Online Appendix

to

The Economic Impact of Seaport and Other Infrastructure Investments and Leakages:

A Literature Review*

by

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In this appendix, we critically review the quantitative and qualitative evidence that seeks to answer the questions of what the economic benefits from infrastructure investments are and, to whom do these benefits accrue. The purpose of this broad review is to establish the some background knowledge on the effects of public capital expenditure and create the context against which we can evaluate our detailed survey of the literature that evaluates the economic impacts of seaport infrastructure investments. Through our wide-ranging review, we find that the expected economic impacts of broadly defined public capital spending, and expenditures on transport infrastructure investment in particular, are a heavily debated subject with a longstanding history in the economic literature.[1] Primary points of disagreement are the quantification of economic benefits[2], such as the reduction in transport costs or induced rise in employment and earnings, and their potentially uneven distribution across the public.[3]

The outline of this appendix is as follows. First, we preempt our survey by carefully defining the benefits from infrastructure investments and discussing the channels through which these benefits can arise in Section A.I. Given the multitude of these benefit mechanisms, begin our review by summarizing the early literatures studying the macroeconomic productivity effects of general public capital expenditures (Section A.II). As the literature has naturally evolved from these national estimates, we then survey a host of studies that contemplate geographically disaggregated infrastructure investment impacts. We highlight the methodological approaches and

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[1] Examples of early studies in this field are given by Ciriacy-Wantrup (1955), Margolis (1957), or Mohring (1961).

[2] Gramlich (1994), Gillen (1996), Jiang (2001), Bhatta and Drennan (2003), and Pereira and Andraz (2013) have provided excellent surveys on this debate and offer key insights into the potential sources driving the divergence of the initial estimates.

[3] Venables et al. (2014) note that "distributional issues are important more widely. Society may value additional income accruing to poor people more than to rich, or to citizens more than to foreigners: the latter issue arises if land rent and land value uplift accrues to overseas landowners."

empirical findings identifying the direct/local effects of such investments as well as the indirect/spatial spillover effects of public spending (Section A.III). Since productivity gains are not the only benefits of public capital expenditures, we also review the existing body of research on the direct and indirect labor market effects in this context of broadly defined public infrastructure spending (Section A.IV) and differentiate studies that have investigated inter-industry differences in investment benefits (Section A.V). Lastly, we turn our attention to a detailed survey of the literature examining the economic benefits of transport infrastructure investments (Section A.VI), which allows us to frame and contrast our review of quantitative and qualitative evidence on the economic effects of seaport investments (main paper).

Overall, the surveyed literature, and in particular the more recent studies with sound empirical strategies (i.e. Duranton and Turner, 2012; Allen and Arkolakis, 2014; Donaldson, 2018), seem to suggest a positive economic impact of transport infrastructure investments in aggregate. Based on our review, however, we would also argue that to this date there is no consensus on the overall magnitude of the macroeconomic gains from such investments. Estimates range from moderate earnings and employment growth effects in the United States and other developed countries (Duranton and Turner, 2012; Möller and Zierer, 2018), to profound increases in output and productivity in developing countries (see, for example, Donaldson, 2018). Moreover, we find that the diversion of earnings and employment benefit estimates is even more striking at the regional and local levels within a country. Throughout our review, we find that the localized effects are subject to a significant degree of volatility that hinges on regional attributes, such as the industrial composition, and the specific transport infrastructure under consideration (Friedt, 2018; Monte et al., 2018).

Despite this large degree of controversy and significant variation across individual studies, we are able to generalize the heterogeneous findings and summarize our literature review in this appendix with the following points of emphasis:

- Public capital investments tend to have positive economic impacts on earnings and employment;
- Positive industry-level effects are generally concentrated in construction, manufacturing, and transport as well as transport-related sectors;
- Infrastructure investment, particularly those in transport networks, create spatial spillover effects that are of generative and redistributive nature.

Additionally, our main survey illustrates that the economic spillover effects transcend national borders and lead to significant international benefit leakages that are particularly pronounced for seaport investments.

