiplier with different assumptions about the spillover term. Column (1) gives the preferred estimate of the relative multiplier from subsection 5.1. Column (2) adds neighbor's spending into the equation. Even though this additional term is not significant, it has a big effect on the estimate of the relative multiplier. Adding up the new estimate of the relative multiplier, and the spillover term delivers a total multiplier of 2.87. In column (3) every state except i is added up into the spillover term. Again, the spillover itself is not significant, and in this case the total multiplier is estimated at 2.06. Results of the second and third columns should be interpreted with caution, since: (a) the high time-series correlation between the shocks across states makes it hard to distinguish between the relative multiplier and the spillover effect, and (b) instrument relevance is weak. That being said, the inclusion of the spillover term seems to indicate that the aggregate multiplier is probably bigger, if not equal, to the relative multiplier.

Table 3: 15-year multiplier with spillovers terms

	(1)	(2)	(3)
Own G	1.70***	3.32***	2.07***
	(0.32)	(0.49)	(0.41)
Neigh. G		-0.44	
		(0.30)	
All other G			-.01
			(.01)
Total Multiplier	1.70***	2.87***	2.06***
	(0.32)	(0.45)	(0.40)
Kleibergen-Paap F	10.09	1.57	3.89
N	7776	7776	7776

6.2 Model

What channels lead transportation spending to have a multiplier of about 1.7? And, if we know the relative multiplier, what can we say about the aggregate multiplier? As noted in section 1, the relation between the two is not obvious and will depend on several factors. Here I study highway investment in a setting where productive government spending reduces transportation costs within and between regions. Usually, models assume that productive spending should enter the production function directly. However, for the case of highway spending it seems more sensible to model it as reducing transportation costs (Donaldson, 2018).

By feeding different types of infrastructure shocks, I estimate the relative and aggregate multiplier predicted by the model. The results suggest that, for the case of highway spending, the relative multiplier is a lower bound on the aggregate multiplier. When all the economy increases its highway stock, each state faces higher external demand, which is met by increasing private capital.

6.3 Setup

The model consists of an economy with 2 regions: ”home” and ”foreign”. The home region is meant to represent one state in the U.S., and the foreign region all other states. While population in the economy is normalized to 1, the home region’s population share is equal to n (which is calibrated to equal 2%).

Market structure, preferences and firm behavior take the same form in both regions. Additionally, the federal government sets the level of productive spending by taxing consumption and may choose to reallocate resources from one region to another. Taxes are levied on consumption goods to mimic the fact that the Highway Trust Fund collects taxes on gasoline, along with other excise taxes.

Each region produces one tradable good which can be used in consumption, investment, or government spending. While consumption and investment in each region are composites of the local and foreign good, government spending only requires the locally produced good. In equilibrium, the tradable goods produced in the home region Y_t, and foreign region Y_t^* must satisfy:

$$Y_t = \kappa_{H,H}\left(C_{Ht} + I_{Ht} + G_{Ht}\right) + \kappa_{H,F}\left(C_{Ht}^* + I_{Ht}^*\right) \tag{8}$$

$$Y_t^* = \kappa_{F,F}\left(C_{Ft}^* + I_{Ft}^* + G_{Ft}^*\right) + \kappa_{F,H}\left(C_{Ft} + I_{Ft}\right) \tag{9}$$

where $\kappa_{i,j} \geq 1$ is the iceberg cost of shipping a tradable good from i to j; C_{Ht} and C_{Ht}^* denote home and foreign consumption of the home-produced good, respectively; I_{Ht} and I_{Ht}^* denote home and foreign private gross investment of the home-produced good, respectively; and G_{Ht} denotes home government spending of the home-produced good. All other variables with an F subscript are defined analogously for the case of the foreign produced good. Throughout the model, the superscript "$*$" is used to denote an analogous foreign variable when needed.

My results are based on comparing steady states equilibria before and after a permanent spending shock. To estimate the relative multiplier, I assume that productive spending goes up in the home region. This situation leads $\kappa_{H,H}$ to decrease, while $\kappa_{F,F}$ remains unchanged. Then, to recreate a situation where the aggregate multiplier can be estimated I assume spending goes up in both regions. In such a case transportation costs decrease in both regions.

6.4 Households

The maximization problem of a "home household" and a "foreign household" are analogous, therefore I only present the home household's problem. For some variable, lower case letters indicate per household (or per capita) amounts.

