Roads to Prosperity or Bridges to Nowhere?
Theory and Evidence on the Impact of Public Infrastructure Investment

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Abstract

We examine the dynamic macroeconomic effects of public infrastructure investment both theoretically and empirically, using a novel data set we compiled on various highway spending measures. Relying on the institutional design of federal grant distributions among states, we construct a measure of government highway spending shocks that captures revisions in expectations about future government investment. We find that shocks to federal highway funding has a positive effect on local GDP both on impact and after 6 to 8 years, with the impact effect coming from shocks during (local) recessions. The direct channel appears to stem from federal grants leading to increased state government spending, and we provide strong evidence of such a "flypaper effect."

Keywords: Fiscal Multiplier, Public Infrastructure, Implementation Lags, Highway Spending, Anticipation Effects

JEL Codes: H3, H54, E62

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I. Introduction

Public infrastructure investment often plays a prominent role in countercyclical fiscal policy. In the United States during the Great Depression, programs such as the Works Progress Administration and the Tennessee Valley Authority were key elements of the government's economic stimulus. In the Great Recession, government spending on "shovel-ready" infrastructure projects was a major component of the 2009 stimulus package. Yet, infrastructure's economic impact and how it varies with the business cycle remain subject to significant debate. Many view this form of government spending as little more than 'bridges to nowhere,' that is, spending yielding few economic benefits with large cost overruns and a wasteful use of resources. Others view public infrastructure investment as an effective form of government spending that can boost economic activity not only in the long run, but over shorter horizons as well through "shovel-ready" projects.

This paper provides both an empirical analysis, using a rich and novel new data set on highway spending, of the dynamic macroeconomic effects of infrastructure investment and a theoretical model to help interpret the results. We focus empirically on highway infrastructure both because it is the largest component of public infrastructure in the United States and because the institutional design underlying the geographic distribution of U.S. federal highway investment helps us identify shocks to local infrastructure spending. In particular, our empirical analysis exploits the formula-based mechanism by which nearly all federal highway funds are apportioned to state governments. Because the state-specific factors entering the apportionment formulas are often largely unrelated to current state economic conditions and also lagged several years, the formula-based distribution of federal highway grants provides an exogenous source of highway funding to states, independent of states' own economic conditions.

The focus on federal grants to states has the advantage of capturing much more precisely the timing with which highway spending affects economic activity. Public highway spending in the United States is ultimately determined by state governments, which allocate a large fraction of their revenues to highway construction, maintenance, and improvement.[1] However, states report highway spending using the concept of outlays and we show that outlays will often lag considerably the movements in actual government commitments (i.e., obligations) that give states the right to contract out and initiate projects.[2] Furthermore, there can be administrative delays between when a state's grants are initially announced and when the state starts incurring obligations. Using grants to measure the timing of highway spending shocks allows one to estimate possible economic effects stemming from agents' foresight of future government obligations and outlays, even before highway projects are initiated.

In addition, the design and distribution of federal highway spending helps us address concerns related to anticipation effects that are likely to arise in the case of large infrastructure projects. Because the U.S. Congress typically sets the total national amount of highway grants and the formulas by which they are apportioned to states many years in advance, there is strong reason to believe that economic agents (especially state governments and private contractors) can anticipate long in advance, albeit imperfectly, the eventual level of grants received by a given state in a given year. Such anticipation of future government spending has been shown by Ramey (2011a) to pose a serious hazard in correctly identifying spending shocks.

Using the institutional details of the mechanisms by which grants are apportioned to states, and very detailed data on state-level apportionments and national budget authorizations, we construct forecasts of current and future highway grants for each state and year between 1993 and 2009. These forecasts are constructed in much the same way that the Federal Highway Administration constructed forecasts of future highway grants to states at the beginning of the most recent multi-year appropriations act (which covered 2005-2009). From these forecasts, we calculate the expected present discounted value of current and future highway grants. The difference in expectations from last year to this year forms our measure of the shock to state highway spending. This shock is driven primarily by changes in incoming data on formula factors which, as mentioned above, reflect information on those factors from a number of years earlier (because of data collection lags).

[1] Local governments also spend a considerable amount on road spending, though the vast majority of that spending is on minor residential roads (according to FHWA statistics) that generally are not considered part of the nation's highway infrastructure.
[2] The theoretical implications of these bureaucratic "implementation lags" have been analyzed by Leeper et al. (2009) and others.

We exploit the variation of our shock measure across states and through time to examine its dynamic effect on different measures of economic activity by combining panel variation and panel econometric techniques with time-series techniques. Specifically, we extend Jorda (2005)'s local projections approach to estimating impulse response functions to allow for state and year fixed effects. We find that these highway spending shocks positively affect GDP at two specific horizons. There is a significant contemporaneous impact, with a multiplier of around 1.5 to 2.0. This effect is particularly noteworthy given the view by many that infrastructure spending is ill-suited to provide short-run stimulus because of long implementation delays. Although this initial impact dies off, we find a second-round effect of about the same magnitude around six to eight years out. This effect could come about as the impact of the increased public stock of capital materializes and boosts the productivity of private inputs.

We obtain the same pattern when we look at the additional outcomes of employment and personal income. Following Auerbach and Gorodnichenko (2011a), we extend the analysis to investigate whether highway spending shocks occurring during recessions lead to a different impulse response function than do shocks occurring in expansions. We find that the initial impact occurs only for shocks in recessions, while later effects are not statistically different between recessions and expansions.

A likely reason for the size of the multiplier in our data is the fact that federal highway grants lead states to spend more on highways. While states spend substantially on highways, the federal government may heavily influence states' decisions by providing highway grants. Changes in federal highway grants to states eventually turn into changes in actual highway spending only to the extent that states actually use those grants to increase highway spending rather than using them to substitute for highway spending the state would have otherwise funded itself. The extent to which grants are not fungible and hence changes in them lead directly to changes in spending for their specified purpose is known as the "flypaper effect," since the money the federal government sends out "sticks were it hits."[3] We provide evidence of a very strong flypaper effect for federal highway grants over our sample period, 1993-2009.

In the second part of the paper, we use a theoretical framework to interpret our empirical findings. In line with our state-level data set and in the spirit of the recent work by Nakamura and Steinsson (2010), we look at the multiplier in an open economy model with productive

[3] See Hines and Thaler (1995) for a review of the flypaper effect.

public capital in which “states” receive federal funds for infrastructure investment calibrated to capture the structure of a typical highway bill in the United States. By considering an open economy model with nominal rigidities, our approach complements the work of Leeper at al. (2010) in a closed economy context, while by studying changes in productive public capital and government borrowing, our paper complements that of Nakamura and Steinsson (2011). Applying the local projection method to our simulated data, we find that the peak multiplier is between 0.8 and 1.3, roughly eight years after the initial increase in public investment, which is in line with the second-round effect that we find empirically. Interestingly, the overall path of the multiplier is similar to that obtained by Leeper et al (2010) using a closed economy model and a very different measure of the multiplier. In contrast to our empirical findings, however, our model does not generate large impact multipliers. One possible reason, suggested by our empirical finding that the impact multiplier only occurs for shocks during a recession, is that our model abstracts from important nonlinearities that cause cycle-dependent heterogeneity in the multiplier. The potential empirical importance of such nonlinearities was emphasized recently in Parker’s (2011) survey of the fiscal multiplier literature.

This paper is one of the first to analyze the dynamic macroeconomic effects of public infrastructure investment. The sparsity of prior work likely owes to the challenges posed by the endogeneity of public infrastructure spending to economic conditions, the partial fiscal decentralization of the spending, the long implementation lags between when spending changes are decided and when government outlays are observed, and the high degree of spending predictability leading to likely anticipation effects. These three features make public infrastructure spending unique and, in particular, different from the type of government spending usually analyzed in the literature on fiscal multipliers, which largely focused on the effects of military spending (see, Ramey and Shapiro (1997), Edelberg, Eichenbaum, and Fisher (1999), Cavallo (2005), Fisher and Peters (2010), Ramey (2011), Barro and Redlick (2011), Nakamura and Steinsson (2011), among others).

Because of our focus on highway spending, our paper is more in line with the work of Blanchard and Perotti (2002), Fishback and Kachanovskaya (2010), or Wilson (forthcoming) that look at the effects of nondefense spending. As in the latter two studies, several recent papers have used variations in government spending across regions, such as states or counties, to identify the effects of fiscal policy.[4] These studies take advantage of the fact that large portions of federal spending are often allocated to regions for reasons unrelated to regional economic performance or needs, a strategy that we also follow. Such variations can be used to identify the effects of federal spending on a local economy. How these local effects relate to the national effects of federal spending depends on, among other factors, whether there are spillover effects to other regions and the extent to which local residents bear the tax burden of the spending (as stressed in Ramey 2011b). We are able to explore the importance of these factors with our theoretical model.

We are aware of only a few studies that explicitly investigate the overall economic effects of public highway spending.[5] A recent paper by Leigh and Neill (2011) estimate a static, cross-section IV regression of local unemployment rates on local federally-funded infrastructure spending in Australia. Because much of that spending in Australia is determined by discretionary earmarks rather than formulas, they use political power of localities as instruments for grants received by localities. Though one might be concerned that local political power also might affect local economic conditions, violating the IV exclusion restriction, they find that local highway grants substantially reduce local unemployment rates. Using U.S. county data, Chandra and Thompson (2000) attempt to trace out the dynamics of local earnings before and after the event of a new highway completion in the county. They find both that earnings are higher during the highway-construction period (1-5 years prior to completion) than when the highway is completed and that earnings after completion rise steadily over many years. This U-shaped pattern is broadly consistent with our estimated GDP impulse response function with respect to highway spending shocks (which would occur several years prior to a highway completion).

The remainder of the paper is organized as follows. The next section provides a background discussion about the Federal-Aid Highway Program and details the process through which federal highway grants are distributed among states. We then present our empirical specification and our results in Section 3, discussing our identification strategy and how we constructed forecasts of highway spending for each state. We also complement this section by

[4] In addition to those discussed below, some notable examples include Shoag (2010), Chodorow-Reich, et al. (2011), Fishback & Kachanovskaya (2010), Feyrer & Sacerdote (2010), Conley & Dupor (2011), and Suarez Serrato & Wingender (2011).

[5] Our paper is also related to the long empirical literature on the contribution of public infrastructure capital to the productivity of the private economy (see, for instance, Aschauer (1989), Holtz-Eakin (1994), Fernald (1999), or Morrison and Schwartz (1996)).

presenting results about the flypaper effect. Our open economy model and the theoretical multipliers are presented in Section 5. The last section concludes.

II. Infrastructure spending: Institutional design

The design of the U.S. Federal-Aid Highway Program allows us to specifically address the issues raised in the introduction. In particular, the distribution of federal highway grants across states is subject to strict rules that reduce the concern that these distributions may be endogenous to states' current economic conditions. These rules were also partly implemented to ease long-term planning and thus provide a natural way to tackle the fact that future spending can be anticipated. Moreover, the data on federal highway funding is detailed enough to distinguish between the provisions of IOUs by the federal government to states and actual payments, which mitigates the possible problem arising from implementation lags that obscure the timing of government spending. This section examines each of these features in turn after first providing some background information on highway bills.

Federal funding is provided to the states mostly through a series of grant programs collectively known as the Federal-Aid Highway Program. Periodically, Congress enacts multi-year legislation that authorizes spending on these programs. Since 1990, Congress has adopted three such acts: the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, which covered fiscal years 1992 through 1997; the Transportation Equity Act for the 21st Century (TEA-21) in 1998, which covered FY1998-2003; and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in 2005, which covered FY2005-2009. However, legislations of much shorter duration have also been adopted to fill the gap between the more comprehensive, multi-year acts. These so-called stop-gap funding bills typically simply extend funding for existing programs to keep them operational. For instance, since SAFETEA-LU expired in 2009, eight highway bill extensions of varying durations have been adopted to continue funding highway programs in accordance with SAFETEA-LU's provisions.

The Federal-Aid Highway Program is extensive and helps fund construction, maintenance, and other outlays on a large array of public roads that go well beyond the interstate highway system. Local roads are often considered Federal-Aid highways and eligible for federal construction and improvement funds, depending on their service value and importance. For instance, **Figure 1** gives a snapshot of roads categorized as federal-aid highways in downtown San Francisco. While it shows that a major thoroughfare like Highway 101 is included in that category, the figure also indicates that many minor roads also fall under that umbrella.

When a highway authorization bill is passed, Congress authorizes the total amount of funding available for each highway program (highway construction, bridge replacement, maintenance, etc.) for each fiscal year covered by the bill.[6] For instance, SAFETEA-LU authorized $244 billion for transportation spending for 2005-2009; 79 percent of that was for the Federal-Aid Highway Program (FAHP). Nearly all of FAHP funding takes the form of formula grants to state governments: The grants for each individual highway program (Interstate Maintenance, National Highway System, Surface Transportation Program, etc.) are distributed to the states according to statutory apportionment formulas also enacted by Congress as part of the current authorization act. The Interstate Maintenance program, for instance, apportioned funds under SAFETEA-LU according to the number of each state's interstate lane-miles, its number of vehicle-miles traveled, and its payments into the Highway Trust Fund, with equal weights on each factor. **Table 1** indicates that most programs (and all major programs) use similar formulas. See **Appendix A** for a more detailed description of the grant distribution mechanism.

In the majority of cases, the formulas and their associated factors have changed little over time (i.e., over different authorization acts). However, highway legislation since 1982 has also included a guaranteed minimum return on a state's estimated contributions to the Highway Trust Fund, which is nominally the financing source for highway authorizations. A state's HTF contributions are the revenues from the HTF's fuel, tire, and truck-related taxes that can be attributed to the state and are estimated by the FHWA based on the same factors used in apportionment formulas. In 1991, the adoption of ISTEA set this minimum guaranteed return to 90 percent, which was then raised to 90.5 percent under TEA-21 in 1998 and 92 percent under SAFETEA-LU. (See **Appendix A** for more detail.) A benefit of the minimum return requirement, along with the statutory formula apportionment of individual programs, is that it

[6] Transportation authorization acts since the Federal-Aid Highway Act of 1956 have been nominally financed by the Highway Trust Fund (HTF), which receives revenues from fuel, tire, and truck-related excise taxes. However, it is debatable whether the HTF actually plays much of a role in ultimately determining transportation funding levels. That is because there are instances (as in 2008) in which Congress has replenished the HTF from the general fund when the HTF was low, and there are instances in which Congress has taken from from the HTF to add to the general fund (see FHWA 2007). That would suggest the HTF balance at a point in time is largely irrelevant to how much Congress authorizes for subsequent transportation spending.

mitigates the potential role of political influence on the distribution of federal funding from year to year. That said, highway bills contain funds earmarked for certain projects that are clearly subject to political influence. For instance, prior to SAFETEA-LU's final legislation, an earlier proposal included an earmark of over $200 million for the now infamous "Bridge to Nowhere" that was to link Ketchikan – with a population of 8,900 – to the Island of Gravina – with a population of 50. Though this and many other proposed earmarks were ultimately dropped from the final legislation, $14.8 billion out of SAFETEA-LU's $199 billion of highway authorizations was set aside for earmarks.[7] However, since earmarks are not distributed according to formulas, we do not use them in our empirical work.

An additional aspect of the apportionment procedure that is key for our empirical strategy is that the factors used in the formulas are lagged three years, since timely information is not readily available to the FHWA. Although the apportionment of federal grants are partly based on factors exogenous to economic activity (lane-miles, for instance), others, like payments into the Highway Trust Fund, may be correlated with movements in current GDP. The use of three-year old data for the factors in the apportionment formulas mitigates the concern that highway spending is reacting contemporaneously to movements in activity.