A.I Benefits of public capital

Economic studies analyzing the public benefits of infrastructure have a longstanding history in the academic and regulatory literatures. While regulatory research attempting to measure the economic benefits accruing from public capital typically employ narrow cost-benefit-analyses of local projects, academic works range from macroeconomic studies estimating the influence of various types of infrastructure on aggregate output, labor, and productivity to microeconomic research exploring these responses at the urban equilibrium level of analysis. As the complexity and challenges of capturing the entire spectrum of benefits has long been recognized in the literature, each of these approaches has received considerable attention and criticism.[4]

[4] While early research by Ciriacy-Wantrup (1955), Margolis (1957), and Maass (1966), for example, point to the shortcomings of traditional cost-benefit-analyses, Holtz-Eakin (1994), Hakfoort (1996), and Gillen (1996), among others, highlight the empirical misspecifications in macroeconomic production function estimations.

We begin our survey carefully defining the various economic benefits that are potentially attributable to public capital. Exploring these channels and following the extensive literature, we then approach the topic with broad strokes highlighting the main findings pertaining to the macroeconomic effects of infrastructure. Plagued with a host of empirical and conceptual challenges, we refine the picture succinctly summarizing the research that expands upon these macroeconomic studies and offers a variety of amendments and extensions. Among the most prominent advances that we discuss are the inclusion of domestic spatial spillovers, the evaluation of factor price and labor market adjustments, and disaggregated industry analyses.

Examinations of the benefits focus on three areas. These are identifying the societal benefits from public capital expenditure, estimating the contribution of infrastructure to national welfare, and determining the effect of public infrastructure spending on the distribution of income. Ciriacy-Wantrup (1955) intuitively addresses each of these points. In his view, the benefits are multilayered and include the direct impact on economic activity, such as the positive demand shock on the construction sector or transport cost reductions valued by manufacturing firms, as well as the indirect effects spilling over across different markets and/or geographic boundaries, such as the positive demand shock experienced by the transport and transport-related service sectors. Lastly, these benefits include the "intangibles" (Ciriacy-Wantrup, 1955). While the interpretation of the direct and indirect effects is straightforward, the intangibles can be thought off as the simultaneity between infrastructure and the larger economy in which it exists. This simultaneity gives rise to a complex system in which economic agents not only receive direct benefits from cost savings and market access, for example, but also adjust their behavior in response.[5] Batten and

[5] Cautioning against the naïve interpretation of aggregate production function estimates, Haughwout (1998) develops a spatial general equilibrium model that clearly depicts the potential biases arising from the interrelations between public capital, production, as well as the markets for labor and land. As Haughwout (1998) clearly explains,

Karlsson (2012) state, *"many counterintuitive outcomes between productivity and infrastructure stem from our ignorance about the complicated dynamic relationships between changes to the network itself and those occurring within the traffic using the network."*

This endogeneity dictates that the overall benefits of infrastructure depend on not only the direct user effects, but also the response of users to the availability of infrastructure. This, in turn, creates a dynamic feedback effect. Informing the analysis, Hakfoort (1996), Haughwout (1996), Eddington (2006), as well as Laird and Venables (2017) develop intuitive frameworks that break down the direct, indirect, and intangible channels of infrastructure benefits highlighted by Ciriacy-Wantrup (1955). The results are a variety of microeconomic mechanisms through which public capital can create economic benefits. While the direct effects are described as 'user benefits', which may include positive productivity and amenity effects, such as reductions in transportation costs and travel time, the indirect impact involves proximity effects, such as greater market access that results in investment and land use changes (Eddington, 2006; Laird and Venables, 2017). In contrast, the intangible components of the benefits to infrastructure are accounted for via employment and factor price adjustments and are best captured by an urban equilibrium model. In short, this theory suggests that household and firm location decisions adjust to the spatial variation in infrastructure and lead to the simultaneous determination of infrastructure investments and jurisdictional employment and factor prices, such as wages and land rents (Roback, 1982; Haughwout, 1996; Duranton and Turner, 2012; Albouy and Farahani, 2017; Friedt, 2018).[6]

"in a spatial equilibrium context, the relationship between public goods and aggregate output is a combination of their productivity, their effects on local prices, and the responses of local producers and workers to local price changes." (p. 226).

[6] Maass (1996) contributes to this discussion of the economic benefits arising from public capital expenditures noting that policy objectives may include a much broader range of desirable outcomes than cost-efficiency, such as income redistribution. Accordingly, policy should be designed and evaluated against the full set of these objectives.