All home households are homogeneous; each owns some capital k_t, an equal share of the home firm, and is endowed with 1 unit of time. In each period, a home household must choose how much to consume, work and invest in capital in order to maximize its utility, given by:

$$\sum_{t=0}^{\infty} \beta^t \left[\log(c_t) - \chi \frac{l_t^{1+1/\nu}}{1+1/\nu} \right] \tag{10}$$

where β is the household's discount factor, c_t is a composite consumption good, and $l_t \in [0,1]$ is household's labor supply. The parameter ν is the Frisch-elasticity of labor supply, and χ is a preference parameter that determines the relative preference between consumption and leisure. In the utility specification, consumption and labor enter separably, therefore they are neither complements nor substitutes.

The composite consumption good in equation 10 is given by the following CES aggregator:

$$c_t = \left[\phi_H^{1/\eta} c_{Ht}^{\frac{\eta-1}{\eta}} + \phi_F^{1/\eta} c_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{11}$$

where ϕ_H and ϕ_F are preference parameters that dictate the relative preference between home and foreign goods, and η is the elasticity of substitution between home and foreign goods. For analytic convenience I normalize $\phi_H + \phi_F = 1$. Then, having $\phi_H > n$ implies home bias.

For $i = \{H, F\}$, a home household wishing to consume 1 unit of c_{it} must pay $(1+\tau_t)\kappa_{i,H} q_{it}$; where τ_t is the home's region consumption tax rate, q_{Ht} is the price charged by the home firm, and q_{Ft} is the price charged by the foreign firm. For home consumption, I denote the price before tax as $p_{it} \equiv \kappa_{i,H} q_{it}$. Home households optimally choose to minimize the cost of attaining the level of consumption c_t. The solution is an ideal price index P_t and demand curves for $c_{H,t}$ and $c_{F,t}$:

$$P_t = \left[\phi_H p_{Ht}^{1-\eta} + \phi_F p_{Ft}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{12}$$

$$c_{H,t} = \phi_H c_t \left(\frac{p_{Ht}}{P_t}\right)^{-\eta} \qquad \text{and} \qquad c_{F,t} = \phi_F c_t \left(\frac{p_{Ft}}{P_t}\right)^{-\eta} \tag{13}$$

Each home household rents its capital stock k_t to the home firm at a rental rate r_t. The private capital law of motion is given by:

$$k_{t+1} = (1-\delta_K)k_t + i_t \tag{14}$$

where δ_K is the depreciation rate, and i_t is gross investment. I assume that, as with consumption, gross investment is a CES composite of home and foreign tradable goods with identical parameters:

$$i_t = \left[\phi_H^{1/\eta} i_{Ht}^{\frac{\eta-1}{\eta}} + \phi_F^{1/\eta} i_{Ft}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{15}$$

The individual flow budget constraint for a home household is therefore:

$$P_t c_t(1+\tau_t) + P_t i_t \leq w_t l_t + r_t k_t + \pi_t \tag{16}$$

where P_t is the ideal price index of the home region (it gives the minimum price of consuming one unit of c_t or i_t), w_t is the wage rate, and π_t is the home firm's profits distributed to each home household.

The optimal choice between current and future consumption leads to the following Euler consumption equation:

$$\frac{1}{c_t(1+\tau_t)} = \frac{1}{c_{t+1}(1+\tau_{t+1})}\beta\left(\frac{r_{t+1}}{P_{t+1}} + 1 - \delta_K\right) \tag{17}$$

and the optimal choice between current consumption and current labor supply leads to the following labor supply equation:

$$w_t = \chi P_t c_t (1+\tau_t) l_t^{1/\nu} \tag{18}$$

6.5 Firms

Each region has a representative firm operating in a perfectly competitive industry. As with households, the maximization problem of the representative ”home firm” and the representative ”foreign firm” are analogous, so I only present the home firm’s problem.

There are two inputs to home production, home labor L and home private capital K. Both labor and capital are fixed across regions. Production takes a Cobb-Douglas form with total factor productivity given by A, constant returns to scale, and a share of private capital in production equal to α. Therefore, home production is equal to $Y_t = AK_t^{\alpha} L_t^{1-\alpha}$ and the home firm’s problem is:

$$\max_{K_t, L_t} q_{Ht} Y_t - w_t L_t - r_t K_t \tag{19}$$

which leads to the following efficiency conditions:

$$r_t = q_{Ht} Y_t \left(\frac{\alpha}{K_t} \right) \qquad \text{and} \qquad w_t = q_{Ht} Y_t \left(\frac{1-\alpha}{L_t} \right) \tag{20}$$

Plugging the efficiency conditions of equation 20 into the objective function leads to the equilibrium level of profits, which is zero.