The use of formulas in allocating funds among states has a long history, going as far back as 1912 with the adoption of the Post Office Appropriation Act, which provided federal aid for the construction of rural postal roads. At the time, the introduction of such formulas was largely welcomed because they made annual grants distribution more predictable and less subject to political influence. They serve the same purpose today, as most highway programs require long-term planning, and advance knowledge of future funding commitments helps smooth operations from year to year. Indeed, before a new highway bill is introduced, the FHWA often estimates what each state is likely to receive each year, using the apportionment formulas. As a result, the Department of Transportation in each state has a good idea of the amount of money the state should expect for each program and can plan accordingly. In the following sections, we use these formulas to generate forecasts, as of each year from 1992 to 2009, of apportionments for each program and for all future years. We show that our forecasts closely match to those produced by the FHWA for those years in which FHWA projections are available.

[7] See Appendix B of FHWA (2007) "Earmarks" are funded by the High-Priority Projects Program.

Another important aspect of the Federal-Aid Highway Program is that it can entail substantial implementation lags between funding authorization and actually spending. Unlike budget authorizations for most government programs, transportation authorization acts do not directly authorize outlays of federal funds. Rather, the acts give "contract authority" to the FHWA to promise states a certain level of reimbursement (for each highway program and each fiscal year) for eligible highway expenditures. As stated in FHWA (2007),

"When an authorization act establishes a program, it sets certain ground rules under which the program operates, including: the amount of funds available to the program for each fiscal year; a description of how those funds are to be distributed; the length of time during which the funds may be used, termed a period of availability; and a listing of eligible activities."

It goes on to say,

"It is important to understand that the FAHP is not a 'cash up-front' program. That is, even though the authorized amounts are 'distributed' to the States, no cash is actually disbursed at this point. Instead, States are notified that they have Federal funds available for their use [apportionments]. Projects are approved [obligations] and work is started; then the Federal government makes payments to the States for costs as they are incurred on projects [outlays]." (Bracketed terms added by authors.)

Both because states have up to four years (the period of availability for most programs) to obligate the fund they are apportioned and because outlays occur during and after the completion of highway projects (which by their nature often can take many years), grant apportionments will show up as outlays with varying and possibly lengthy time lags. We use the distinction between apportionment announcements, obligations, and outlays to provide evidence on the importance of timing in studying the effects of highway spending on states' economic activity.[8]

[8] We are unaware of prior research exploiting data on funding announcements and obligations to better measure the timing of government spending shocks, with the exception of Wilson (2011). Using as instruments formula factors used to distributed funds from the American Recovery and Reinvestment Act (ARRA) of 2009, Wilson estimated the employment effect of ARRA funds alternately based on announcements, obligations, and outlays. He found that

Finally, we note that the cost of construction or improvement of federal-aid highways is not fully covered by the federal government. In most highway programs, the federal government will reimburse a state for 80 percent of the cost of eligible projects, up to the limit set by state's grant apportionment. Thus, it is important to recognize that not all highway spending on federal-aid highway projects is financed by the federal government; some of it is financed by states' own funds such as tax revenues. This has interesting implications for interpreting our empirical results on the economic effects of this type of government spending. The effects from "windfall-financed" spending such as spending fully financed by the federal government – and hence, paid for largely by residents in other states – are likely to be different that the effects from "deficit-financed" spending which is paid for by a state's own residents (Ramey (2011b), Clemons and Miran (forthcoming)).

It should also be noted that this requirement that state's match a portion of the federal funding with their own funding need not imply that a $1 increase in federal grants will automatically generate more than $1 is state highway spending. In fact, it need not imply any increase in state spending at all. An extra dollar of grants may simply substitute for a dollar of a state's own highway funding, leaving total highway spending by the state unchanged. Yet, there is a large literature in public finance finding that federal grants for a given purpose often do increase state spending on that purpose, a phenomenon known as the "flypaper effect." We document in the following section that empirically changes in federal highway grants trigger nearly equivalent amounts of state spending. This is an important issue, since compared to the federal government, states allocate a much larger share of their nondefense expenditures on highways.

III. Measuring Shocks to Highway Spending

In this section, we detail the construction of our shocks to highway spending, which uses revisions in forecasts of federal grants apportionments. Before turning to that topic, however, we first discuss the importance of implementation lags and timing in highway infrastructure projects, which support our use of apportionments to measure our shocks.

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the results for announcements and obligations were similar, but that the estimated effect of ARRA funding based on outlays was much larger, likely because a low level of outlays at a given point in time actually represents a much larger level of announcements or obligations which are the true shocks to government spending.

A. Implementation Lags and Correctly Measuring the Timing of Highway Spending

Leeper, et al (2010) and others have strongly argued that implementation lags between government spending authorization and government outlays can greatly distort inferences regarding the economic impacts of government spending. This is likely to be especially true for highway and other infrastructure spending. The bureaucratic process underlying this implementation lag for highway spending is well detailed in FHWA (2007) and depicted in **Figure 2**. We obtained this figure directly from FHWA (2007) and then augmented it with the two red "events" at the top. The process begins at the beginning of each fiscal year when federal grants are distributed to states according to the formulas laid out in the current highway bill and the factors entering those formulas. Each state then writes contracts with contractors, obligating funds up to a maximum set by current and unobligated past grants.[9] Work then proceeds by contractors and those contractors, along the way and/or at the end of the project, submit bills to their state. The state essentially passes those bills on to the federal government (FHWA) which approves them and instructs the U.S. Treasury to transfer funds to the state which in turn sends funds to the contractor. Note that it is these final transfers of funds by the federal and state governments that show up as "spending" or "outlays" in official government statistics.

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[9] At this point, the state is also implicitly obligating itself to pay for future auxiliary costs associated with completed highway projects such as highway police services, snow removal, administrative expenses, etc.. Such auxiliary costs show up in data on overall highway outlays but do not show up in data on obligations. For this reason, measured obligations may understate the true level of obligations at a point in time, an issue that affects our interpretation of the government spending multiplier we obtain based on obligations later in the paper. We discuss this in Section IV.D.

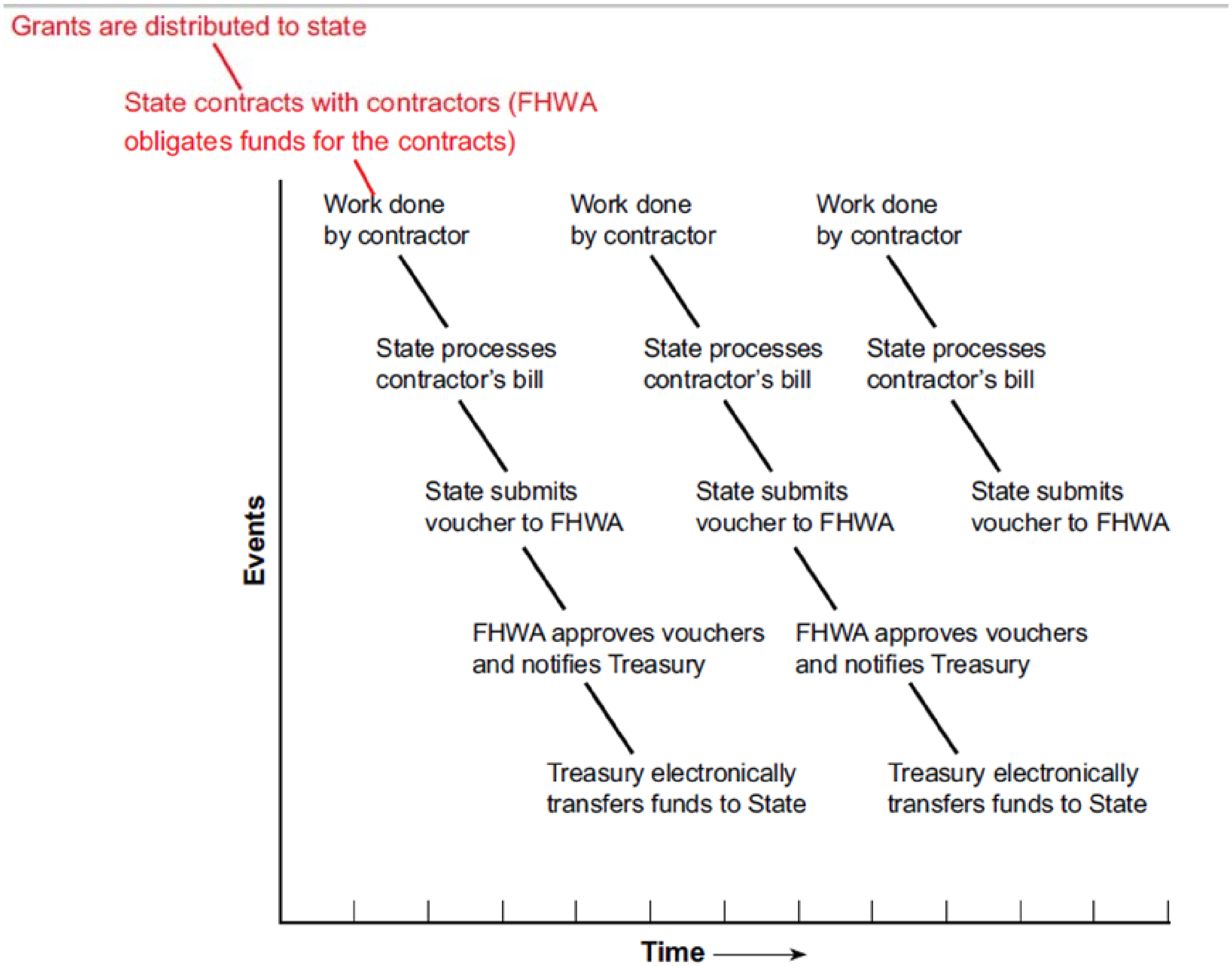

Figure 2. Implementation Lag Process

There are at least two steps in this process that can introduce substantial delays between grants and final outlays. First, states legally have up to four years to obligate funds from a given year of grants. Second, and more importantly, once a contract has been written, the work itself may take several years. This, of course, is a distinguishing characteristic of infrastructure spending. Using state panel data that we collected from the FHWA Highway Statistics series (see the data glossary in **Appendix C** for details), we can estimate exactly what these implementation lags look like. First, we estimate the dynamic lag structure leading from federal highway grants ("apportionments") received by a state to its obligations of funds for federal-aid highway projects. Specifically, we estimate the following distributed lag model with state and year fixed effects:

$$OBLIG_{it} = \alpha_i + \alpha_t + \sum_{s=0}^{3} \beta_s A_{i,t-s} + \epsilon_{it}. \quad (1)$$

where $OBLIG$ is obligations and A is apportionments. Both are per capita.

The results are shown in **Table 2**. The key findings are that \$1.00 of grants leads to \$0.77 in obligations within the first year (after grant authorizations are announced) and \$0.97 within four years, which is the statutory time frame within which they must obligate funds or lose the money. In other words, states do eventually obligate virtually all of the highway funds to which they are entitled and about three-quarters of the obligations take place in the first year. Thus, the step from grants to obligations introduces only modest implementation lags.

The step from obligations to outlays, however, can lead to substantial lags. This can be seen by estimating a distributed lag panel model as above but with outlays of federal aid (from the FHWA, via Treasury, to state governments) as the dependent variable and obligations on the right-hand side.[10] Both variables are per capita. We include current-year and up to seven years of lagged obligations to fully describe the implementation lag process. Further lags are found to be economically and statistically insignificant. The results are shown in the second column of **Table 2.** We find that an initial dollar of obligations of federal-aid funds by a state takes up to six years to result in actual outlays (reimbursements to the state) by the federal government. The results in columns (1) and (2) suggest that the implementation lag between grants and outlays is quite long, and this is indeed confirmed when we regress FHWA outlays on current and seven lags of grants. As shown in the third column, \$1 in grants does eventually lead to \$1 in outlays (our point estimate is \$0.98 and the 95% confidence interval is \$0.88 to \$1.09), but the process can take up to seven years.

These results provide strong evidence that there are substantial implementation lags between when highway spending amounts are authorized, and hence known with certainty to all agents in the economy, and when final outlays occur. That is, agents have near-perfect foresight of outlays several years in advance. Thus, one would not want to use outlays in deriving a measure of highway spending shocks in order to estimate the dynamic effects of highway spending. For this reason, we rely instead on information from apportionments (i.e., announced grants) in our analysis. Unanticipated shocks to such announcements (which we measure in Section III.B below) may have economic effects both in the short-run, as agents respond now to known future increases in government spending, and in the long-run as they lead to obligations, then outlays,

[10] The data on outlays by the FHWA to states are from the FHWA Highway Statistics for various years. See Table FA-3, "Expenditure of Federal Funds Administered by the Federal Highway Administration During Fiscal Year."

and finally real infrastructure capital being put in place and potentially enhancing productivity in the real economy.

B. Distinguishing Unanticipated from Anticipated Changes in Highway Grants

In this subsection, we construct a measure of highway spending shocks using data from the FHWA on apportionments, statutory formulas, and formula factors from 1993 to 2009. In doing so, we make use of the fact that highway spending is likely to be partially forecastable owing to the multi-year nature of the federal highway appropriations acts, which as discussed in **Section 2** typically cover a 5-6 year period. In a given year, agents know the full path of aggregate (national) grants for each highway program for the remaining years of the current appropriations bill and they also know the formulas by which each program's grants are apportioned to states. However, they do not know the future values of the factors that go into those formulas and that will determine the distribution of grants among states. At the beginning of each fiscal year, the latest data on formula factors are released at the same time as the year's apportionments are announced.[11] Importantly for our empirical identification strategy, there is a three-year data-collection lag for these factors. For instance, the number of vehicle-miles traveled on federal-aid highway in each state in 2006 is used, along with other factors in 2006, to apportion Surface Transportation Program grants to states in 2009. As we mentioned in Section 2, this data collection lag helps eliminate potential reverse causality running from current economic activity to formula factors and hence to highway grant apportionment. It also implies that to correctly forecast future apportionments, agents need to make forecasts of the formula factors.

The partial forecastability of future highway apportionments means that observed movements in apportionments may not represent true shocks to expected current and future highway spending. Therefore, we utilize the information provided in each highway appropriations bill to forecast current and future highway spending and then measure the shock to expectations as the difference between the current forecast and last year's forecast. This is similar in spirit to the approach of Ramey (2011) and especially Auerbach and Gorodnichenko (2011). The latter paper measures shocks to government spending in OECD countries as the

[11] The data on formula factors primarily come from the FHWA's Highway Performance Monitoring System (HPMS).

year-over-year change in a one-year ahead forecast of government spending made by the OECD. One difference between that and what we do here is that our shock is based on a forecast of the present discounted value of all future government (highway) spending rather than just next year's spending.

To construct real-time forecasts of future highway grants, we follow and extend the methodology used by the FHWA Office of Legislation and Strategic Planning (FHWA 2005) in its report providing forecasts, as of 2005, of apportionments by state for the years of the 2005-2009 SAFETEA-LU highway bill. Basically, the methodology involves assuming that a state's current formula factors (as a share of the nation), and hence the state's current share of federal grants for each of the 17 FHWA apportionment programs, are constant over the forecast horizon. That is, the best guess of what the relative values of formula factors will be going forward is their current year relative values. Given apportionment shares for each program, one can then distribute to states the known nationwide totals for each program for the remaining years of the current legislation. One can then aggregate across programs to get a state's total apportionments in each of these future years.

We extend this methodology such that if one is forecasting for years beyond the current legislation, one assumes a continuation of the use of current formulas (i.e., one's best guess of the formulas to be used in future legislation is the formulas currently in use) and one assumes that nationwide apportionments by program grow at the current inflation rate from the last authorized amount in the current legislation. Assuming constant formulas for future bills is reasonable since, as discussed in Section 2, there's been relatively little change in the formulas used to apportion federal grants over the past 20 years. The details of how we construct these forecasts are provided in **Appendix B**.

How accurate are these forecasts? To get a sense of their accuracy both in absolute terms and relative to the 2005-2009 FHWA forecasts (as of 2005) mentioned above, we generate three scatterplots shown in **Figure 3**. The top scatterplot compares our four-year ahead forecasts, as of 2005 (the first year of the 2005-2009 SAFETEU-LU appropriations bill), of 2009 highway apportionments to actual 2009 apportionments. The red line is a 45° line. The forecasts are extremely close to the actuals. The middle scatterplot compares the FHWA forecasts, as of 2005, of 2009 apportionments to actual 2009 apportionments. The FHWA forecasts are also very close to the actuals. The bottom plot compares our forecasts of 2009 apportionments to those of the FHWA. Not surprisingly given we use a similar forecast methodology, our forecasts are very close to the FHWA's. Thus, our forecasts, like those of the FHWA, are extremely accurate. Moreover, this is not just true for 2009. A panel regression of actual apportionments in year *t* on year fixed effects and five-year ahead forecasts in year *t*-5 yields a coefficient of 1.10 (*s.e.* = 0.01) and an R^2 of 0.95.