A.II Macroeconomic productivity gains

When considering the macroeconomic impact of infrastructure, the estimation of aggregate production functions dependent on public capital constitutes a natural point of departure. Such estimates provide a benchmark for the net macroeconomic benefits of public capital including the direct, indirect and intangible effects averaged across all types of infrastructure. Although initial production function estimations by Mera (1973) considered the regional effects of infrastructure in the case of Japan, it was not until Aschauer (1989) that this important issue gained significant popularity among the academic community. In his seminal study, Aschauer estimates an aggregate production function and reports an output elasticity with respect to infrastructure of 0.39. The implications of this finding drew much attention, as it suggested that the return on public capital is about twice as large as the return on private capital (Aschauer, 1990) and enough to attribute the U.S. productivity slowdown in the 1970s to the simultaneous stagnation in infrastructure spending.

Since Aschauer's insight, the literature on the macroeconomic effects of public capital, and transportation infrastructure in particular, has taken off. Empirical scrutiny of the initial result has led to substantial controversy in the related literature and a number of output elasticity estimates ranging from Aschauer's benchmark estimate of 0.39 to insignificant overall effects (Munnell, 1990 and 1992; Hulten and Schwab, 1991; Garcia-Mila and McGuire, 1992; Holtz-Eakin, 1994; Evans and Karras, 1994, Fernald, 1999; Pereira, 2000; Cohen and Morrison Paul, 2004; Crescenzi and Rodriguez-Pose, 2011).[7] Instinctively, the explanations for the wide array of statistical results are grounded in the microeconomic mechanisms that govern the direct, indirect, and intangible effects, as well as concerns over the econometric production function specification.

[7] While Gramlich (1994), Gillen (1996), Button (1998), Jiang (2001), Bhatta and Drennan (2003) and Pereira and Andraz (2013) provide excellent surveys of the early literature on this debate, Melo et al. (2013) and Elburz et al. (2017) offer meta-analysis disentangling the common findings from the persistent controversy.

Concrete criticisms have been raised by a number of authors and are summarized in Gillen (1996) as well as Button (1998). The most prominent criticisms include ad hoc modeling frameworks, such as the aggregate production function, or spurious correlations that result from the problematic time-series properties of macroeconomic data (see, for example, Pereira, 2001). Moreover, the research has been criticized for a failure to control for congestion and other negative externalities, such as air pollution, that may arise from the redistribution of economic activity and reorganization of traffic flows. Lastly, the literature has expressed concern over biased cost-benefit analyses that ignore the simultaneity of infrastructure and adjustments in logistics, private investment and labor markets (Gillen, 1996).[8] Overall, these criticisms and inconsistency in output elasticity estimates have cast significant doubts over the macroeconomic impact of public capital expenditure (Button, 1998). We present a succinct overview of this literature and the relevant output elasticity point estimates in Table A.1. While the employed methodologies are similar across the highlighted studies, the reported elasticity estimates range greatly from -0.344 to 0.5.

A.III Direct effects and geographic spillovers

Responding to these criticisms, the literature has turned towards more disaggregate analyses at the state, metropolitan, and county levels, both within the U.S. and abroad, differentiating between the direct local impact of public capital and its indirect peripheral spillovers. Over time, these refinements have produced a rich set of studies that disentangle the direct effects in terms local output, employment and wage changes from geographic spillover effects.

[8] Pereira (2001), for example, shows that aggregate public investment, and sewage and water supply systems in particular, crowd in aggregate private investment, and industrial as well as transportation equipment in particular. Haughwout (1998, 2002) provides evidence of the simultaneous adjustments of local factor prices to changes in infrastructure that undermine and invalidate the conclusions drawn from production function estimations.

The push for more disaggregated analyses is grounded in the idea that domestic spillovers arising from public capital are more localized and may bias macroeconomic estimates leading to misinformed policy guidance (Munnell, 1992; Boarnet, 1998). A negligible estimate of the macroeconomic impact of seaports, for example, may confound a positive direct effect on the port community and offsetting negative spillovers in neighboring locales, or vice versa. Additional sources for this bias include the fact that macroeconomic studies tend to average across multiple types of public capital. Boarnet (1998), for example, points out that public capital is comprised of *'point'* and *'network'* infrastructures that vary in their respective economic impact. The distinction is based on the services offered. Whereas a *point* infrastructure, such as water and sewage systems, can offer local cost savings that attract economic activity away from neighboring regions causing negative spillovers, a *network* infrastructure, such as roads, can reduce trade costs for remote neighbors leading to positive spillovers and dispersion of economic activity (Boarnet, 1998).