6.6 Government & Transportation Costs

The federal government sets a level of productive spending G_t and G_t^* in the home and foreign regions, respectively. Productive spending takes the form of investment in highways, which depreciate at rate δ_H. In each region, the public capital law of motion is given by:

$$H_{t+1} = (1-\delta_H) H_t + G_t \qquad \text{and} \qquad H_{t+1}^* = (1-\delta_H) H_t^* + G_t^* \tag{21}$$

where H_t is the stock of highways in period t at the home region, and H_t^* is defined analogously for the foreign region. I assume that government spending of region i only requires the tradable good produced in that region, that is, $G_t = G_{Ht}$ and $G_t^* = G_{Ft}^*$.

To finance its spending, the federal government collects taxes $T \equiv P_t c_t \tau_t$ from the home region, and $T^* \equiv P_t^* c_t^* \tau_t^*$ from the foreign region. Moreover, each period the federal government runs a balanced budget, so:

$$p_{Ht} G_t + p_{Ft}^* G_t^* = P_t c_t \tau_t + P_t^* c_t^* \tau_t^* \tag{22}$$

The federal government can also choose to reallocate resources from one region to another. I denote regional aid to the home region as $Aid = p_{Ht} G_t - P_t c_t \tau_t$, and to the foreign region as $Aid^* = p_{Ft}^* G_t^* - P_t^* c_t^* \tau_t^*$. The balanced budget requirement of equation 22 then leads to $Aid + Aid^* = 0$.

Regarding transportation costs, I assume that $\kappa_{i,i} > 1$, and $\kappa_{i,j} = \kappa_{i,i} \kappa_{j,j}$. This implies that $\kappa_{H,F} = \kappa_{F,H}$. The size of $\kappa_{i,i}$ is meant to capture the resources needed to transport the tradable goods within region i, and will be a function of the region's land area and the highway stock available inside the region, i.e., $\kappa_{i,i}(H_i, Area_i)$. While highway stocks are chosen by the federal government, each region's area is assumed to be proportional to its population share. The assumptions imply that increasing H_i decreases $\kappa_{i,i}$, $\kappa_{i,j}$, and $\kappa_{j,i}$, but that it does not affect $\kappa_{j,j}$.

6.7 Calibration

For consistency with the empirical part of the paper, the model is calibrated using a quarterly frequency. A summary of the calibrated parameters is shown in table 4, and of the targeted moments in 5. Most of the parameters in the model are common in the literature, and only few require calculations. The asymmetry in population size across regions implies that $\kappa_{H,H} \neq \kappa_{F,F}$, and $\phi_H \neq \phi_H^*$ (as there is also home bias). In order to calibrate some of the foreign regions' parameters I assume that the economy starts from a symmetric equilibrium.

Table 4: Calibration of Parameters

(Quarterly Frequency)

Description		Parameter	Value	Source / Target
Home Size		n	0.020	Approx. 1/48
Discount Factor		β	0.984	King & Rebelo (1999)
Leisure-Consumption Pref.		χ	20.94	$l = l^* = 0.2$
Frisch-elasticity		ν	1.000	Nakamura & Steinson (2014)
Elast. of Subst.		η	2.000	Nakamura & Steinson (2014)
Home Pref. of Home Goods		ϕ_H	0.0310	Home bias = 55%
Foreign Pref. of Foreign Goods		ϕ_F^*	0.9803	Pre-shock symmetry conditions
TFP		A	1.000	Normalization
Share of private capital		α	0.330	King & Rebelo (1999)
Private capital depreciation rate		δ_K	0.025	King & Rebelo (1999)
Highways depreciation rate		δ_H	0.005	BEA (2003)
Transportation Costs	Before IHS	$\kappa_{H,H}$	1.0165	Relative Multiplier = 1.70
		$\kappa_{F,F}$	1.5217	Pre-shock symmetry conditions
	After IHS	$\kappa_{H,H}$	1.0109	1 hour drive, Allen & Arkolakis (2016)
		$\kappa_{F,F}$	1.5133	After-shock symmetry condition