From these forecasts, we calculate the present value of current and expected future highway grants for state *i* as:

$$E_t\left[PV_i\right] = \sum_{s=0}^{4} \frac{E_t\left[A_{i,t+s}\right]}{(1+r)^s} + E_t\left[A_{i,t+5}\right]\frac{\beta^5}{1-\beta}, \tag{2}$$

where $E_t[A_{i,t+s}]$ is the forecast as of *t* of apportionments (in nominal dollars) in year *t*+*s* and $\beta = (1+\pi)/(1+r)$. The presence of the factor β acknowledges that, because highway appropriations bill cover at most 6 years (*t* to *t*+5), forecasts beyond *t*+5 simply assume perpetual continuation of $A_{i,t+5}$ growing with expected inflation of π. We assume the nominal interest rate, *r*, is 0.05 and expected inflation, π, is 0.02.

Shocks to expected future highway spending can then be measured simply as the percentage difference between last year's expectations and this year's expectations:

$$dE_t\left[PV_i\right] = logE_t\left[PV_i\right] - logE_{t-1}\left[PV_i\right]. \tag{3}$$

When both *t* and *t*-1 are covered by the same appropriations bill, as is the case for most of the sample period, $dE_t\left[PV_i\right]$ primarily will reflect shocks to incoming data on formula factors. When *t* and *t*-1 span different appropriations bills, $dE_t\left[PV_i\right]$ also will reflect news in year *t* about the new path of aggregate apportionments for the next 5-6 years and about any changes to apportionment formulas.

To get a sense for what these shocks look like over time and states, in **Figure 4** we plot $dE_t\left[PV_i\right]$ over our time for a selection of states. We include several states with large populations (California (CA), Texas (TX), New York (NY), Florida (FL), and Pennsylvania (PA)), a couple of states with large areas but small populations (North Dakota (ND) and South Dakota (SD)), and a couple of states with small areas and small populations (Rhode Island (RI) and Delaware (DE)). There is considerable variation over both time and space. As expected, there are large shocks in the first years of appropriations bills – 1998 and 2005. But there also are some large shocks in other years, such as 1996 and 2004. There is are obvious differences in volatility relating to state size or population. For instance, Rhode Island tends to experience large shocks but Delaware does not. Similarly, Pennsylvania displays large shocks while New York does not.

IV. Results – The Dynamic Effects of Highway Spending Shocks on GDP

A. Estimation Technique

Our objective in this section is to use our measure of highway spending shocks to estimate the dynamic effects of highway spending on GDP. Our empirical methodology utilizes the Jorda (2005) local projections approach to estimate impulse response functions (IRFs), extended to a panel context. This approach was also used recently by Auerbach and Gorodnichenko (2011) in their study of the dynamic effects of government spending, using panel data on OECD countries. The basic specification is:

$$y_{i,t+h} = \alpha_i^h + \alpha_t^h + \sum_{s=1}^{p} \beta_s^h y_{i,t-s} + \sum_{s=1}^{q} \gamma_s^h g_{i,t-s} + \delta^h \cdot dE_t\left[PV_i\right] + \epsilon_{i,t+h}, \qquad (4)$$

where $y_{i,t}$ and $g_{i,t}$ are the logarithms of GDP and government highway spending, respectively, for state *i* in year *t*, and $dE_t\left[PV_i\right]$ is the government highway spending shock defined above. The parameter δ^h identifies the impulse response function (IRF) at horizon *h*. Equation (4) is estimated separately for each horizon *h*. Lags of output and highway spending are included to control any additional forecastability or anticipation of highway apportionment changes missed by our forecasting approach that generates $dE_t\left[PV_i\right]$. We use (log) state federal-aid highway obligations to measure $g_{i,t-s}$ (though using other measures of state highway spending yield similar results). We set $p = q = 3$, but find the results to be robust to alternative lag lengths. State fixed effects are included in case there are any persistent state-specific forecast errors (in $dE_t\left[PV_i\right]$) that could be correlated with state GDP (conditional on past GDP).

The previous literature estimating the dynamic effects of government spending generally has omitted time trends or time fixed effects. This omission likely is due to the difficulty in a dynamic time series model, such as a local projection or a vector autoregression, of separately identifying a time trend or time fixed effects from the parameters describing the dynamics of the model. The advantage of estimating a dynamic model with panel data is that it allows one to control for aggregate time effects. This is 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.

Notice that by "sweeping out" any potential effect of federal tax policy, we effectively are removing any negative wealth ("Ricardian") effects on output associated with agents expecting increases in government spending to be financed by current and future increases in federal taxes. In other words, to that extent that increases in state government spending are paid for with federal transfers, this spending is "windfall-financed" rather than "deficit-financed"; (see Clemons and Miran (forthcoming)). In a standard New Keynesian model, windfall-financed spending will have a greater output multiplier than deficit-financed spending. In reality, state government highway spending, even on "federal-aid" highways, is part windfall-financed – because it is partly reimbursed by federal transfers – and part deficit-financed – because reimbursable outlays on federal-aid highways necessitates additional non-reimbursable expenditures such as police services, traffic control, snow and debris removal, future maintenance, etc. Our estimated IRFs will reflect any wealth effects from states' deficit financing of non-reimbursable spending but not wealth effects from the federal government's deficit financing of states' reimbursable spending.

Because $dE_t\left[PV_i\right]$ is constructed to be exogenous and unanticipated, the equation can be estimated via Ordinary Least Squares. However, because the equation contains lags of the dependent variable, the error term is expected to be serially correlated. For this reason, we allow for arbitrary serial correlation by allowing the covariance matrix to be clustered within state. (In a robustness check below, we also show how results are affected by additionally allowing for cross-sectional correlation via Driskoll-Kraay (1998) standard errors.)

B. Baseline Results

We estimate equation (4) using state panel data from 1990 to 2009. The shock variable is only available for years 1993-2009, but the regressions uses three lags of spending (obligations) and GDP.

The baseline results, where the local projection regressions control for a linear time trend but not time fixed effects, are shown in **Table 3**. **Figure 5** displays the IRF – that is, the estimates of δ^h – for horizons h = 0 to 10 years. The light blue band in the figure gives the 90% confidence interval. This IRF indicates that state highway spending shocks lead to a positive and statistically significant increase in state output on impact. The effect on output falls over the next few years but then increases sharply around six years out, peaking at seven years out, and remains large and significant through nine years out. **Table 4** and **Figure 6** shows the results when we replace the time trend with year fixed effects. The basic contour of the IRF is the same – with an initial positive impact that fades away until a second round of positive effects occurs 7 to 8 years out – but the relative magnitude of that second round effect is now smaller. In addition, the confidence band is larger when year fixed effects are included.

How large are these effects? Because the variables in these regressions are in logs, the point estimates of δ^h should be interpreted as elasticities. For instance, δ^0 in the regression with year fixed effects is 0.017. This elasticity implies that a positive 10% shock to expected current and future highway spending results in a 0.17% increase in output. To translate that elasticity into a government spending multiplier – i.e., the expected increase in output due to a $1 increase in spending – one can multiply the elasticity by the ratio of output to spending. The average ratio of state GDP to state highway spending (according to the Census Bureau's SGF data on state government highway outlays) in our sample is 119.[12] Thus, the implied fiscal multiplier on highway spending is found to be 119*0.017 = 2.0 on impact. The peak elasticity occurs after seven years and also is 0.017, implying a peak multiplier of 2.0.[13]

C. Direct Transmission Channel and Flypaper Effect

Using state spending to convert our elasticity to a multiplier relies on the presence of a strong "flypaper effect" in our data. States may use federal highway funds to offset some or all of the highway spending that the state would have done anyway and paid for with the state's own funds. The extent to which federal transfers to local governments earmarked for a specific purpose actually increase spending by regional governments on that purpose is known as the

[12] It is possible that federal highway grants necessitate not only auxiliary state government highway spending (via matching requirements and flypaper effect) but also some auxiliary local government highway spending. For instance, construction or expansion of a new federal-aid highway may cause local governments to build new roads connecting to that highway. Because the average ratio of state GDP to combined state and local government highway spending is 89, this would imply a somewhat smaller multiplier of 89*0.017 = 1.5.

[13] The peak multiplier implied by the IRF estimated without year fixed effects but with a time trend is considerably larger, at 5.1, highlighting the importance of controlling for aggregate effects that are contemporaneously correlated with highway spending shocks. One possibility for why excluding year fixed effects yields larger multipliers 6-8 years out is that positive aggregate spending shocks (e.g., increases in federal budget authorizations of highway grants) may be more likely in downturns and downturns are naturally followed 6-8 years later by expansions. Not controlling for aggregate time fixed effects would lead one to misattribute these subsequent expansions to the spending shocks rather than the aggregate business cycle.

flypaper effect. The recent literature on the flypaper effect of federal grants has found mixed results. Studies by Baicker (2001); Evans & Owens (2005), Singhal (2008), and Feiveson (2011) find evidence of strong flypaper effects across a variety of spending categories. However, Knight (2002) and Gordon (2004) find the opposite. Knight (2002) is especially relevant to this paper, as it also looks specifically at highway grants, and we discuss his results in greater detail below.

To empirically evaluate the flypaper effect of federal highway grants for our sample period 1993-2009, we estimate a panel distributed lag model similar to equation (1), but using as the dependent variable various measures of state government spending on highways. Because of the implementation lags documented above, it is important to include several lags of federal grants on the right-hand side of this model, something which is omitted from most previous analyses of the flypaper effect.

The thought experiment behind these regressions is the following: Suppose in an average year a state spends \$100 million on highways and gets \$50 million reimbursed through federal highway grants. Then, one year grants increase by \$10 million to \$60 million. Does the state's highway spending increase by \$10 million to \$110 million dollars – a flypaper effect of 1? Or does the additional \$10 million of grants entirely crowd out the state's own funds for highways such that state highway spending remains at \$100 million – a flypaper effect of 0? Or somewhere in between?

The results are shown in **Table 5**. The dependent variable in the first column is overall state government highway outlays, as reported in the Census Bureau's State Government Finances (SGF) data. This measure is quite broad, including not only highway capital outlays and maintenance but also snow removal and salting, administrative expenses, and transfers to local governments for road spending. Note that highway outlays here are not just outlays on federal-aid highways but outlays on all roads administered by states plus outlays on locally-administered roads paid for with state-to-local transfers. The second column uses state government capital outlays on major ("federal-aid") highways, as reported by the FHWA. The third column looks at state government construction outlays (from the SGF); conceptually, construction outlays are a subset of total capital outlays (which also includes outlays on right-of-way acquisition).

We find strong evidence of a flypaper effect, regardless of the measure of highway spending. A \$1 increase in federal highway grants leads to a \$0.38 increase in overall state highway spending in the first year and exactly \$1.00 after five years. Using capital outlays or construction outlays as the dependent variable, the peak increase occurs in the third year – later than for total highway spending. In all cases, the cumulative effect after five years is large, ranging from \$0.88 to \$1.00. In no case is the cumulative effect statistically different from one.

Why do these results differ from those of Knight (2002), which found no evidence of a flypaper effect for federal highway grants? The difference appears attributable partly to our inclusion of lags of grants and partly to our use of a more recent sample period. Knight regressed state highway spending on grants in the same year, using data from 1983 to 1997. He finds a strong positive correlation between the two variables, which goes to zero when state fixed effects are added.[14] Though we do not have data on grants back to 1983, we do have it back to 1987. Hence we can run a static regression similar to Knight's for the similar sample period of 1987-1997. The results are shown in column (4) of **Table 5**. As in Knight, we find a precisely estimated near-zero effect. Column (5) shows that adding lags of grants increases the cumulative flypaper effect to about 0.15, though it remains statistically insignificant. These results indicate that, while there was a weak or zero flypaper effect during the 1980s and early 1990s, the flypaper effect is very strong from the mid-1990s onward. The explanation for this change is not clear.[15] The key point for this paper is that, at least over the time period we study, there is a strong flypaper effect from federal highway grants. This evidence suggests that *a*, if not *the*, key direct channel by which grants affect economic activity is by inducing additional state government highway spending which in turn affects local economic activity.[16]

[14] Knight finds that the coefficient on grants actually becomes negative when he instruments for grants using variables meant to capture the political influence of a state's Congressional members. However, the first-stage fit in these regressions is quite low (F-statistic < 3), suggesting both that grants are not significantly subject to political influence and that this negative IV coefficient may well be due to the weak-instrument bias recently analyzed by Stock, Wright, and Yogo (2002) and others.

[15] We suspect that this change is related to the shift in the nature of highway spending that occurred around the mid-1990s. That was the time in which federal funding for the construction of the Interstate Highway system ended and federal funding shifted to interstate maintenance, resurfacing, and constructing more minor roads and highways.

[16] Consider the alternative extreme where federal highway grants received by a state have no effect whatsoever on state, and hence total, government highway investment. In this case, shocks to grants are entirely wasteful and should have no long-run effect on productivity and hence no long-run effect on GDP. The only short-run effect such shocks would have would come through the traditional negative wealth effect channels associated with wasteful government spending.

D. Robustness [to be completed for next draft]

We will display results pertaining to the following robustness checks:

1. Driscoll-Kraay std errors.
2. Dummying out observations for years 1998 and 2005 to make sure results are not unduly driven by the large spending shocks at the beginning of appropriations bills. This has been done. The resulting IRF looks similar to our baseline IRF, except the confidence band is larger, such that the IRF is not statistically significantly different from zero at any horizon.
3. Alternative identification strategy: IV using obligations with 0-3 lags of grants as instruments. This also has been done. The shape of the estimated IRF is very similar to that in our baseline results, though the initial impact is somewhat smaller, the second-round effects are somewhat larger, and the confidence band is larger. Though these IV results are estimated imprecisely, they indicate that the general U-shaped IRF found in our baseline results are not driven by idiosyncratic measurement error introduced by the way in which we computed the expected future highway spending shock.

E. Extensions

1. *Impact of Highway Spending Shocks in Expansions vs. Recessions*

In this subsection, we report the results of a number of interesting extensions of the baseline results. First, we explore whether the impact of government highway spending is different in expansion than in recessions. To do so, we follow the approach of Auerbach and Gorodnichenko (2011a, 2011b), which involves calculating the probability of being in an expansion (vs. recession), based on a regime-switching model, and interacting that probability with the right-hand side variables in the local projection regressions (equation (4)). Expansions and recessions here are state- and time-specific. Following Auerbach and Gorodnichenko (2011b), we first calculate for each state and year the deviation of real GDP growth from the state's long-run trend (estimated from a HP filter with a high smoothing parameter of 10,000). We then take a logistic transformation of that variable in order to map it onto the [0,1] range. The IRF of output with respect to highway spending shocks during an expansion is given by the coefficient, for each horizon *h*, on the interaction between the shock, $dE_t[PV_i]$, and the expansion probability.[17] Conversely, the IRF during a recession is given by the coefficient, for each horizon, on the interaction between the shock and one minus the expansion probability. An important caveat of this approach, as has been pointed out by Ramey (2011b), is that it assumes that economy i remains in the same regime throughout the interval t to $t+h$, which is increasingly unrealistic as h increases. For this reason, we focus mainly on the IRF results for the first two or three years; results beyond that should be viewed with caution.