To control for these different types of infrastructures and disentangle positive from negative spillover effects, the literature has innovated the definition of what constitutes a 'close' neighbor that is likely to be affected by local infrastructure investments and differentiated across various types of public capital expenditure. The most intuitive notion of 'closeness' is based on physical distance or contiguity across regions, states or counties and used by a host of studies including, for example, Forkenbrock and Foster (1990), Bergman and Sun (1996), Chandra and Thompson (2000), Ozbay et al. (2007), Moreno and López-Bazo (2007), Crescenzi and Rodriguez-Pose, (2011), and Arbues et al. (2015). Forkenbrock and Foster (1990) as well as Ozbay et al. (2007), for example, focus on the effects of highway capital on output and define closeness based on contiguity. Forkenbrock and Foster (1990) estimate the impact of a four-lane highway construction from St. Louis, Missouri, to St. Paul, Minnesota, on transport costs prevailing in counties contiguous to the roadway improvement and find that transport cost savings are marginal. In contrast, Ozbay et al. (2007) focus on counties located in the states of New York and New Jersey. As expected, the authors find a positive direct effect of highway capital on gross county product (GCP) and a significant reduction in GCP arising from the cumulative highway capital of neighboring counties. Moreno and López-Bazo (2007) provide complementary evidence from manufacturing sectors located in Spanish provinces. In this study, both local and transport infrastructures exhibit positive direct effects on the value added of manufacturing firms, while transportation infrastructure investment causes negative spillover effects in proximate provinces.

Unlike Forkenbrock and Foster (1990) and Ozbay et al. (2007), Bergman and Sun (1996) employ a distance decay function to measure proximity. Accounting for various types of infrastructures and differentiating between urbanized and rural counties, Bergman and Sun (1996) find that only urbanized counties experience positive direct effects from local infrastructures, whereas rural-county productivity, measured by value added per manufacturing employee, varies with regional infrastructure access. Importantly, the authors find that not all types of infrastructure lead to these positive rural productivity spillovers. In fact, the results suggest that interstate highways have negative output effects in rural counties that are attributable to a drain of skilled labor and production towards more urbanized agglomerated counties.

Boarnet (1998) is the first to deviate from geographical distance as the primary determinant of closeness and, in addition to distance, uses a host of alternative specifications that arguably affect factor mobility. The resulting estimations are based on a spatial lag model where the likeness of counties and the ease of factor mobility are measured by spatial weights based on the relative difference in county characteristics, such as per capita income, population density, or industrial composition. The intuitive insight is that counties with a greater degree of similarity within this characteristic space are more susceptible to spillover effects from infrastructure. The results are consistent with expectations. That is, Boarnet (1998) finds a positive direct effects of public capital on GCP and negative spillovers across counties of similar economic and demographic characteristics. In fact, the author concludes, “the evidence here suggests that negative spillovers are strongest across similarly urbanized counties, and that similarly urbanized counties are close competitors for mobile factors of production.” (Boarnet, 1998, p. 395)

While all of these results indicate negative indirect effects arising from infrastructure in locales of close proximity and likeness, none of the previous studies consider spillovers arising in economically integrated communities. Addressing this gap in the literature, Cohen and Morrison Paul (2004) and Cantos et al. (2005) estimate the direct and indirect effects of infrastructure across economically integrated regions by constructing spatial weights based on the relative level of bilateral trade. Although Cohen and Morrison Paul (2004) and Cantos et al. (2005) take different empirical approaches (total cost function vs. production function) and estimate the effects in the U.S. and Spain, respectively, the results are quite comparable. While local motorway infrastructure reduces U.S. manufacturing cost and increases Spanish provincial value added in the directly affected area, highway infrastructure in economically integrated locales causes positive spillovers across trade partners.