The population share of the home region is set at $n = 2\%$; this is approximately equal to $1/48$ where 48 is the number of contiguous states in the U.S. As in King & Rebelo (1999): $\beta = 0.984$, $\alpha = 0.33$, and $\delta_K = 2.5\%$. I calibrate χ to have labor per household equal 0.2 (similar to Baxter & King, 1993; and King & Rebelo, 1999). This method leads to $\chi = 20.94$. As is standard in macroeconomics, I let $\nu = 1$ and $\eta = 2$ (see Nakamura & Steinson, 2014). The BEA (2003) estimates highway depreciation to be around 2% annually, so in quarterly frequency $\delta_H = 0.005$. I also normalize $A = 1$.

To calibrate ϕ_H, I use Hillberry & Hummels' (2003) home bias estimate of 55%. The estimate implies that, once transportation costs are controlled for, states still purchase 55% more of their own production. In the model, this translates to:

$$\left.\frac{C_H}{n(C_H + C_F)}\right|_{\tau_{i,i}=1\ \forall\ i} = 1.55 \tag{23}$$

Starting from a symmetric equilibrium where $p_{Ht} = p_{Ft}$, equation 23 becomes $\phi_H/n = 1.55$. This leads to $\phi_H = 0.031$ and $\phi_F = 0.969$.

Some of the most important parameters in the model are the iceberg costs. Let $\kappa_{i,i}^{(B)}$ and $\kappa_{i,i}^{(A)}$ denote the within transportation costs before and after construction of the IHS, respectively. To find the value of $\kappa_{H,H}^{(A)}$, I do a calculation based on Allen & Arkolakis (2016), who use data from the Commodity Flow Survey of 2012. They estimate $\kappa_{ij} = \exp(\theta * H_{ij})$, where H_{ij} are the hours it takes to travel from i to j, and find $\hat{\theta} = 0.0108$. The average land area of a contiguous U.S. state is 61,558 thousand square miles. Assuming states have the shape of a circle, this leads to a radius of 140 miles. I assume that, within a state, the tradable good must travel in average half of that radius, i.e. 70 miles. Speed limits in the interstate range between 65 and 85 miles per hour. Then, assuming an average speed of 70 miles per hour, the tradable good can be transported in 1 hour within the home region. This leads to $\kappa_{H,H}^{(A)} = 1.0109$.

I find $\kappa_{H,H}^{(B)}$ by matching the relative multiplier of 1.7 estimated in section 5 to the one implied by the model. This leads to an estimate of $\kappa_{H,H}^{(B)} = 1.0165$. Using the equation from Allen & Arkolakis (2016), this transaction cost implies that, before the IHS, a 70 mile drive took on average 1.52 hours (31 minutes more).

Calibration of $\kappa_{F,F}^{(B)}$ and ϕ_F^* is done by imposing initial symmetry in the economy, i.e., I require that initially $p_H = p_F$, $P = P^*$, $c = c^*$ and $n = (C_H + C_H^*)/(C_H + C_H^* + C_F + C_F^*)$. The last condition means that overall demand for home products as a fraction of overall demand for all products should be equal to the size of the home population relative to the total population of the economy. This same symmetry condition method is used by Nakamura & Steinson (2014) in a simpler case with no transportation costs. This leads to $\kappa_{F,F}^{(B)} = 1.5217$ and $\phi_F^* = 0.969$. Finally, calibration of $\kappa_{F,F}^{(A)}$ is done by requiring transportation costs to decrease symmetrically in both regions. This leads to $\kappa_{F,F}^{(A)} = 1.5133$.

Since government spending is required to rise in order to decrease the transportation costs, it is also important to match the steady state ratios $(G+G^*)/(Y+Y^*)$. To perform the calibration I use Table SF-4 of the highway statistics series, which has information on disbursements for state administered highways.[28] By dividing these disbursements by nominal GDP, I find that between 1948 and 1952 the ratio was between 0.19% and 0.20%. Between 1989 and 1993, the ratio was between 0.19% and 0.22%. While the IHS was under construction, the economy grew due to a large number of factors, meaning that the 1989-1993 ratios just provide a lower bound on what we should observe in the model. I calibrate the initial value of G/Y, and the increase in H, to match these moments.