The results are shown in **Figure 7**. The top panel shows the results for recessions; the bottom panel shows results for expansions. Interestingly, the initial impact of highway spending shocks are much larger when they occur in state-years experiencing a recession. The impact elasticity in recessions is about 0.05, which is statistically significant and which implies a multiplier of about 5.9 (0.05 times 119, the sample average ratio of state GDP to state government highway spending). The impact elasticity in expansions, on the other hand, is slightly below zero and statistically insignificant. After the initial shock, the output response from shocks hitting during recessions falls and becomes statistically insignificant. For shocks hitting during expansions, the output response grows slightly over time but remains statistically insignificant except for the horizon six years out. Only in $h = 0$ are the IRF coefficients statistically significantly different between expansions and recessions. Overall, these results suggest that the initial positive impact of highway spending shocks found in the baseline results is driven by the large multiplier on such spending in recessions, while the second-round positive effects coming six to eight years later may be independent of the business cycle conditions at the time of the shock. This pattern is consistent with an economic model in which the initial impact stems from wealth effects (e.g., increased labor supply, perhaps along with increased consumption if households have preferences such that consumption and labor are complementary, as agents react to expected future tax increases) while the second-round effects stem from the increased potential output generated by a larger stock of infrastructure capital.

2. *IRFs for Additional Outcomes – Employment and Personal Income*

Next, we estimate the IRFs with respect to highway spending shocks for some additional outcomes. In particular, we look at state employment and personal income. (Many other

[17] To avoid potential simultaneity bias from the fact that the expansion probability will be contemporaneously correlated with the dependent variable (log output), we follow Auerbach and Gorodnichenko (2011b) in lagging the expansion probability by one year.

potential interesting variables – such as consumption and investment – are not generally available at the state level.) The results for employment and personal income are shown in **Figure 8**. The estimated IRFs are both quite similar to that estimated for GDP. This finding underscores the robustness of the GDP results in that they appear not to be driven by some idiosyncratic measurement error in state GDP data.

V. Theory – Multipliers in a Model with Productive Public Capital

In this section we turn to assessing the impact of public infrastructure investment in a theoretical framework with productive public capital. Our model is relatively standard and contains many features that have proven useful in addressing the macroeconomic impact of fiscal policy (see, King and Baxter (1993), or the more recent analysis of Leeper et al (2010) and Uhlig (2011), using closed economy models, and Corsetti, Kuester, and Müller (2011), in the context of a small open economy). In line with our empirical framework above and in the spirit of Nakamura and Steinsson (2011), we conduct our analysis in a monetary union using an open economy model, which allows us to remove the effects of aggregate shocks and monetary policy on the local fiscal multiplier.

We consider a cashless national economy consisting of two regions, H and F, of possibly different sizes, n and $1-n$. The national government invests in public infrastructure projects in the two regions and finances these investments by levying taxes and by borrowing. Each region specializes in one type of tradable good, produced in a number of varieties or brands, defined over a continuum of unit mass. Firms are monopolistic suppliers that combine private and public capital with domestic labor to produce one brand of goods. Although we assume complete financial markets, Ricardian equivalence does not hold in our baseline model, due to the presence of distortionary income taxes.

We first provide a description of the households and the behavior of the monetary and fiscal authorities, before presenting the firms' problem.

A. Households

The Home region is populated by a continuum of infinitely-lived households who choose a consumption basket, C_t, and hours worked, L_t, to maximize the expected value of their lifetime utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, L_t\right) \tag{2.1}$$

where β denotes the agent's subjective discount factor.[18] Home households consume all the different types of traded goods produced in the two regions, with $C_t(h)$ representing the consumption of the Home region's brand h at time t, while $C_t(f)$ is the consumption of the Foreign region's brand f. For each type of good, we assume that one brand is an imperfect substitute for all other brands, with constant elasticity of substitution θ. Consumption of Home and Foreign goods by the Home agent is defined as:

$$C_{\mathrm{H},t} \equiv \left[\int_0^1 C_t(h)^{\frac{\theta-1}{\theta}} dh\right]^{\frac{\theta}{\theta-1}}, \qquad C_{\mathrm{F},t} \equiv \left[\int_0^1 C_t(f)^{\frac{\theta-1}{\theta}} df\right]^{\frac{\theta}{\theta-1}} \tag{2.2}$$

In turn, Home households' full consumption basket is composed of the bundles of Home and Foreign produced goods defined by the following CES aggregator

$$C_t \equiv \left[a_{\mathrm{H}}^{\frac{1}{\eta}} C_{\mathrm{H},t}{}^{\frac{\eta-1}{\eta}} + (1-a_{\mathrm{H}})^{\frac{1}{\eta}} C_{\mathrm{F},t}{}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \qquad \eta > 0, \tag{2.3}$$

where a_{H} dictates the degree of home bias in consumption (a_{H} = 0.5 equates to no home bias) and where the elasticity of substitution between the consumption of Home goods and the consumption of imports is given by η. The price index associated with the consumption aggregator is given by

$$P_t \equiv \left[a_{\mathrm{H}} P_{\mathrm{H},t}{}^{1-\eta} + (1-a_{\mathrm{H}}) P_{\mathrm{F},t}(j)^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{2.4}$$

where $P_{\mathrm{H},t}$ is the price sub-index for home-produced goods and $P_{\mathrm{F},t}$ is the price sub-index for foreign produced goods, both expressed in the common national currency:

$$P_{\mathrm{H},t} \equiv \left[\int_0^n P_t(h)^{1-\theta} dh\right]^{\frac{1}{1-\theta}}, \qquad P_{\mathrm{F},t} \equiv \left[\int_0^n P_t(f)^{1-\theta} df\right]^{\frac{1}{1-\theta}}. \tag{2.5}$$

The Home households derive income from working, $W_t L_t$, from renting capital to firms, $R_t K_t$, and from the state-contingent payoffs $B_t(s)$ in state of nature s. We assume that the profits

[18] For convenience, we do not index variables by households.

of Home firms are rebated to Home households in the form of dividends, $\Pi(h)$. Households face a time-varying labor income tax τ^l and may also pay a consumption τ^c, and use their disposable income to consume, invest in domestic capital, and buy state-contingent assets $B_{t+1}(s)$, which pays one unit of Home consumption goods if a particular state of nature s occurs in period $t+1$, at price $p_{bt,t+1}$. The households can also invest in a one-period government bond, B^G_{t+1}, which has a price p^g_{bt}.

We assume that, as for aggregate consumption, aggregate private investment is a CES composite of Home and Foreign tradable goods with identical weight and elasticity. Private capital accumulates according to the following law of motion

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{2.6}$$

where δ denotes the depreciation rate. The individual flow budget constraint for the representative agent in the Home country is therefore:

$$\begin{aligned}(1+\tau^c_t)P_{\mathrm{H},t}C_{\mathrm{H},t} + P_{\mathrm{F},t}C_{\mathrm{F},t} + P_t I_t + \int_s p_{bt,t+1}B_{t+1}(s) + p^g_{b,t}B^g_{t+1} \\ \leq (1-\tau^l_t)W_t L_t + R_t K_t + B_t(s) + B^g_t + \int_0^1 \Pi_t(h)dh - T_t.\end{aligned} \tag{2.7}$$

B. Fiscal and monetary policies

As discussed in **Sections II and IV.A**, there can be long implementation lags between the time when government transportation spending is authorized and when actual outlays occur. These lags are likely for other types of government investment spending. Following Leeper et al (2010), we capture this feature of government investment by assuming that only a fraction of authorized funds show up as outlays in an given year.

Let $A_{\mathrm{H},t}$ denote the federal grants per capita apportioned to region H at time t, which we assume follows an AR(1) process

$$A_{\mathrm{H},t} = (1-\rho_A)\overline{A}_{\mathrm{H}} + \rho_A A_{\mathrm{H},t-1} + \varepsilon_A, \tag{2.8}$$

where $\overline{A}_{\mathrm{H}}$ is the steady state level of region H's apportionments and ε_A normally-distributed error term. In turn, we denote per capita government infrastructure outlays (by all levels of government, net of intergovernmental transfers) in the Home region by $G^I_{\mathrm{H},t}$ and assume that it evolves according to the following process

$$G^{I}_{\mathrm{H},t} = \sum_{n=0}^{N-1} \omega_n A_{\mathrm{H},t-n} \tag{2.9}$$

where $\sum_{n=0}^{N-1} \omega_n = 1$. The spending rates, i.e., the rate at which authorized funds will show up as government outlays, is determined by $\omega_i, i = 0, N-1$.

Because it may take time for public infrastructure projects to be completed, we introduce a time-to-build component by letting government funds apportioned at time t only impact the public capital stock N periods later:

$$K^{G}_{\mathrm{H},t+1} = (1-\delta) K^{G}_{\mathrm{H},t} + A_{\mathrm{H},t-N} \,. \tag{2.10}$$

We assume that public capital in a region is a composite good, given as a CES index of the differentiated goods in that region, and for simplicity we assume that the public investment index has the same form as the consumption index in ((2.2))

$$A_{\mathrm{H},t} = \left[\int_0^1 A_t(h)^{\frac{\theta-1}{\theta}} dh \right]^{\frac{\theta}{\theta-1}} , \tag{2.11}$$

so that the government's demand for each type of differentiated good is given by

$$A_t(h) = \left(\frac{P_t(h)}{P_{\mathrm{H},t}} \right)^{-\theta} A_{\mathrm{H},t}, \qquad A_t(f) = \left(\frac{P_t(f)}{P_{\mathrm{F},t}} \right)^{-\theta} A_{\mathrm{F},t} \tag{2.12}$$

To finance infrastructure investments, the national government borrows using a one-period bond, B^{G}_t, and levies either an income or a consumption tax. The national government's budget constraint is

$$\tau^j_t (nW_t L_t + (1-n) W^*_t L^*_t) + p^g_{b,t} B^g_{t+1} = nP_{\mathrm{H},t} G^{I}_{\mathrm{H},t} + (1-n) P_{\mathrm{F},t} G^{I}_{\mathrm{F},t} + B^g_t \qquad j \epsilon \{c, l\}, \tag{2.13}$$

where asterisks denote foreign variables.

We consider deficit-financed public infrastructure investment and assume that taxes react with a T-period delay to an increase in the government-to-GDP ratio

$$\tau^j_t = \overline{\tau}^j_t + \psi \left(\frac{B^g_{t-T}}{Y_{t-T}} - \frac{\overline{B}^g}{\overline{Y}} \right) \qquad j \epsilon \{c, l\},$$

where variables with a bar denote steady state values.

Similar to Nakamura and Steinsson (2011), monetary policy is set at the national level according to an interest-rate rule that is a function of aggregate consumer price inflation, $\widehat{\pi}^{ag}_t$, and aggregate output, $\widehat{y}^{ag}_t$, given by

$$\widehat{r}_t = \rho_R \widehat{r}_{t-1} + \beta_\pi (1-\rho_R) \widehat{\pi}_t^{ag} + \beta_y (1-\rho_R) \widehat{y}_t^{ag}, \tag{2.14}$$

where hatted variables denote deviations from steady state and where aggregate inflation and aggregate output are weighted sums of respective variables in the Home and Foreign regions: $\widehat{\pi}_t^{ag} = n\widehat{\pi}_t + (1-n)\widehat{\pi}_t^*$ and $\widehat{y}_t^{ag} = n\widehat{y}_t + (1-n)\widehat{y}_t^*$.

C. Firms' problem

Firms producing Home tradables are monopolist in producing their brand; they employ a technology that combines domestic labor with private and public capital inputs, according to the following Cobb-Douglas function:

$$Y_t(h) = L_t(h)^{\phi} K_t(h)^{1-\phi} K_t^G(h)^{\phi_g} \tag{2.15}$$

where $K_{t-1}^G(h)$ is public capital used in the production of good h. Positive value of ϕ_g, the elasticity of output with respect to public capital, imply that the production function has increasing returns with respect to public capital, as in the analysis of King and Baxter (1993) and Leeper et al (2010).[19]

We assume that there is no impediment to goods trade across regions, so that the law of one price holds. Moreover, in setting their prices, firms take into account the fact that, in any given period, there is a probability α that they will have to leave prices unchanged as in Calvo (1983). When they can reset their prices (which occurs with probability $1-\alpha$), firms act to maximize the expected discounted sum of profits

$$\Pi_t(h) = E_t \left\{ {}_{k=0}^{\infty} p_{bt,t+k} \alpha^k \left(P_t(h) Y_{t+k}(h) - MC_{t+k}(h) Y_{t+k}(h) \right) \right\},$$

where MC_t is the firm's nominal marginal cost and where the firm's demand at time t is given by

$$Y_t(h) = \left(\frac{P_t(h)}{P_{\mathrm{H},t}} \right)^{-\theta} (nC_{\mathrm{H},t} + (1-n)C_{\mathrm{H},t}^* + nI_{\mathrm{H},t} + (1-n)I_{\mathrm{H},t}^* + nA_{\mathrm{H},t}).$$

D. Calibration

In our baseline calibration, we parameterize the size of the Home country, n, to $\frac{1}{50}$to correspond to a U.S. state in our empirical data set. We use the following preferences

[19] Studying optimal taxation in a model with productive capital, Lansing (1998) assumes a production function with constant return to scale.

$$U\left(C_t, L_t\right) = \frac{C_t^{1-\sigma}}{1-\sigma} - \psi \frac{L_t^{1+\xi}}{1+\xi},$$

and set the coefficient of relative risk aversion, σ, to 1 and the value of ξ to imply a Frisch labor elasticity of 0.75, but we also consider alternative values in a our simulation exercises below to account for the uncertainty surrounding the empirical estimates of this elasticity. We calibrate the model to a quarterly frequency and set the discount factor, β, to 0.99. To determine the value of the elasticity of substitution across goods' varieties we use a markup of 20 percent in steady state, implying that $\theta = 6$.

The extent to which regions are relatively open to trade can have an important effect on the size of the fiscal multiplier through a "leakage" effect associated with movements in goods between regions. Our baseline calibration considers very open regions as we set the value of a_{H} and a_{H}^* to 0.5, which implies no home bias. Following Nakamura and Steinsson (2011), we will also examine the effects of less openness by letting a_{H} equal 0.69 in light of their evidence on goods shipments across U.S. states. Moreover, we assume that households view goods from different regions as being close to perfect substitutes, so that the expenditure switching effect is high in our model economy.

For the goods production function, we use a labor share of 70 percent. However, the range of empirical estimates of the output elasticity of public capital, ϕ_g, is very wide. In a review of the early estimates of this elasticity for the United States, Munnell (1992) reports the findings of 9 studies, with estimates ranging between 0.05 and 0.4. While we set $\phi_g = 0.1$ in our baseline model to facilitate comparison with other studies (e.g., King and Baxter (1993) and Leeper et al (2010)), we also experiment with different values given this uncertainty. In particular, we will examine the change in the fiscal multiplier when public capital is unproductive, i.e., $\phi_g = 0$.

We set the steady state value of the debt-to-GDP ratio to 38 percent, the average between 1990 and 2011 in the United States. We calibrate the steady state share of public investment in output to 3.8 percent in line with the 1991-2010 average value across states in our dataset. We assume that infrastructure spending are authorized for 4 years, about the same duration as the SAFETEA-LU bill covering 2005 through 2009 (inclusive), but less than the previous two bills that both lasted 6 years. We set the spending rate ω in equation (2.9) to be divided equally across quarters, except we assume an administrative lag of one quarter ($\omega_0 = 0$).Because a substantial fraction of the spending in highway bills is directed toward road improvement and maintenance instead of the construction of new roads, we assume that the time-to-build process in (2.10) takes only one year.

In our baseline, we assume that the national government uses income taxes and borrows to finance public spending. We first look at income taxes since, as discussed in **Section II** the Treasury Department has been known to transfer general funds, largely collected from income taxes, to cover any shortfalls in the Highway Trust Fund. However, we also examine consumption taxes since a major source of revenues for federal highway grants comes from fuel, tire, and truck-related taxes. As in Uhlig (2011) and Leeper et al (2010), we assume that taxes respond fairly slowly to changes in the debt-to-GDP ratio by setting ψ equal to 0.1. However, we also consider a version of the model in which the government cannot borrow and must finance infrastructure investments solely with income taxes.

The probability that firms update their prices is chosen such that prices are on average fixed for 4 quarters. The coefficients in the interest-rate rule are set to the values in Nakamura and Steinsson (2011) — $\rho_R = 0.8$, $\beta_\pi = 1.5$, and $\beta_y = 0.5$ — though monetary policy will not affect our estimates of the multiplier as it will be differenced out.