Recent studies, have employed these spatial methodologies and have reignited the debate over the effectiveness of public infrastructure investment. Both Crescenzi and Rodriguez-Pose (2011) and Arbués et al. (2015) find very limited evidence of spillover effects from European infrastructure. Crescenzi and Rodriguez-Pose (2011), in fact, report that controlling for previously excluded determinants of economic growth, such as innovation or migration, renders the coefficient estimates on the direct and indirect impacts of motorways within and across European regions insignificant. Similarly, Arbués et al. (2015) demonstrate that, with the exception of roads and airports, the response of output of Spanish provinces to various types of transportation infrastructures is negligible and that domestic spillover effects can only be attributed to Spanish roadways. Interestingly, the authors find that ports create a statistically insignificant spillover effect, but negative effect on local output.[9] In contrast, the recent experience for China is markedly different. Studies by Liu et al. (2007), Zhang (2009) and Yu et al. (2013) produce evidence in support of positive direct effects of transport infrastructure and generally positive spatial spillovers at the city, regional, and national levels. Yu et al. (2013), in fact, report that spatial spillovers, unlike direct effects, increase in magnitude over the sample period from 1978 to 2009 and rival the direct effects by the end of the sample.

Overall, this literature on the direct and indirect effects of public capital is summarized in Table A.2 and suggests a large degree of controversy concerning the net economic benefits. With the exception of the estimated domestic motorway spillovers, the common patterns point to the existence of national geographic spillovers that redistribute, rather than generate, economic activity in response to infrastructure expenditures in developed countries. The experience of developing countries appear markedly different and poses the question of whether infrastructure networks are saturated in developed countries and whether the marginal return of further investments is simply diminishing. Moreover, the research warrants caution when disentangling the economic benefits of point and network infrastructures and reveals the sensitivity of the empirical results to different types of infrastructures, industries, and spatial weight specifications,

[9] While the authors do not formally explore the mechanisms that drive this result, they offer a brief discussion of the potential explanations. In the authors' own words, "a plausible explanation is that whereas positive effects of new port investments could be spread across the nation, the direct and indirect costs (pollution and congestion) are assumed by the local authority and consequently by the province." (Arbués et al., 2015, p. 174).

which we summarize in Table A.3. As previously discussed, these spatial weights capture the likelihood of a given community being affected by an infrastructure investment elsewhere and are often based on geographic characteristics, such as a common border among localities or distance between them. Alternative spatial weight specifications that might govern domestic investment benefit spillovers are based on market potential or economic similarity.

A.IV Labor market adjustments

To gain a deeper understanding of the overall macroeconomic impact on output and productivity, and to determine the innate drivers of the geographic spillover effects, another strand of the literature has developed and considers the adjustment in factor prices and labor market outcomes in response to public capital investments.[10] Eberts (1991) and Eberts and Stone (1992) provide an intuitive discussion of the channels through which infrastructure might influence earnings and employment. When households and firms make location decisions across a geographic region, local infrastructure acts as a determinant of the jurisdictional amenity and competitiveness levels (see, for example, Woodward 1992, Florida and Smith 1994, Coughlin and Segev 2000, or Kim et al. 2018). Reduced transport costs and commuting times, for example, enhance firm productivity and raise households' valuation of a given location. In turn, relocating households and firms will bid up local land prices and adjust their respective wage demands and offers.[11]

[10] Aside from these considerations of output, productivity, and employment effects from public capital, the literature has addressed issues of inequality (see, for example, Hooper et al., 2018) and rural development as well. Ghani et al. (2016), for example, investigate the impact of the Golden Quadrilateral on the spatial distribution of Indian firms and finds that greater accessibility has a decentralizing effect that induces land and building-intensive industries to relocate to peripheral districts.

[11] Haughwout (1996) develops a tractable urban equilibrium model based on these principles.

Early studies by Carlino and Mills (1987), Deno (1988), and Munnell (1990) provide evidence in support of the theoretical employment effects arising from transport infrastructure. Munnell (1990), for example, estimates that a $1,000 increase in public capital per capita raises average annual employment growth by about 0.2 percent. The empirical analysis by Carlino and Mills (1987) suggests that doubling highway miles per square mile of land during the late 1970s would have raised total and manufacturing employment densities by 6 percent over the following decade, while Eberts (1991) shows that employment growth is largely driven by infrastructure-investment-induced new business openings of smaller firms during recessionary periods.