Table 5: Moments Targeted

Moment		**Data**	**Model**
Relative Multiplier		1.70	1.70
Before IHS	$G/Y = G/^*Y^*$	$[0.19\%, 0.20\%]$	0.19%
After Aggregate Shock	$(G+G^*)/(Y+Y^*)$	Lower Bound of 0.19%	0.45%

[28] I consider the categories of maintenance, and safety funds.

6.8 Results

To simulate a situation where the relative multiplier can be estimated with the model, I let government spending rise only in the home region. This increase in G_t decreases $\kappa_{H,H}$, $\kappa_{H,F}$, and $\kappa_{F,H}$, but leaves $\kappa_{F,F}$ intact. I call this the "Relative Case". An important question is what share of this increase should be paid by the home region, and what share by the foreign region? I require the home region to pay for all of it. Since I am looking at steady state equilibria, I have to consider who pays for the depreciation of the new highway. In the interstate program each state pays gas taxes to the federal government, which depend on how much highways are used. These gas taxes are redistributed to states for maintenance by looking at the share of interstate miles in a state relative to all states. Therefore, a state ends up paying for its own depreciation, whether they realize it or not.

In addition to the IHS case, I create an aggregate shock counterfactual where I let G rise in both regions (I also require each region to pay for its spending). I call this the "Aggregate Case".

To calculate the relative multiplier (μ_R), and the aggregate multiplier (μ_A) I use the formulas:

$$\mu_R = \frac{Y_R - Y_0}{G_R - G_0} \text{ and } \mu_A = \frac{Y_A + Y_A^* - Y_0 - Y_0^*}{G_A + G_A^* - G_0 - G_0^*} \tag{24}$$

where the subscript 0 denotes the initial steady state, R denotes the "Relative Case" and A denotes the "Aggregate Case".

The results, summarized in table 6, suggest that the relative multiplier is very close, and a lower bound on the aggregate multiplier. The model suggests that if the relative multiplier is 1.70, then the aggregate multiplier is 1.73. An additional result is that small regions (in this case the home region), are more benefited by an aggregate shock that the whole economy. This may be visualized by the multiplier of 2.03 estimated exclusively for the Home region, in the aggregate shock case. This result goes in line with the notion that small economies benefit more from liberal trade policies.

In the relative shock case, spending decreases transportation costs at home,

Table 6: **Steady States Comparison by Type of Shock**

		Relative	Aggregate	
Level of Aggregation		Home	Home	Home + Foreign
Long-Run Multiplier		1.70	2.03	1.73
	Y	0.41	0.51	0.29
Per Cent Increase	**w**	0.36	0.51	0.35
From Initial	**K**	0.98	1.55	0.87
Steady State (%)	**G**	128	128	128
	C	0.57	1.23	0.55
	L	0.04	0.00	0.00
	$\mathbf{p_F/p_H}$	-0.02	0.06	0.06

which increases supply of the home-good. As a result, investment, consumption and government spending all increase. Rise in the home region's production leads to an increase in demand for both goods, and due to home-bias the price of the home good slightly rises. Private capital adjusts to take advantage of the higher demand for the home good, which leads to higher long-run output.

If productive spending increases everywhere something similar occurs in both regions, with the added advantages that inter-regional transportation costs go down and external demand goes up. This leads both regions to export more, which rises production even more. The model suggests that with transportation spending there is a positive spillover to other regions, which makes the aggregate multiplier slightly higher than the relative multiplier.

7 Conclusions

The Federal-Aid Highway Act of 1956 envisioned that completing the IHS would require 13 years of federal funds, and 28 billion dollars. However, both the cost and the construction time of the IHS were greatly underestimated. The system continued receiving funding until 1996 and cost 2.2 times its initial cost-estimate (inflation adjusted). Today, the IHS accounts for 25% of all distance traveled by vehicles, and is the most important system of highways in the U.S.

In this paper I show how to use news of future IHS spending, along with institutional knowledge, to construct a measure of exogenous IHS news-shocks. Then, I use the news-shocks as an instrument in an IV local projection framework and estimate a relative multiplier of 1.7. The external validity of the estimate has important limitations, so I simply refer to it as "the interstate multiplier". I expect this estimate to be more relevant for developing countries in the early stages of building their transportation infrastructure. Regarding the estimation of the multiplier, this paper makes the following contributions: (1) It combines the news-shock methodology with institutional knowledge specific to the IHS in order to tackle both endogeneity and anticipation concerns; and (2) It shows the importance of spending crowd-in in this context, and how by not considering the response of other types of spending one can easily overestimate the returns to highway spending.