Finally, we set the persistence of the shocks to 0.95, a value consistent with regressing states' highway grants on one lag for the period covered by our dataset. Throughout our exercises, we look at the effect of one percent shocks to government spending.

E. Findings

In this section, we examine the theoretical analog to our empirical multiplier. As in **Section IV**, we apply Jorda (2005)'s local projection method on our simulated data. Specifically, we calculate the multiplier as a regression of the logarithm of regional output on its first lag and on the logarithm of regional public investment with state and time fixed effects.[20] We then compute an impulse response by stepping the dependent variable ahead through time and running the regression keeping the independent variables the same. The dynamic response of the

[20] In contrast to our empirical specification in Section V, here it unnecessary to include lags of government spending as the spending shock in our simulated data is, by construction, exogenous with respect to lagged output or spending.

multiplier is given by the series of coefficient estimates on public investment multiplied by the ratio of output to public investment in steady state.

Figure 9 reports our theoretical estimate of the dynamic multiplier in our baseline model, as well as under alternative specifications. The top left chart of the figure shows that the path of the multiplier is hump shaped in our model, rising to roughly 1.3 after 8 years, before starting to decline. This chart also shows the shape of the multiplier when public capital is less productive, $\phi_g = 0.05$, or not productive at all, $\phi_g = 0$. Lowering the output elasticity of public capital to 0.05 reduces the peak multiplier to just above 0.8. We find it reassuring that the local projection method is able to clearly distinguish between frameworks, imputing a much lower multiplier to the model with unproductive capital compared to our baseline framework.

The shape of the fiscal multiplier calculated using the local projection regression is in line with the responses of regional output in the model. In **Figure 10**, we report the responses of output, consumption, and hours worked in the two regions following an increase in public infrastructure spending in the Home region, as well as the Home region's terms of trade and net exports. Because government spending is productive, Home agents anticipate greater output in the future and raise their consumption as a result, which tends to boost output. In turn, households in the Home region supply more labor on impact, despite the positive wealth effects associated with higher public investment.

As shown in **Figure 11**, the impact multiplier is small in part because there is some "leakage" to the Foreign region immediately following the shock. Foreign output also tends to rise initially boosted partly by the rise in Foreign consumption arising from complete international risk sharing. Thereafter, relative output widens as the impact of a higher public capital stock on output materializes at Home, and as Foreign output declines due to higher income taxes, which are not offset there by higher public spending. Moreover, these increases in relative output are exacerbated by the high expenditure switching effect, which leads to a large increase in the Home region's net export. As a result, public investment has a bigger bang for the buck the more open is the economy receiving it and the more substitutable are goods across regions.

In the remaining charts of **Figure 10**, we look at the sensitivity of our result to the presence of nominal rigidities, the degree of openness, and two alternative ways of financing infrastructure spending: via either income or consumption taxes, with and without debt finance.

In each alternative specifications, we obtain a hump-shaped multiplier, similar in magnitude to our benchmark estimate, at least for the first 8 years, suggesting that our baseline result is fairly robust. Thereafter, the multipliers tend to decline more rapidly under the alternative frameworks. Following Nakamura and Steinsson (2011), we have also examined the effect of introducing GHH preferences on our multiplier and found that they tended to increase the multipliers slightly. Our results are also robust to relaxing the assumption that consumption risk is fully shared across regions.

Overall, using the local projection method, our model predicts that the effect of infrastructure spending rises slowly over time, peaking roughly 8 years after the start of public investment, with peak estimates ranging between 0.85 and 1.3. Interestingly, this general pattern is similar to that obtained by Leeper et al (2010) using a closed economy model and a very different measure of the multiplier, a "cumulative multiplier." This pattern also is consistent with the “second-round” peak multiplier we found empirically in Section IV. It remains a challenge, however, to account for the initial increase in the multiplier that we find empirically.

VI. Concluding Remarks

This paper analyzed the dynamic economic effects of public infrastructure investment. The prior literature on dynamic fiscal multipliers generally has shied away from studying this type of government spending because of several unique but challenging features of public infrastructure investment. First, how much and where the public sector invests in infrastructure often is a complicated, partially-decentralized process. In the United States and many other countries, infrastructure investment is administered primarily by lower-level governments, though the federal government provides much of the funding.

Second, infrastructure investment typically involves long implementation lags between when funding decisions are made, and hence when agents may begin acting on the knowledge of forthcoming spending, and when actual government outlays show up. This feature makes the standard measure of government spending, outlays, particularly unsuited for the purpose of identifying shocks to government infrastructure investment.

Third, and related, in order to given agents (especially local governments and private contractors) a sense of how much infrastructure funding will be available down the road, federal governments often lay out the levels of nationwide funding and/or the mechanism by which that funding is distributed geographically for several years in advance. This raises the possibility that government infrastructure spending could have macroeconomic effects even before the exact distribution of infrastructure funding is known, and potentially well before actual infrastructure production begins.

Finally, a defining characteristic of government infrastructure investment is that it is at least intended to increase the economic efficiency or productivity of the private sector. Productivity-enhancing government spending should have different macroeconomic effects than other types of government spending. For instance, the standard Neoclassical effect of increased government spending leading households to increase labor supply as they recognize the burden that spending has on the government's budget constraint is potentially offset if agents also recognize the positive wealth generated by the resulting productivity gains.

Given these unique features of public infrastructure investment, our paper utilized the institutional details behind public highway spending in the United States. Many aspects of the institutional mechanism behind how federal highway funds are distributed to U.S. states allow us both to avoid the potential pitfalls posed by the feature above and to turn them to our advantage in providing strong identification of exogenous shocks to infrastructure spending. In particular, federal funds are distributed to states based on strict formulas which are set many years in advance and make use of formula-factor data that are several years old, making these distributions exogenous with respect to current local economic conditions.

Furthermore, rather than simply use changes in these distributions directly as a measure of spending shocks, we constructed forecasts of these distributions based on information available to agents in the years prior to the distributions. We measured spending shocks as year-over-year changes in expected future highway spending in a given state.

Using these shocks to estimate dynamic panel regressions following the local projections approach of Jorda (2005), we found that highway spending shocks positively affect GDP at two specific horizons. There is a significant impact in the first 1-2 years and then a second-round effect after 6-8 years. The implied multiplier at both peaks is 1.5 to 2.0, which is within though on the higher end of the typical range of multiplier estimates. (For instance, Ramey (2011a) reports a range in the literature of 0.5 to 2.0.) In an extension, we found that the initial impact occurs only for shocks in recessions, while later effects are not statistically different between recessions and expansions.

A natural hypothesis is that the direct channel by which federal highway funding to a local area affects local economic activity is that federal highway grants lead state to spend more on highways. We confirmed that, at least in our data sample, there is a very strong flypaper effect for federal highway grants. Namely, one dollar of federal highway grants tends to increase overall highway spending at the state-level over the next 4 or 5 years by almost exactly one dollar.

In the final part of the paper, we used a theoretical framework to interpret our empirical findings. We looked at the multiplier in an open economy model with productive public capital in which states receive federal funds for infrastructure investment calibrated to capture the institutional framework of highway funding in the United States. Applying the local projection method to our simulated data, we found the peak multiplier to be between 0.8 and 1.3, roughly eight years after the initial increase in public investment, which is in line with the second-round effect that we found empirically. However, the model does not generate the large impact multipliers seen in the empirical results. One possible reason, suggested by our empirical finding that the impact multiplier only occurs for shocks during a recession, is that our model abstracts from important nonlinearities that cause cycle-dependent heterogeneity in the multiplier. Developing non-linear general equilibrium models capable of yielding such cycle-dependent multipliers is clearly a critical area for future research.

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Appendix A

Apportionment Mechanism for FHWA Grants

Sources:

FHWA (2005), "Analysis of the Conference Report to H.R.3 as filed on 7/28/05 (RTA-000-1664A)."

URL as of 11/3/2011: http://www.fhwa.dot.gov/safetealu/fundtables.htm

FHWA (1999), "Financing Federal-Aid Highways", Publication No. FHWA-PL-99-015.

FHWA (2007), "Financing Federal-Aid Highways", Publication No. FHWA-PL-07-017.

Bureau of Transportation Statistics (1992), "Intermodal Surface Transportation Efficiency Act of 1991 – Summary"

<u>TEA-21, FY1998-2003 (continued through 2004 via continuing resolutions)</u>

Step 1:

Each individual FHWA program's national budget authorization is provisionally apportioned to states based on formula factors, conditional on a minimum apportionment share of 0.5%:

$$A'_{pi} = A_p \left\{ \min\left[f_p\left(\frac{z^1_{pi}}{z^1_p}, \frac{z^2_{pi}}{z^2_p}, \ldots \right), 0.005 \right] \right\} \tag{1}$$

for each program p and state i. z denotes formula factors (e.g., highway lane-miles). "Primes" on variables indicate that they are provisional, not final, values.

Step 2:

Calculate provisional total FHWA apportionment for each state:

$$A'_i = \sum_p A_{pi} \tag{2}$$

Step 3:

Apply "Minimum Guarantee" constraint, which ensures that each state receives a minimum return, R, on its contribution to the Highway Trust Fund (HTF):

$$A_i = \max\left[A_i', RH_i\right], \tag{3}$$

where H_i is state i's contribution to the HTF. R is 90.5% during all TEA-21 years. Amounts required to satisfy the minimum-guarantee $\left(A_i - A_i'\right)$ come out of a separate Congressional appropriation. That is, it does NOT lower the apportionments determined by steps 1 and 2 for other states. This amount is called the Minimum Guarantee apportionment and is reported in Tables FA-4 on the FHWA Highway Statistics website.

SAFETEA-LU, FY2005-2009 (continued through FY2011 via continuing resolutions)

Steps 1 and 2 are the same as under TEA-21. In SAFETEA-LU, the Minimum Guarantee program (Step 3) is replaced with the "Equity Bonus" program. The Equity Bonus program also imposes a minimum guaranteed return, R, on contributions to the HTF (though now R varies by year: R=90.5% in 2005-6, 91.5% in 2007, and 92% in 2008-9), but also imposes two additional constraints. First, for states satisfying certain criteria, the state must receive a total FHWA apportionment share at least as great as its average share over the TEA-21 period. Second, for all states, the state must receive at least a specified percentage of its average annual apportionment (T_i) under TEA-21. This percentage (M) is 117% in 2005, 118% in 2006, 119% in 2007, 120% in 2008, and 121% in 2009.

The effect of these added constraints is to replace equation (3) with the following:

$$A_i = \max\left[A_i', RH_i, \frac{T_i}{T}A_i'D_i, MT_i\right], \tag{5}$$

where D is a dummy variable indicating whether the state is one of the selected states mentioned above.

The $A_i - A_i'$ amount is called the Equity Bonus apportionment and is reported in Table FA-4 on the FHWA Highway Statistics website. Note, however, that for years 2007 onward (only), the apportionments for the STP, NHS, IM, Bridge, CMAQ, and HSIP programs in Table

FA-4 include the amounts those programs received out of the equity bonus and the equity bonus apportionment in Table FA-4 excludes the amounts distributed to those core programs.

ISTEA, FY1992-1997

Steps 1 and 2 are the same as under TEA-21. But in ISTEA, the Minimum Guarantee program was more complicated. In addition to getting a minimum guaranteed return, R = 90.5%, on contributions to the HTF, states whose return on contributions to the HTF was below 100% ("donor" states) received an additional bonus.

Appendix B

Constructing Real-time Forecasts of Expected Future Highway Funding

Our objective is to forecast, as of the beginning of a given year *t*, the present value of current and future federal highway grants for each state, using only real-time information available at the beginning of *t*. At the beginning of year *t*, agents have the following information: (1) year *t* apportionments (grants) in each state *i* for each FHWA program *p* (along with the formula factors that determine these apportionments), (2) the path of nationwide apportionment authorizations for the remaining years of the current highway authorization legislation (which typically cover a 5-6 year period), and (3) the formulas used to distribute each program's grants to states for the remainder of the current legislation. What agents do <u>not</u> know is the future values of the formula factors that determine the distribution of grants for the remaining years of the current legislation, nor do they know (1)-(3) above for years beyond the current legislation.

To construct real-time forecasts of future highway grants, we follow and extend the methodology used by the FHWA Office of Legislation and Strategic Planning (FHWA 2005) in its report providing forecasts, as of 2005, of apportionments by state for the years of the 2005-2009 SAFETEA-LU highway bill. Basically, the methodology involves assuming that a state's current formula factors (as a share of the nation), and hence the state's current share of federal grants for each of the 17 FHWA apportionment programs, are constant over the forecast horizon. That is, the best guess of what the relative values of formula factors will be going forward is their current year relative values. Given apportionment shares for each program, one can then distribute to states the known nationwide totals for each program for the remaining years of the current legislation. One can then aggregate across programs to get a state's total apportionments in each of these future years.

We extend this methodology such that if one is forecasting for years beyond the current legislation, one assumes a continuation of the use of current formulas (i.e., one's best guess of the formulas to be used in future legislation is the formulas currently in use) and one assumes that nationwide apportionments by program grow with inflation from the last authorized amount in the current legislation.

More formally, we construct real-time forecasts of future highway grants by state using the following three-step procedure:

1. Let $A_{i,p,t+s} \equiv \omega_{i,p,t+s} A_{p,t+s}$ denote state i's apportionments for program p in year t+s, where $A_{p,t+s}$ is nationwide apportionments for program p and $\omega_{i,p,t+s}$ is state i's share of those apportionments. Calculate the forecast $E_t\left[A_{i,p,t+s}\right]$ for all p and for $s \geq 0$ by assuming that $\omega_{i,p,t+s} = \omega_{i,p,t}$ and using the known authorized levels of $A_{p,t+s}$ for year t+s within the current highway legislation. (Note that, for s = 0, $E_t\left[A_{i,p,t}\right] = A_{i,p,t}$.) For any year t+s beyond the last year of the current legislation, t+j, assume $A_{p,t+s} = A_{p,t+j}\left(1+\pi^e\right)^{s-j}$, where π^e is expected future inflation. We assume $\pi^e = 0.03$.

2. Sum across programs within state for each forecast horizon:
$$E_t\left[A_{i,t+s}\right] = \sum_p E_t\left[A_{i,p,t+s}\right].$$

3. Calculate the present value of current and expected future highway grants:
$$E_t\left[PV_i\right] = \sum_{s=0}^{4} \frac{E_t\left[A_{i,t+s}\right]}{(1+r)^s} + E_t\left[A_{i,t+5}\right] \frac{1}{1-\left(\left(1+\pi\right)/(1+r)\right)^5}.$$

We assume the real interest rate, r, is 0.08 and expected inflation, π, is 0.02. The last term in the equation above reflects the discounted, by $(1+\pi)/(1+r)$, infinite stream of expected grants based on apportionments as of year t + 5 (last possible known year of authorizations) growing with inflation in perpetuity.

Dealing with the Equity-Bonus/Minimum-Guarantee Apportionments

One complication for implementing the above is that the equity-bonus/minimum-guarantee apportionments are treated differently in the FHWA data tables in years prior to 2007 than they are for 2007 onward. Prior to 2007, apportionments for all programs in the FHWA highway statistics (Table FA-4) do not include any added amounts distributed to those programs from the pool of funds Congress authorizes to satisfy the equity-bonus/minimum-guarantee constraints discussed in Appendix X. For 2007 onward, however, the reported apportionments for the "core programs" (STP, NHS, IM, Bridge, CMAQ, and HSIP) include the amounts distributed from the equity-bonus/minimum-guarantee pool. Therefore, apportionments by program, $A_{i,p,t}$, from the raw FHWA data are not comparable before and after 2007. We handle this by distributing, for years prior to 2007, part of the equity-bonus/minimum-guarantee nationwide authorization to each of these core programs in proportion to their share of total FHWA authorizations for that year. This extra amount is added to the reported $A_{i,p,t}$ to get the true $A_{i,p,t}$ that we use in the steps above.