Building on this research, Eberts and Stone (1992) as well as Duffy-Deno and Dalenberg (1993) develop their respective empirical analyses to account for the simultaneous labor and wage adjustments in response to the provision of infrastructure. Essentially, the authors jointly estimate the labor supply and demand equations and find that infrastructure continues to exert a positive influence on local employment. Duffy-Deno and Dalenberg (1993) provide an estimate of the employment elasticity with respect to public capital of 0.06 percent suggesting that a 10 percent increase in per capita capital stock would raise employment by 0.6 percent. Moreover, this study provides evidence of a negligible wage impact. In contrast, Eberts and Stone (1992) produce estimates of the statistically significant negative influence of public capital on local wages. Both of these estimated wage effects are consistent with the theoretical model and suggest that the amenity effect of infrastructure tends be at least as significant as the productivity effect. In other words, households derive considerable value from public goods that compensates wage differentials with respect to alternative locations and tends to outweigh the upward pressure on wages due to the enhanced productivity of local firms.

Haughwout (1996, 2002) as well as Wu and Gopinath (2008) expand upon this theory and develop an urban equilibrium model in the spirit of Roback (1982), where not only employment and wages are simultaneously determined, but other input demands and factor prices, such as land rents, play a critical role as well.[12] Jointly estimating the system of equations, Haughwout (1996, 2002) finds negative, yet insignificant wage effects and statistically significant inelastic and positive public capital effects on employment and land prices that are similar in magnitude to the estimates by Duffy-Deno and Dalenberg (1993). With the exception of a positive wage effect, the results by Wu and Gopinath (2008) are comparable to Haughwout's findings and complementary to the findings by Dalenberg and Partridge (1997) who differentiate the impacts across industries.

While these studies have provided consistent evidence of a positive employment and negative wage effects from public capital expenditure, there exists some evidence to the contrary illustrating that public capital, and transport infrastructure in particular, may act as a substitute, rather than weak complement to labor. Berndt and Hansson (1991), for example, report negative employment effects stemming from public capital during the 1970s and mid 1980s of their Swedish sample from 1960-1988, whereas Dalenberg and Partridge (1995) document a similar pattern for U.S. highway and local infrastructure expenditures. Theoretically, the productivity enhancement from public capital may alter the marginal rates of return in favor of land and/or capital inputs relative to labor leading to a substitution towards these non-labor inputs. Following the theory, Nadiri and Manumeas (1994) investigate the effects of public capital on costs as well as input demands of 12 manufacturing sectors and find significant cost reductions that coincide

[12] Albouy and Farahani (2017) criticize these models for the assumption of free labor and firm mobility. Relaxing this presumption, the authors show that the value of local infrastructure exceeds previous results due to the impact on non-tradable production and the inability of firms and households to relocate.

with a decline in labor demand; a finding that is robust to the integration of spatial spillovers (Cohen and Morrison Paul 2004).

The controversy over the sign of the estimated employment effects from public capital have led to a reconsideration of the previously assumed exogeneity of infrastructure and the development of more rigorous identification strategies as well as structural modelling techniques in hopes of resolving the conflicting coefficient estimates.[13] Examples of these alternative empirical and structural approaches include the work by Chandra and Thompson (2000), Brueckner (2003), Michaels (2008), Duranton and Turner (2012), Allen and Arkolakis (2014), Blonigen and Cristea (2015), Möller and Zierer (2018), Monte et al. (2018) as well as Heuermann and Schmieder (2018). Chandra and Thompson (2000) and Michaels (2008), for example, exploit the arguably exogenous location of U.S. interstate highways with respect to rural/non-MSA counties. The authors find that the provision of highways increases earnings, employment, and retail trade in non-MSA highway counties. Brueckner (2003) and Blonigen and Cristea (2015) estimate the effect of air traffic on employment and find a consistent positive impact when controlling for the employment-air traffic simultaneity via exogenous geographic network characteristics or a quasi-natural policy experiment given by the 1978 deregulation of air traffic. In contrast, Duranton and Turner (2012), Möller and Zierer (2018), and Heuermann and Schmieder (2018) base their identification on the quasi-random variation in the interstate highway and/or rail network plans in the U.S. and Germany. As these plans were developed far in advance of the actual sample periods or without consideration of the prevailing local economic factors, the authors argue that they render convincing instrumental variables for the existing and endogenously determined

[13] For further discussion of these instrumental variables' approaches, often referred to as `planned route IV', `historical route IV' and `inconsequential place approach', and a review of the recent literature employing these approaches see Redding and Turner (2015).

stock of public capital. The results are consistent and give hope that transport infrastructure investments, indeed, have a positive influence of on employment, population, and wage growth. Duranton and Turner (2012), for example, estimate that a 10 percent increase in roadways leads to a 1.5 percent increase in employment over a 20-year period.