My estimate of the multiplier is relatively higher than most estimates provided by the literature. This raises the question of what is driving the results? I argue that depending on its category, government spending can have very different effects on output. Most of the work estimating multipliers looks at fluctuations in military spending, which is likely to be less productive. There are not too many investment projects that can boost productivity as much as building an initial system of highways that connects a country. Today, with only 1% of the nation's road mileage, the IHS account for 25% of all distance traveled by vehicles in the U.S. A second interstate, or any other highway built today in the U.S., is likely to generate fewer productivity gains.

Finally, I study the relation between the relative and aggregate multiplier for the case of highway spending. I create a multi-region model where spending decreases transportation costs (motivated by Donaldson, 2018) and find that, for this type of spending, the relative multiplier is very close, and a lower bound, on the aggregate multiplier. Among the many effects present in the model, the decrease of inter-regional transportation costs and increase in external demand promote exports and production in both regions.

Bibliography

Allen, T., & Arkolakis, C. (2016). The welfare effects of transportation infrastructure improvements. *Manuscript, Dartmouth and Yale.*

Arezki, R., Ramey, V. A., & Sheng, L. (2017). News shocks in open economies: Evidence from giant oil discoveries. *The Quarterly Journal of Economics*, *132*(1), 103-155.

Barro, R. J. (1981). Output Effects of Government Purchases. *The Journal of Political Economy*, *89*, 1086-1121.

Barro, R. J., & Redlick, C. J. (2011). Macroeconomic effects from government purchases and taxes. *The Quarterly Journal of Economics*, *126*(1), 51-102.

Baxter, M., & King, R. G. (1993). Fiscal policy in general equilibrium. *The American Economic Review*, 315-334.

BEA (2003). Fixed Assets and Consumer Durable Goods in the United States, 1925–97. *US Department of Commerce*.

Blanchard, O., & Perotti, R. (2002). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. *The Quarterly Journal of economics*, *117*(4), 1329-1368.

Bloem, A., Dippelsman, R., & Mæhle, N. (2001). *Quarterly national accounts manual: concepts, data sources, and compilation.* International Monetary Fund.

CBO (2015). Public Spending on Transportation and Water Infrastructure, 1956 to 2014.

Chandra, A., & Thompson, E. (2000). Does public infrastructure affect economic activity?: Evidence from the rural interstate highway system. *Regional Science and Urban Economics*, *30*(4), 457-490.

Chodorow-Reich, G. (2017). *Geographic Cross-Sectional Fiscal Spending Multipliers: What Have We Learned?* (No. w23577). National Bureau of Economic Research.

Cox, W., & Love, J. (1998). *The best investment a nation ever made: A tribute to the Dwight D. Eisenhower system of interstate and defense highways.*

DIANE Publishing.

Eaton, J., & Kortum, S. (2002). Technology, geography, and trade. *Econometrica*, *70*(5), 1741-1779.

Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*, *108*(4-5), 899-934.

Dupor, B., & Guerrero, R. (2017). Local and aggregate fiscal policy multipliers. *Journal of Monetary Economics*, *92*, 16-30.

Hall, R. E. (1986). The Role of Consumption in Rconomic Fluctuations. *The American Business Cycle: Continuity and Change*. University of Chicago Press, 237-266.

Hall, R. E. (2009). By how much does GDP rise if the government buys more output? (No. w15496). *National Bureau of Economic Research*.

Hillberry, R., & Hummels, D. (2003). Intranational home bias: Some explanations. *Review of Economics and Statistics*, *85*(4), 1089-1092.

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. Stata Journal, 7(3), 281.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *The American Economic Review*, *95*(1), 161-182.

King, R., & Rebelo, S. (1999). Resuscitating real business cycles. *Handbook of macroeconomics*, *1*, 927-1007.

Kuttner, K. N. (2001). Monetary policy surprises and interest rates: Evidence from the Fed funds futures market. *Journal of Monetary Rconomics*, *47*(3), 523-544.

Leeper, E. M., Walker, T. B., & Yang, S. C. S. (2013). Fiscal foresight and information flows. *Econometrica*, *81*(3), 1115-1145.

Leduc, S., & Wilson, D. (2013). Roads to prosperity or bridges to nowhere? theory and evidence on the impact of public infrastructure investment. *NBER Macroeconomics Annual*, *27*(1), 89-142.