Data

Data on actual apportionments by program, state, and year ($A_{i,p,t}$), which also are used to construct apportionment shares ($\omega_{i,p,t}$), were obtained from FHWA Highway Statistics, Table FA-4 (various years). Data on nationwide authorizations by program and year ($A_{p,t+s}$) for each of the three highway authorization legislations during our sample period were obtained from FHWA (1992), FHWA (1999), and FHWA (2007).

Appendix C. Data Glossary

Format: **variable_name** – Data description. (Source)

BEA_employment – Total annual employment from the BEA's National Income and Product Accounts. (Haver Analytics/Bureau of Economic Analysis)

capoutlays_total – State highway agency total capital outlays, in millions of dollars. These data are obtained from the Office of Highway Policy Information's annual Highway Statistic Series publications. (Federal Highway Administration)

capoutlays_fedaid– State highway agency capital outlays on federal-aid highways, in millions of dollars. These data are obtained from the Office of Highway Policy Information's annual Highway Statistic Series publications. (Federal Highway Administration)

F_S – State government expenditures on construction of regular and toll highways, in millions of dollars. This variable is one of the components of **Shighway_gross**. (US Census Annual Survey of State & Local Government Finances)

FHWA_oblig – Total federal funds obligated by the Federal Highway Administration to state governments, in millions of dollars. These data are obtained from the Office of Highway Policy Information's annual Highway Statistic Series publications, Table FA-4B, various years. (Federal Highway Administration)

FHWA_apport – Federal Funds apportioned by the Federal Highway Administration to state governments, in millions of dollars. These data are obtained from the Office of Highway Policy Information's annual Highway Statistic Series publications, Table FA-4, various years. (Federal Highway Administration)

LNAGRA – Total nonfarm employment. The annual employment figure is the 12-month mean of monthly data over the calendar year. (Haver Analytics/BLS Establishment Survey)

population – Annual resident population (Haver Analytics/ US Census Bureau)

RealGSP_TO – Real gross domestic product by state, in millions of chained 2005 dollars. (Haver Analytics/Bureau of Economic Analysis)

Shighway_gross – State government highway expenditures, in millions of dollars. This data series is constructed from the Census Bureau's Annual Survey of State & Local Government Finances (SLGF). It is the sum, for regular and toll highways, of state government expenditures on state government expenditures on current operations; construction capital outlays; other capital outlays; and transfers to local governments for roads. (US Census Bureau)

totaldisbursements – Total state and local government disbursements for highways, in millions of dollars. These data are obtained from the Office of Highway Policy Information's annual Highway Statistic Series publications, Table SF-2, various years. Total disbursements are the sum of capital outlays; maintenance; administration, research and planning; highway law enforcement and safety; interest payments on highway bonds; bond retirement; and transfers to local governments for roads. (Federal Highway Administration)

YPH – Real annual personal income, in millions of chained 2005 dollars. (Haver Analytics/Bureau of Economic Analysis)

Table 1

FUND	FACTORS	WEIGHT	MINIMUM APPORTIONMENT	SHARE OF TOTAL FUNDS
Interstate Maintenance (IM)	Interstate System lane miles Vehicle miles traveled on the Interstate System Annual contributions to the Highway Account of the Highway Trust Fund attributable to commercial vehicles	33.33% 33.33% 33.33%	1/2 percent of Interstate Maintenance and National Highway System apportionments combined	18.2%
National Highway System (NHS)	Remainder apportioned as follows: Lane miles on principal arterial routes (excluding the Interstate System) Vehicle miles traveled on principal arterial routes (excluding the Interstate System) Diesel fuel used on highways Total lane miles on principal arterials divided by the State's total population	25% 35% 30% 10%	1/2 percent of Interstate Maintenance and National Highway System apportionments combined	22.1%
Surface Transportation Program (STP)	Total lane miles of Federal-aid highways Total vehicle miles traveled on Federal-aid highways Estimated tax payments attributable to highway users paid into the Highway Account of the Highway Trust Fund	25% 40% 35%	1/2 percent	23.3%
Bridge Replacement and Rehabilitation (BRR)	Relative share of total cost to repair or replace deficient bridges	100%	1/4 percent (10 percent maximum)	14.8%
Congestion Mitigation and Air Quality Improvement Program (CMAQ)	Weighted nonattainment and maintenance area population	100%	1/2 percent	6.1%
Recreational Trails Program (RT)	Equal shares to each eligible State Non-highway recreational fuel use during the preceding year	50% 50%	None	0.2%
Metropolitan Planning (MP)	Urbanized area population*	100%	1/2 percent	0.8%
Highway Safety Improvement Program	Total lane-miles of Federal-aid highways Total vehicle miles traveled on lanes on Federal-aid highways Total fatalities on the Federal-aid system	33.33% 33.33% 33.33%	1/2 percent	3.9%

* Usually places of 50,000 or more persons. Definition contained in 23 U.S.C. 101(a)

Note: Main programs only. Share of total funds will not sum to 100%.

Table 2

The Implementation Lags of Highway Spending

	FHWA Obligations β/SE	FHWA Outlays β/SE	FHWA Outlays β/SE
FHWA Grants	**0.773**	-	**0.291**
	(0.132)		**(0.087)**
FHWA Grants, Lagged 1 year	0.096	-	**0.339**
	(0.154)		**(0.106)**
FHWA Grants, Lagged 2 years	0.080	-	0.115
	(0.117)		(0.095)
FHWA Grants, Lagged 3 years	-0.002	-	0.093
	(0.039)		(0.074)
FHWA Grants, Lagged 4 years	0.028	-	0.026
	(0.038)		(0.024)
FHWA Grants, Lagged 5 years	-	-	**0.047**
			(0.023)
FHWA Grants, Lagged 6 years	-	-	**0.054**
			(0.016)
FHWA Grants, Lagged 7 years	-	-	0.017
			(0.016)
FHWA Obligations	-	**0.187**	-
		(0.019)	
FHWA Obligations, Lagged 1 year	-	**0.229**	-
		(0.034)	
FHWA Obligations, Lagged 2 years	-	**0.108**	-
		(0.022)	
FHWA Obligations, Lagged 3 years	-	**0.086**	-
		(0.020)	
FHWA Obligations, Lagged 4 years	-	**0.157**	-
		(0.031)	
FHWA Obligations, Lagged 5 years	-	**0.063**	-
		(0.031)	
FHWA Obligations, Lagged 6 years	-	-0.040	-
		(0.031)	
FHWA Obligations, Lagged 7 years	-	0.018	-
		(0.028)	
Year fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes
Cumulative Effect	**0.976**	**0.806**	**0.983**
	(0.076)	**(0.035)**	**(0.054)**
N	816	768	720
R^2	0.496	0.714	0.615

Notes: Bold indicates significance at 10 percent level. All variables are per-capita. Sample covers 1993 - 2009

<u>Table 3</u>

Response of GDP to Changes in the Expected Present Value of Federal Highway Grants
All Regressions Include a Year Trend

	Shock Variable β/SE	GDP_{t-1} β/SE	GDP_{t-2} β/SE	GDP_{t-3} β/SE	$Obligations_{t-1}$ β/SE	$Obligations_{t-2}$ β/SE	$Obligations_{t-3}$ β/SE
GDP_t	**0.012**	**1.138**	-0.009	**-0.218**	-0.003	0.006	0.010
	(0.004)	**(0.056)**	(0.087)	**(0.056)**	(0.007)	(0.005)	(0.006)
GDP_{t+1}	**0.011**	**1.124**	**-0.155**	**-0.167**	-0.001	0.006	**0.015**
	(0.006)	**(0.072)**	**(0.088)**	**(0.076)**	(0.010)	(0.008)	**(0.008)**
GDP_{t+2}	-0.001	**0.866**	-0.002	**-0.177**	0.001	0.008	0.024
	(0.009)	**(0.088)**	(0.076)	**(0.098)**	(0.008)	(0.007)	(0.015)
GDP_{t+3}	-0.009	**0.644**	0.041	-0.094	0.006	0.014	0.005
	(0.009)	**(0.100)**	(0.077)	(0.109)	(0.009)	(0.009)	(0.018)
GDP_{t+4}	-0.005	**0.397**	**0.260**	-0.144	**0.026**	0.003	-0.017
	(0.009)	**(0.108)**	**(0.078)**	(0.101)	**(0.011)**	(0.011)	(0.019)
GDP_{t+5}	**-0.020**	**0.388**	**0.244**	**-0.167**	0.020	-0.017	-0.022
	(0.008)	**(0.107)**	**(0.081)**	**(0.095)**	(0.013)	(0.014)	(0.019)
GDP_{t+6}	**0.019**	**0.358**	**0.278**	**-0.250**	0.006	-0.023	-0.018
	(0.006)	**(0.091)**	**(0.068)**	**(0.073)**	(0.017)	(0.015)	(0.017)
GDP_{t+7}	**0.040**	**0.480**	**-0.136**	-0.010	-0.014	-0.017	-0.016
	(0.008)	**(0.096)**	**(0.058)**	(0.068)	(0.018)	(0.014)	(0.015)
GDP_{t+8}	**0.034**	**0.301**	0.078	-0.107	**-0.034**	-0.025	0.015
	(0.009)	**(0.104)**	(0.078)	(0.069)	**(0.019)**	(0.015)	(0.014)
GDP_{t+9}	**0.029**	**0.249**	0.138	**-0.184**	**-0.047**	-0.002	**0.025**
	(0.009)	**(0.127)**	(0.089)	**(0.091)**	**(0.018)**	(0.013)	**(0.014)**
GDP_{t+10}	-0.002	0.206	0.081	-0.157	-0.023	0.005	**0.037**
	(0.009)	(0.144)	(0.107)	(0.109)	(0.018)	(0.013)	**(0.014)**

Notes: Bold indicates significance at 10 percent level. All regressions include state fixed effects.
FHWA obligations are measured in billions of dollars; GDP is measured in millions of dollars.
Sample covers 1993 - 2009. Variables are in logs.

Table 4

Response of GDP to Changes in the Expected Present Value of Federal Highway Grants

All Regressions Include Year Fixed Effects

	Shock Variable β/SE	GDP_{t-1} β/SE	GDP_{t-2} β/SE	GDP_{t-3} β/SE	$Obligations_{t-1}$ β/SE	$Obligations_{t-2}$ β/SE	$Obligations_{t-3}$ β/SE
GDP_t	**0.017**	**1.058**	-0.035	**-0.130**	-0.001	-0.003	-0.001
	(0.009)	**(0.050)**	(0.084)	**(0.057)**	(0.008)	(0.004)	(0.006)
GDP_{t+1}	0.015	**1.075**	**-0.223**	-0.073	-0.003	-0.006	0.000
	(0.011)	**(0.079)**	**(0.081)**	(0.082)	(0.010)	(0.007)	(0.007)
GDP_{t+2}	-0.013	**0.816**	-0.100	-0.050	-0.003	-0.005	-0.004
	(0.012)	**(0.107)**	(0.084)	(0.098)	(0.007)	(0.006)	(0.013)
GDP_{t+3}	-0.019	**0.658**	-0.108	0.018	-0.002	-0.012	0.000
	(0.014)	**(0.114)**	(0.079)	(0.113)	(0.008)	(0.011)	(0.015)
GDP_{t+4}	-0.015	**0.466**	0.022	-0.012	-0.005	-0.006	0.002
	(0.012)	**(0.124)**	(0.083)	(0.101)	(0.011)	(0.012)	(0.016)
GDP_{t+5}	-0.010	**0.385**	-0.015	0.027	0.003	-0.002	-0.010
	(0.012)	**(0.119)**	(0.110)	(0.094)	(0.013)	(0.014)	(0.016)
GDP_{t+6}	0.003	**0.277**	0.049	-0.004	0.011	-0.012	-0.010
	(0.011)	**(0.109)**	(0.086)	(0.078)	(0.016)	(0.013)	(0.015)
GDP_{t+7}	**0.017**	**0.278**	**-0.118**	**0.127**	0.005	-0.012	-0.011
	(0.008)	**(0.111)**	**(0.062)**	**(0.072)**	(0.016)	(0.013)	(0.016)
GDP_{t+8}	**0.016**	0.180	-0.046	**0.137**	-0.006	-0.017	-0.003
	(0.008)	(0.120)	(0.090)	**(0.078)**	(0.016)	(0.014)	(0.016)
GDP_{t+9}	0.007	0.150	-0.039	0.137	-0.019	-0.007	-0.003
	(0.008)	(0.116)	(0.073)	(0.085)	(0.016)	(0.013)	(0.015)
GDP_{t+10}	-0.002	0.114	0.010	0.083	-0.009	-0.006	-0.001
	(0.008)	(0.144)	(0.111)	(0.091)	(0.016)	(0.015)	(0.014)

Notes: Bold indicates significance at 10 percent level. All regressions include state fixed effects.
FHWA obligations are measured in billions of dollars; GDP is measured in millions of dollars.
Sample covers 1993 - 2009. Variables are in logs.

Table 5

State Government Highway Spending Regressed on Federal Highway Grants

	1993-2009 Total Highway Outlays β/SE	1993-2009 Highway Capital Outlays β/SE	1993-2009 Highway Construction Outlays β/SE	1987-1997 Total Highway Outlays β/SE	1987-1997 Total Highway Outlays β/SE
FHWA Grants	**0.384**	0.183	**0.313**	0.011	0.158
	(0.206)	(0.210)	**(0.182)**	(0.038)	(0.202)
FHWA Grants, Lagged 1 year	0.248	0.191	-0.013	-	0.040
	(0.241)	(0.244)	(0.213)		(0.050)
FHWA Grants, Lagged 2 years	0.247	**0.337**	**0.492**	-	0.015
	(0.183)	**(0.181)**	**(0.162)**		(0.049)
FHWA Grants, Lagged 3 years	0.035	0.062	0.038	-	-0.026
	(0.061)	(0.058)	(0.054)		(0.035)
FHWA Grants, Lagged 4 years	0.083	**0.105**	0.078	-	-0.035
	(0.059)	**(0.056)**	(0.052)		(0.035)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes
Cumulative Effect	**0.998**	**0.877**	**0.909**	0.011	0.153
	(0.119)	**(0.120)**	**(0.105)**	(0.038)	(0.223)
N	816	763	816	528	336
R^2	0.285	0.188	0.203	0.059	0.051

Notes: Bold indicates significance at 10 percent level. All variables are per-capita.