Similar to the work on the output and productivity effects from infrastructure, the literature on the underlying labor market and factor price adjustments has considered the potential spatial spillover effects arising from public capital expenditures. Early examples include studies by Dalenberg et al. (1998) and Chandra and Thompson (2000), who consider the employment and earnings effects of the U.S. highway system. Both studies find evidence in support of the re-distributional effects of transport infrastructure and report considerable negative employment and wage spillovers originating from locales equipped with interstate highways into the adjacent, neighboring counties. More recent work by Jiwattanakulpaisarn et al. (2009), Gómez -Antonio and Fingleton (2012), and Heuermann and Schmieder (2018) reinforces the initial evidence. While the reduction in transport costs due to the provision of highway infrastructure is found to reduce employment and wages in neighboring regions (Jiwattanakulpaisarn et al. 2009; Gómez-Antonio and Fingleton 2012), reduced commuting times trigger a relocation of work away from urban settings (Heuermann and Schmieder 2018).

We present a concise summary of these findings in Table A.4. For each of the reported studies, we indicate the methodological approach, type of infrastructure and time horizon under consideration, and document the geographic area of study. Given the varying methodologies, we offer short summary of each paper's primary results, rather than a single statistic that cannot be compared across studies.

A.V Industry-specific effects

As public capital expenditures involve a large number of infrastructures that are utilized with varying intensities across industries, the heterogeneity in industry-specific outcomes is a natural consideration. Generally, the literature distinguishes between manufacturing and service sectors and evaluates the industry-specific heterogeneity with respect to output, productivity, and labor market outcomes. Fernald (1999) offers one of the most convincing studies differentiating the productivity effects of highway infrastructure across vehicle-intensive and non-vehicle-intensive industries. As expected, the author finds that the effects are much larger for vehicle-intensive industries able to take advantage of the publicly provided transport infrastructure. Cohen and Morrison Paul (2004) complement this finding and show that, within the manufacturing industry, production workers gain from state-wide infrastructure investments, whereas nonproduction workers are negatively affected. In a recently conducted meta-analysis, Melo et al. (2013) summarize this literature and suggest that the output elasticity estimates with respect to public capital are largest in the primary and manufacturing sectors and decrease for the construction and service industries.

In terms of the industry-specific labor market outcomes, the results tend to vary drastically across industries and types of infrastructure. The findings by Clark and Murphy (1996), for example, suggest that employment growth in the finance, insurance, and real estate (FIRE) sectors responds positively to fiscal spending, whereas other commercial sectors, such as service and trade, and industrial sectors, including manufacturing and construction, are largely unaffected. Chandra and Thompson (2000) offer convincing evidence in support of these initial findings. Focusing on highway infrastructure and averaging across direct and indirect effects, the authors show that the FIRE and transportation, warehousing, and public utilities industries experience the largest gains in earnings, whereas wages in retail trade are estimated to decline. Moreover, the authors find that export-oriented manufacturing industries exhibit positive spillover effects in adjacent non-highway counties that can be attributed to the resulting reduction in transport costs and increase in accessibility (Matas et al., 2015).

A.VI Transport infrastructure investments benefits

As evidenced by the previous summary, much of the literature on public capital expenditures rests on the effects of transport infrastructure in particular. In this section, we build on the previous discussion and expand our survey with a detailed summary of the more influential studies that bring to light new evidence on the subject of the economic impact of transport infrastructure investments. The primary and long-standing methodological themes include the cost-benefit analyses of isolated investment projects, such as the expansion Chicago O'Hare airport (Brueckner 2003)[14], or computable general equilibrium models relying on the input-output tables to estimate the economic impact of these transport investments.[15] More recently, widely recognized research has turned towards empirical investigations of the economic benefits derived from motorway,

[14] Examples of such case studies are too plentiful to comprehensively review and go beyond the scope of this study. A few 'handpicked' studies include, for example, the analyses of the economic impacts of the M62 British motorway by Dodgson (1974), the Channel Tunnel connecting Britain and France (Vickerman, 1987, 1988), the expansion of the Chicago O'Hare airport (Brueckner, 2003), or Auckland's Northern Motorway extension (Grimes and Liang, 2010).