McIntosh, C., Alegría, T., Ordóñez, G., & Zenteno, R. (2018). The Neighborhood Impacts of Local Infrastructure Investment: Evidence from Urban Mexico. *American Economic Journal: Applied Economics*, *10*(3), 263-86.

Montiel Olea, J. L., & Pflueger, C. (2013). A robust test for weak instruments. *Journal of Business & Economic Statistics*, *31*(3), 358-369.

Nakamura, E., & Steinsson, J. (2014). Fiscal stimulus in a monetary union: Evidence from US regions. *American Economic Review*, *104*(3), 753-92.

Newey, W. K., & West, K. D. (1994). Automatic lag selection in covariance matrix estimation. *The Review of Economic Studies*, *61*(4), 631-653.

Owyang, M. T., Ramey, V. A., & Zubairy, S. (2013). Are government spending multipliers greater during periods of slack? Evidence from twentieth-century historical data. *The American Economic Review*, *103*(3), 129-134.

Pereira, A. M. (2000). Is all public capital created equal?. *Review of Economics and Statistics*, *82*(3), 513-518.

Ramey, V. A., & Shapiro, M. D. (1998). Costly capital reallocation and the effects of government spending. *Carnegie-Rochester Conference Series on Public Policy*, *48*, 145-194.

Ramey, V. A. (2011A). Identifying government spending shocks: it's all in the timing. *The Quarterly Journal of Economics*, *126*(1), 1-50.

Ramey, V. A. (2011B). Can Government Purchases Stimulate the Economy? *Journal of Economic Literature*, *49*(3), 673-685.

Ramey, V. A., & Zubairy, S. (2018). Government spending multipliers in good times and in bad: evidence from US historical data. *Journal of Political Economy*, 126(2), 850-901.

Ramey, V. A., (2018B). Ten Years after the Financial Crisis: What Have We Learned from the Renaissance in Fiscal Research? Prepared for the NBER Conference "Global Financial Crisis @10".

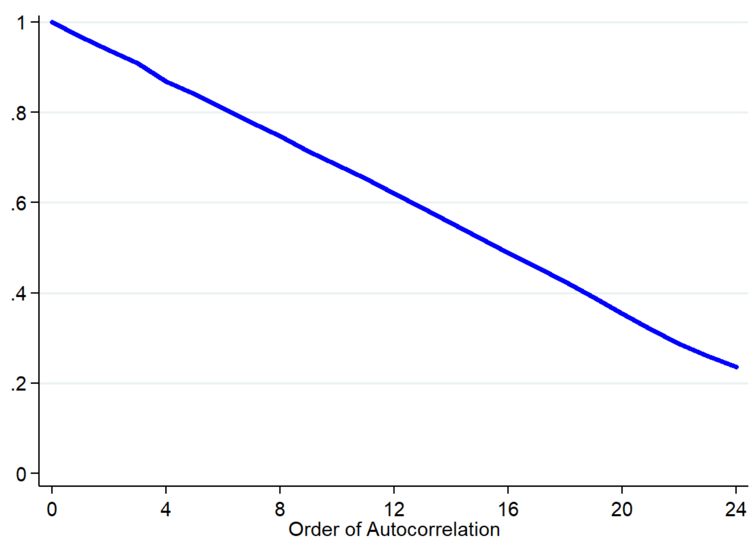
Rotemberg, J. J., & Woodford, M. (1992). Oligopolistic pricing and the effects of aggregate demand on economic activity. *Journal of political Economy*, *100*(6), 1153-1207.

A Appendix: Time-series and cross-sectional correlation

A.1 Time-series correlation for H=60

Analysis of the predicted residuals of equation 1 shows high autocorrelation (which is to be expected from a local projection framework). Using all 48 states, one can estimate 48 autocorrelation coefficients of the pth order $\hat{r}_{i,p} \equiv \hat{corr}(\hat{\varepsilon}_{i,t}, \hat{\varepsilon}_{i,t-p})$. The average of these, across i, is plotted in Figure 16 for different values of p. The figure shows a high degree of autocorrelation in the residuals.