Figure 1

Federal-Aid Highways

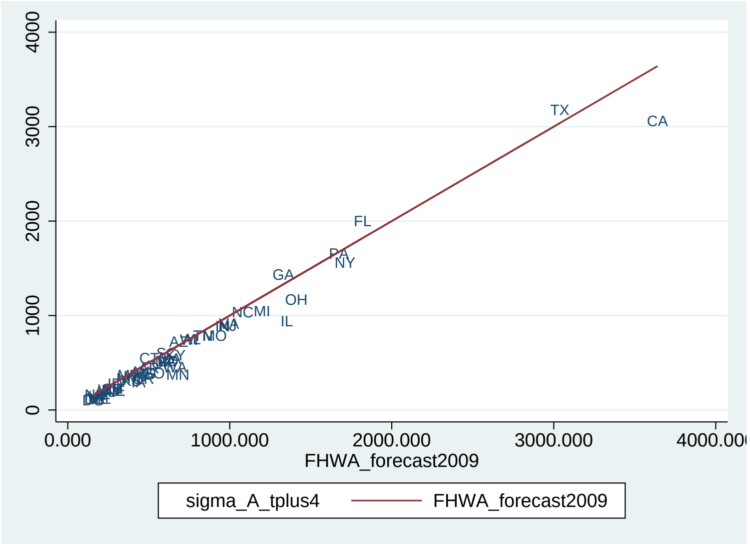
INTERSTATE 11
OTHER FWY OR EXPWY 12
OTHER PRINCIPAL ARTERIAL 14
MINOR ARTERIAL 16
COLLECTOR 17

Non Federal-Aid Highways

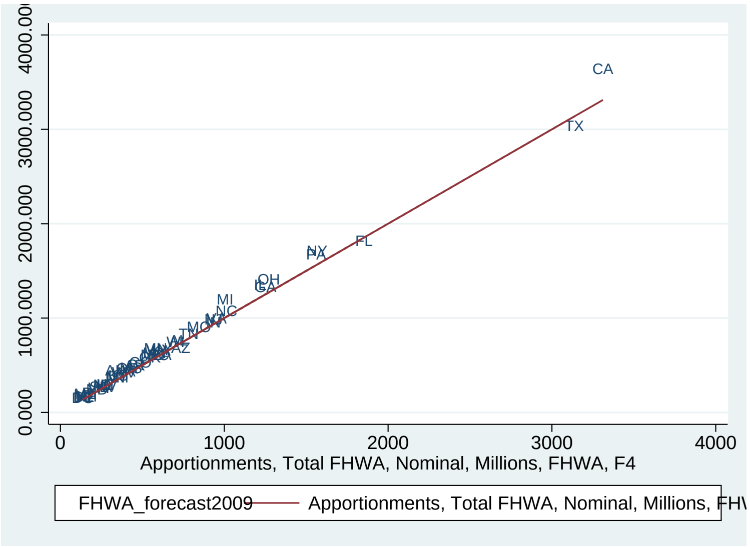
LOCAL 19

Figure 3

Panel A



Panel B



Panel C

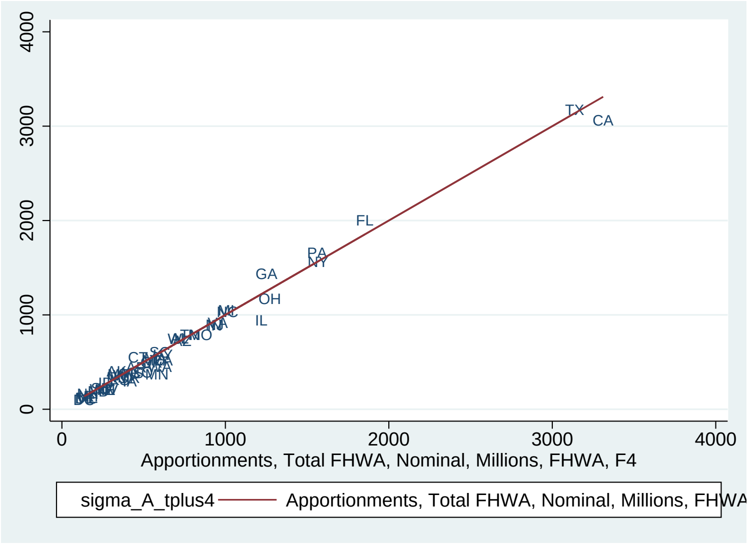


Figure 4

Change in Expected Present Value of Federal Highway Grants by State

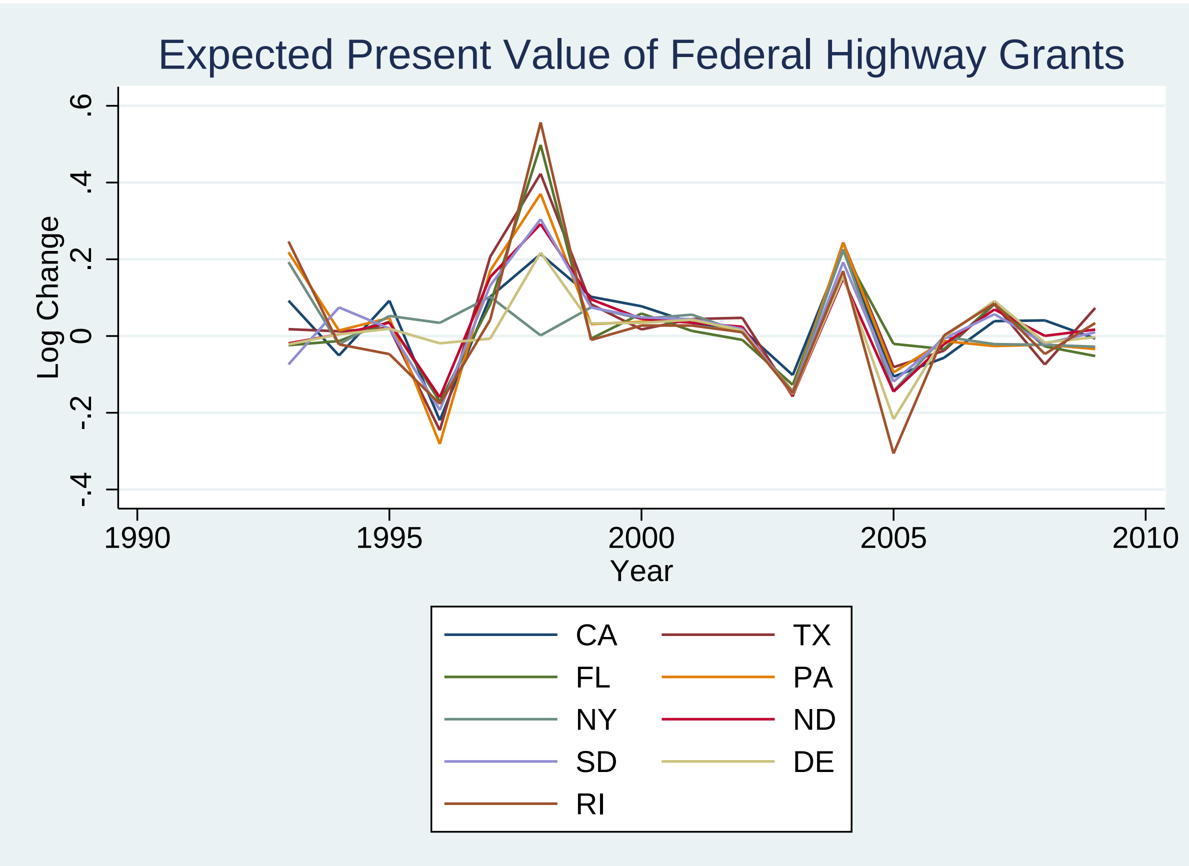


Figure 5

OLS IRF of state GDP with respect to the expected present value of FHWA grants, with a year trend

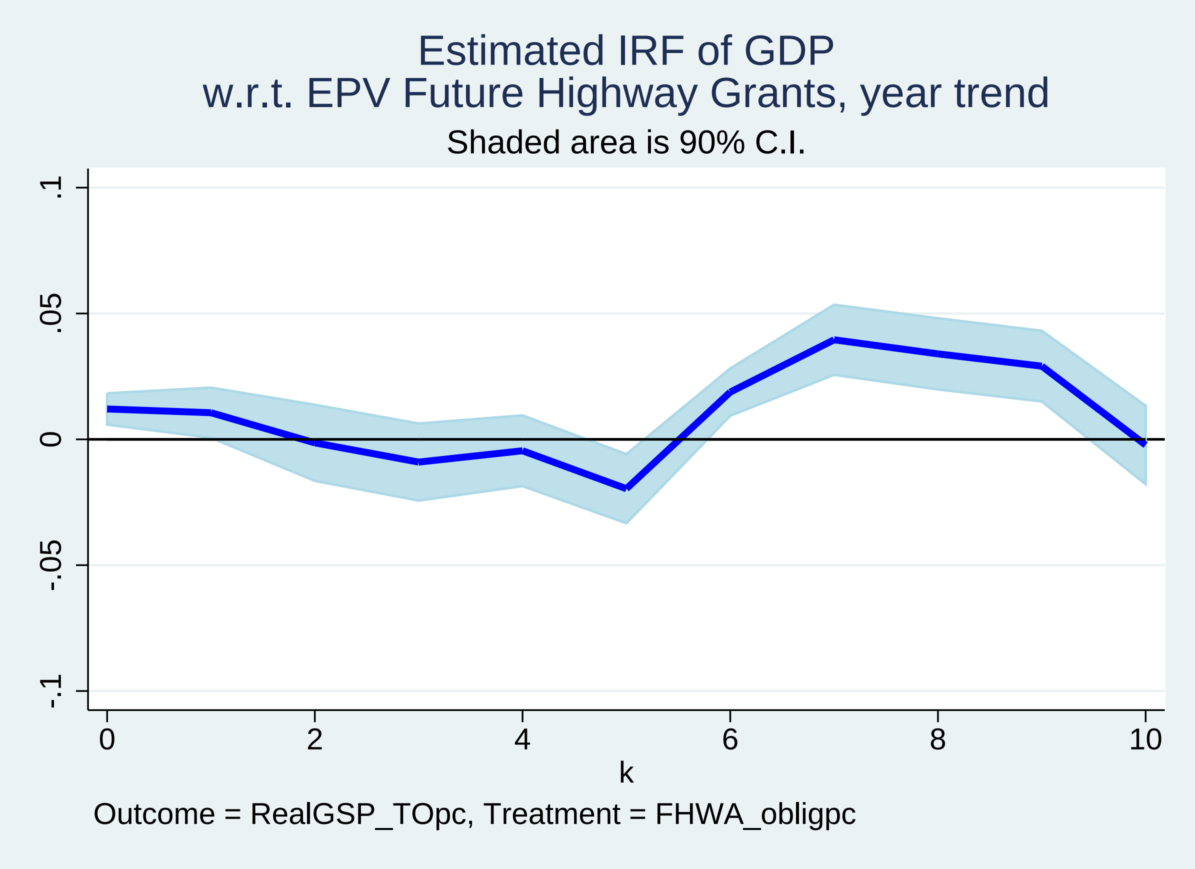


Figure 6

OLS IRF of state GDP with respect to the expected present value of FHWA grants, with year fixed effects

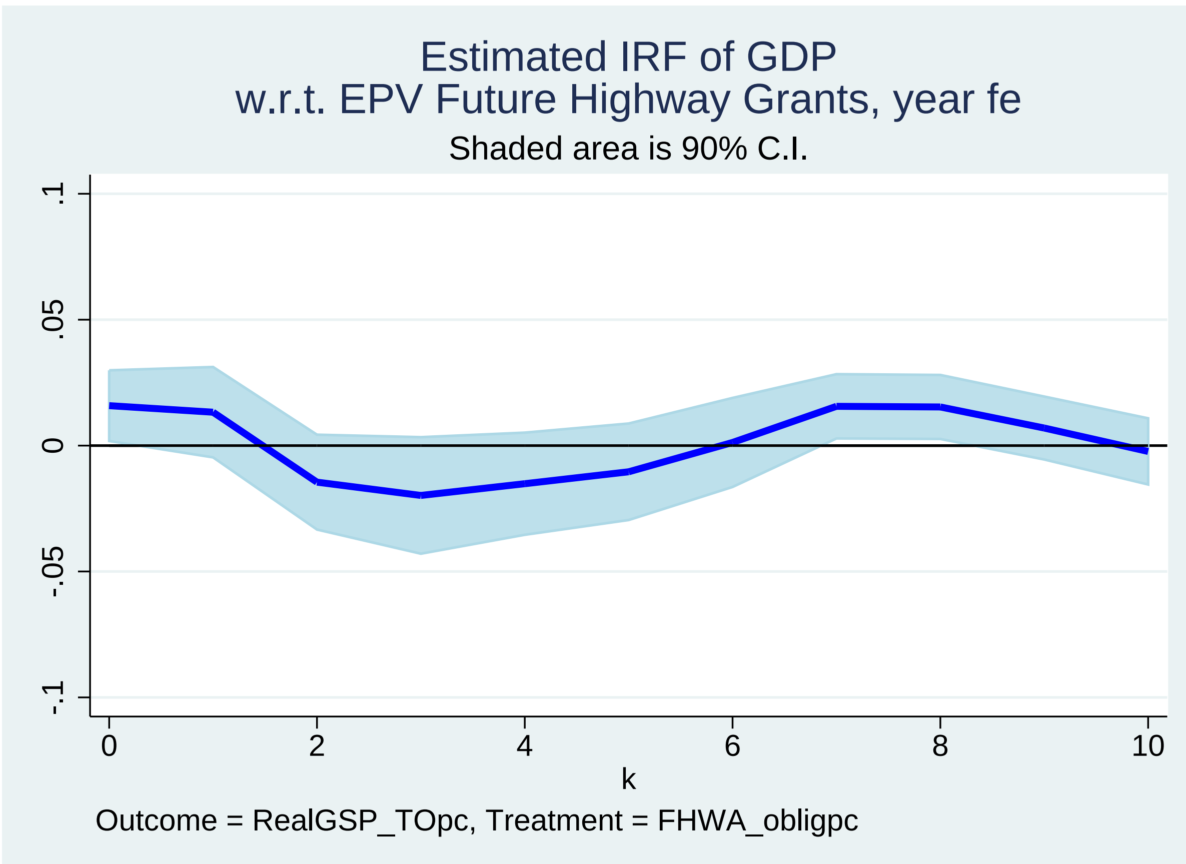


Figure 7

IV IRF of state GDP with respect to the expected present value of FHWA grants, with year fixed effects

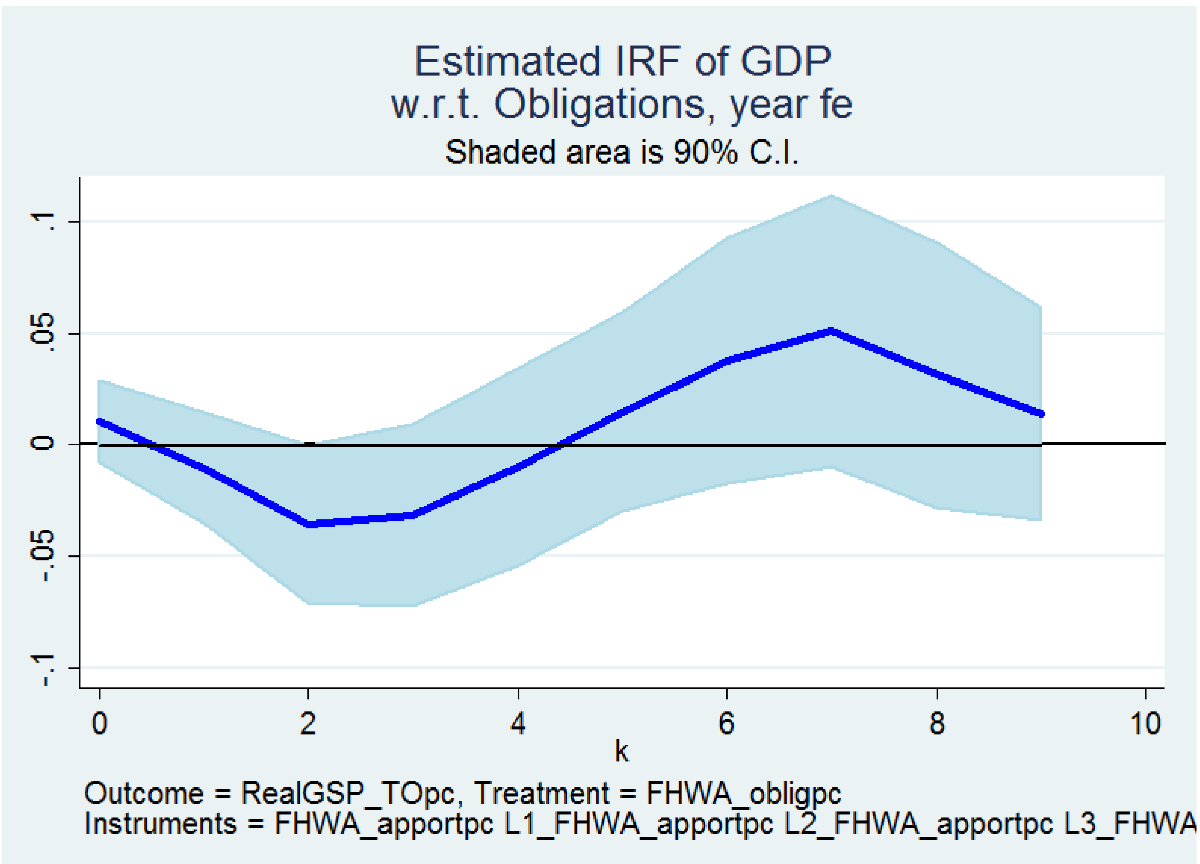
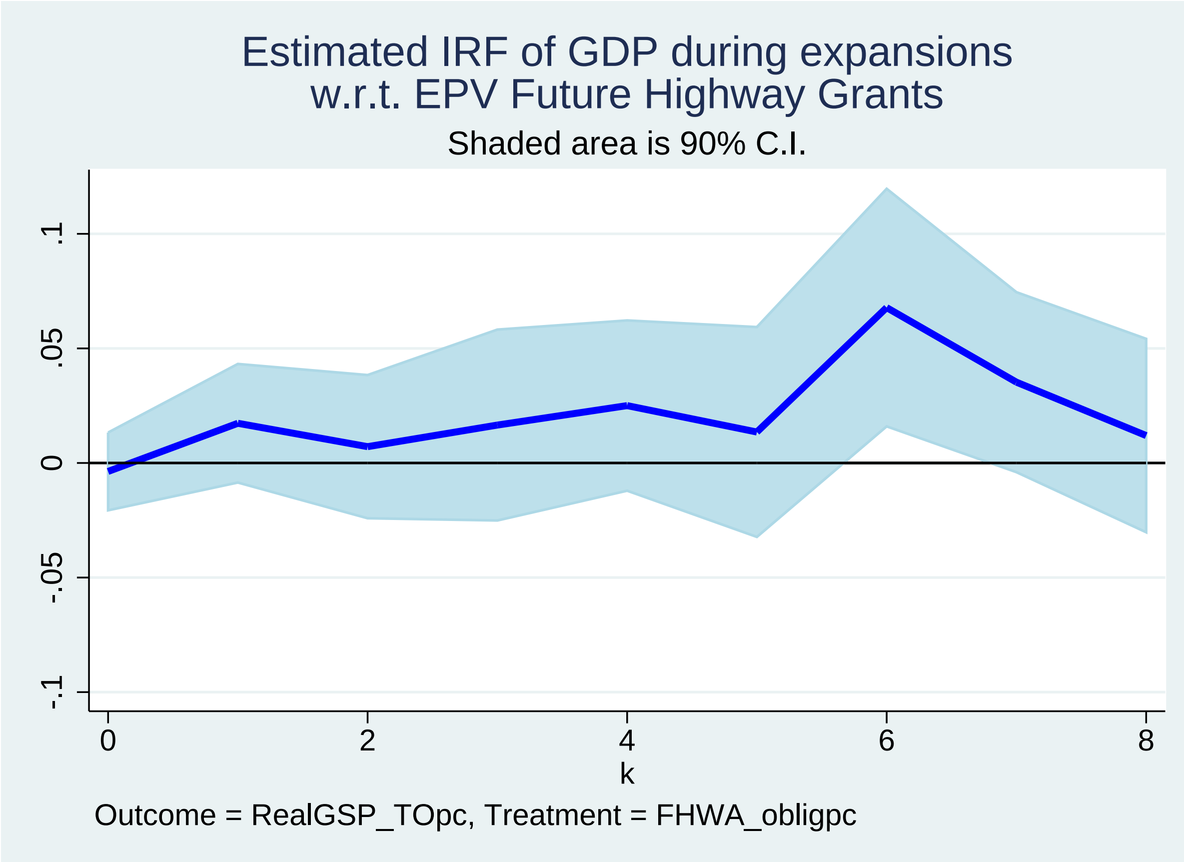


Figure 8

Panel A



Panel B

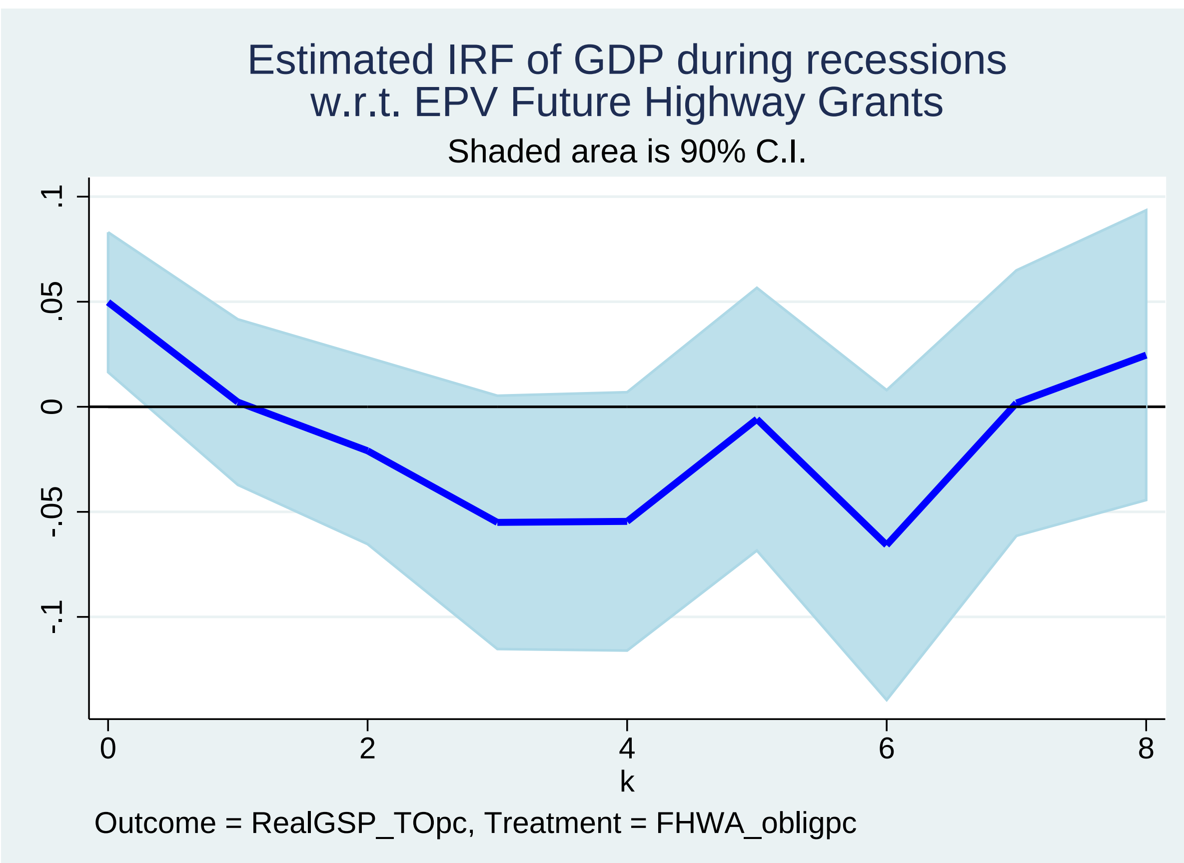
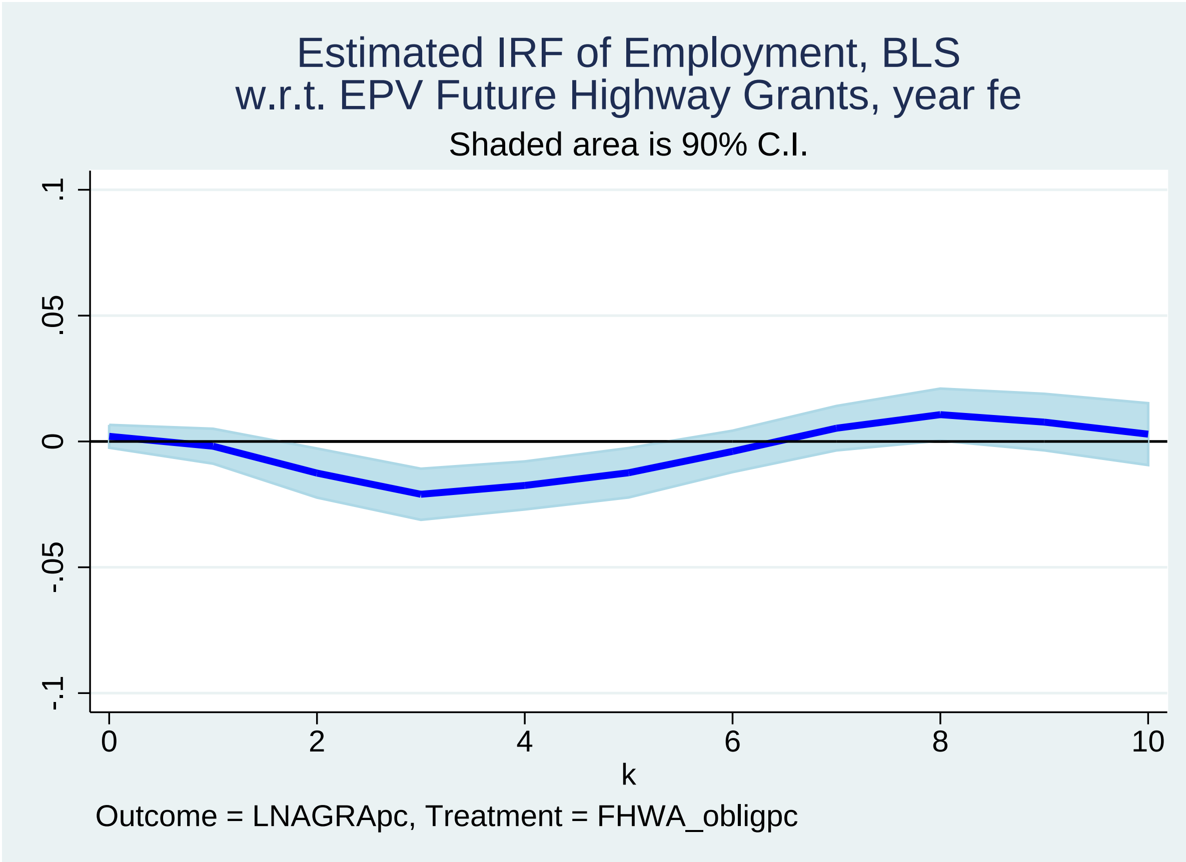


Figure 9

Panel A



Panel B

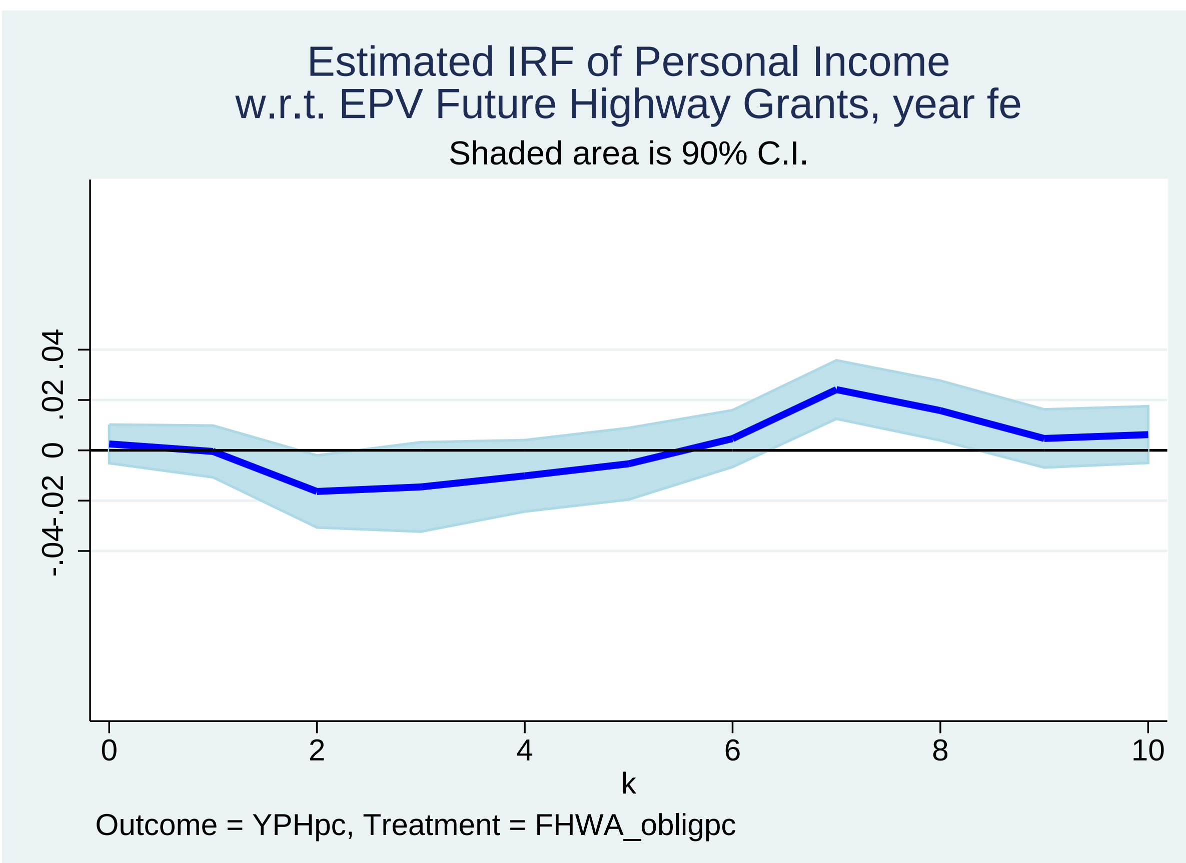


Figure 10
Theoretical Multipliers

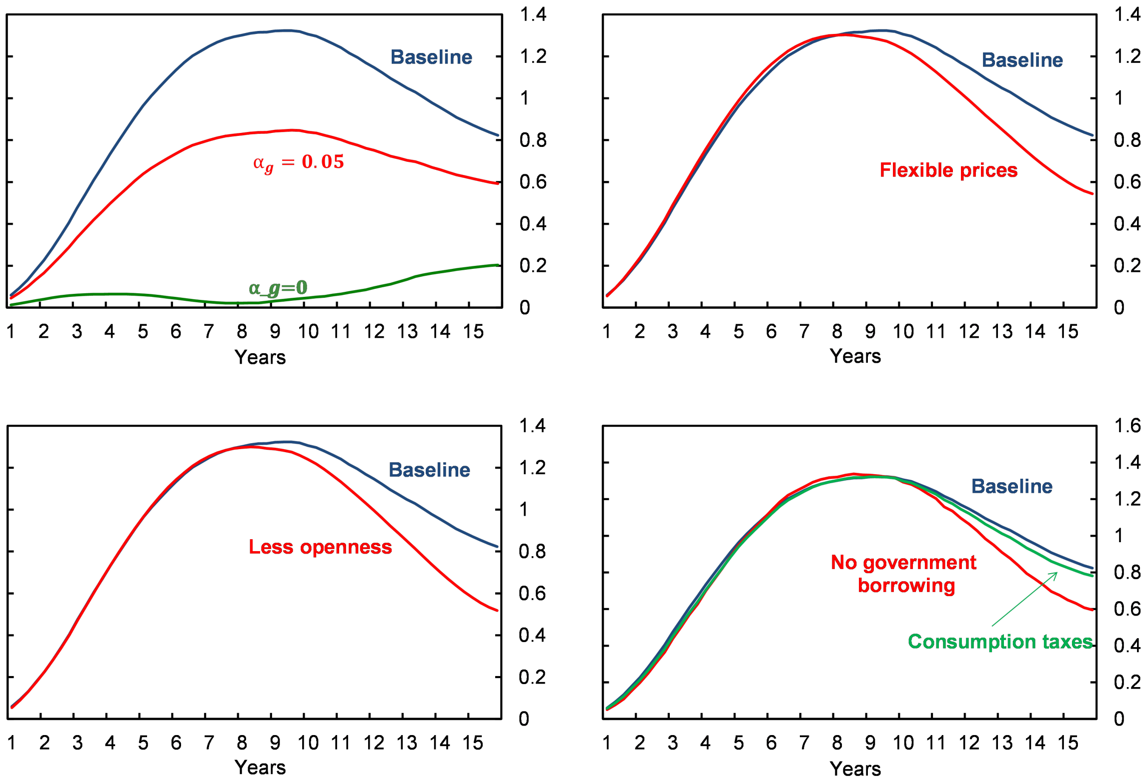


Figure 11

Responses to a Home Increase in Public Spending