Figure 16: Autocorrelation



A.2 Cross sectional correlation for H=60

Analysis of the predicted residuals from equation 1 suggests no cross-sectional correlation. Using all 48 states, one can obtain estimates of 1,128 pairwise cross-sectional correlation coefficients $\hat{\rho}_{ij} \equiv \hat{corr}(\hat{\varepsilon}_{it}, \hat{\varepsilon}_{jt})$ for $i \neq j$. The average of these is $\bar{\rho} = -0.0026$. Note that $\bar{\rho}$ being so close to zero provides some evidence of no cross-sectional correlation. More evidence is provided in Table 7, which presents results from 3 hypothesis tests based on the sufficient statistic $\bar{\rho}$: all tests suggest that there is no cross-sectional correlation in the residuals.

Table 7: Cross-Sectional Correlation Tests
H_o : No cross-sectional correlation

	P-Value	Reject if $\bar{\rho}$ is outside of For $\alpha = 5\%$	For $\alpha = 10\%$
Monte-Carlo $\phi = 0.99$	0.936	[-0.0152, 0.0396]	[-0.0142, 0.0265]
Monte-Carlo $\phi = 0.00$	0.286	[-0.0046, 0.0047]	[-0.0038, 0.0038]
Pesaran's CD test	0.268	[-0.0046, 0.0046]	[-0.0038, 0.0038]

Note: Monte-Carlo simulations based on $\varepsilon_{it} = \phi\varepsilon_{i,t-1} + u_{it}$, where $u_{it} \sim N(0, s^2)$.

The first two tests are based on Monte-Carlo simulations, where N=48 and T=162 (as in the data), and the third test is based on Pesaran's CD test-statistics, which relies on asymptotic theory. For reasons explained below, the favorite test is the Monte-Carlo with $\phi = 0.99$, where ϕ is the hypothesized 1st order auto-correlation in the residuals. The Monte-Carlo simulations are described below in more detail; however, it should be noted that the only difference between these is that the first allows for autocorrelation in the residuals, while the second does not. The second and third test provide almost identical conclusions; this is satisfactory and suggests that, for the case where $\phi = 0$, N=48 and T=162 are sufficiently large to apply asymptotic results.

While the three tests find no cross-sectional correlation, it is important to note that tests, such as the one by Pesaran, are prone to type-1 error when autocorrelation is present. To note this, consider the model used for the Monte-Carlo simulations: $\varepsilon_{it} = \phi\varepsilon_{i,t-1} + u_{it}$, where $u_{it} \sim N(0, s^2)$ (u_{it} is independent across the time and cross-section dimensions). The object of interest is the distribution of $\bar{\rho}$. By doing a Monte-Carlo simulation with 1,000 repetitions, I obtain such a distribution for different values of ϕ.[29] Table 8 shows relevant descriptive statistics from the distributions. The results suggest that as ϕ increases, the distribution of $\bar{\rho}$ becomes wider, skewed to the right, and develops fatter tails. Such a change in the shape of the distribution renders Pesaran's CD test, and other cross-sectional correlation tests inadequate when analyzing residuals with autocorrelation.

One disadvantage of a test based on $\bar{\rho}$ is that large and small values of $\hat{\rho}_{ij}$

[29]To match the data from section 5 I let $s^2 = 288^2 * (1 - \phi^2)$ (for $H = 60$, the average standard deviation of the residual across the 48 states is 288).

Table 8: Cross-Sectional Correlation Tests

H_o : No cross-sectional correlation

ϕ	Mean	St. Dev	Skewness	Kurtosis	5th Ptile	Median	95th Ptile
0.00	0.000	0.002	0.12	2.86	-0.004	-0.0001	0.004
0.50	0.000	0.003	0.33	3.09	-0.005	-0.0002	0.005
0.90	0.000	0.007	1.03	4.87	-0.009	-0.0010	0.012
0.95	-0.001	0.008	1.34	6.43	-0.011	-0.0022	0.015
0.99	0.000	0.014	2.29	11.39	-0.014	-0.0035	0.026

cancel out, so if there is a cluster with positive correlation and another one with negative correlation, on average it will appear as if there is no correlation. Therefore, it has been suggested that one should do tests based on the sufficient statistic $\bar{\rho}^{(2)}$, the average of $\hat{\rho}^2_{i,j}$. While $\bar{\rho}^{(2)} = 0.1837$ in the data, the Monte-Carlo simulation with $\phi = 0.99$ suggests that the mean of $\rho^{(2)}$ is 0.1848. The P-Value of the hypothesis test based on the Monte-Carlo with $\phi = 0.99$ is exactly 1.00.