[15] Weisbrod (2008) provides an excellent review of the various I-O methodologies used to predict the effects of national, regional, state, and local transport infrastructure investment and offers insights on the potential shortcomings of these models. Moreover, Weisbrod and Reno (2009) apply the I-O methodology to estimate the economic impact of the public transportation investment and project significant increases in employment, income, and tax revenue in response to public expenditure.

railroad, air- and seaport infrastructures at various levels of aggregation.[16] Historically, the economic impact of the U.S. interstate highway system as well as other motorways has played a prominent role within this subfield.[17] More recent work, however, has broadened the scope and explores transport infrastructure investments in developing countries, such as the 'Golden Quadrilateral' in India (Datta, 2012; Ghani et al., 2016; Asturias et al., 2016) or the dramatic Chinese infrastructure expansion (Banerjee et al., 2012; Faber, 2013). Throughout this section, we provide a chronological summary of the most influential studies and point to the key advances.

One of the earlier studies includes the research by Keeler and Ying (1988). In contrast to a host of cost-benefit analyses projecting the efficacy of various infrastructure investments ex ante, Keeler and Ying (1988) study the ex post economic benefits of the U.S. highway system, built between 1950 and 1973, accruing to the U.S. trucking industry. Estimating a trans-log cost function for the trucking industry, the authors find that interstate highway investments throughout the 1950s and 1960s reduced trucking costs by almost 20 percent by 1973 and covered at least one-third of the original investment costs. While this finding by Keeler and Ying (1988) suggests the productive nature of the U.S. highway investments, Thompson et al. (1993) as well as Rephann and Isserman (1994) provide evidence to the contrary. Developing an empirical strategy similar to Chandra and Thompson (2000), Rephann and Isserman (1994), for example, investigate the impact of U.S. highway construction across counties directly linked to the instate highway network and those in close proximity. The authors' findings indicate that highway construction does not create

[16] Vickerman (2008) offers an overview of these methodologies and summarizes a subset of the relatively recent literature employing them.

[17] Blum (1982) studies the effect of 'traffic infrastructure', including, for example, motorways and railroads, on regional German output and provides a brief overview of the early research on the economic impact of U.S. and international transport infrastructure investments.

a local boom in general and that only those counties in proximity to metropolitan areas or some degree of prior urbanization reap the long-run benefits from these infrastructure investments, in part due to the decentralization from a nearby city.

This reorganization and decentralization of intra-city production, employment, and population in response to the construction of highway infrastructure is echoed through the U.S. based findings by Thompson et al. (1993) and Baum-Snow (2007), Spain-based results by Garcia et al. (2015) and China-based findings by Baum-Snow et al. (2017). In the case of Portugal, Pereira and Andraz (2006) investigate these domestic spillover effects from transport infrastructure investment at a more aggregated regional level and find significant evidence in favor of regional agglomeration, rather than decentralization. The authors demonstrate that regional spillover effects outweigh direct effects for more centrally located, interior regions, whereas peripheral regions benefit most from the direct effects of these investments. Pereira and Andraz (2006) measure these benefits in terms of infrastructure-investment-induced changes in private investment, employment, and regional private output. The authors' long-run analysis, based on a vector autoregressive model, suggests that centrally located regions and Lisbon in particular, capture the majority of these transport investment benefits. These long-run regional effects for Portugal stand at odds with the decentralization hypothesis supported by the aforementioned studies.

Berechman et al. (2006) reconcile these conflicting domestic spillover estimates using an extended production function approach that controls for spatial and time lags in terms of transport infrastructure investment. Based on this model, the authors show that the economic impact of U.S. interstate highways on gross state, county and municipal product declines with the disaggregation of the geographic units. The authors identify intensifying geographic spillovers at more disaggregated levels of analysis as the root cause for this decline. Equally important, the authors show that the direct effects of U.S. highways on gross state, county or municipal product follow an inverse U-shape with respect to the preexisting highway stock. That is, states with minor highway capital experience no economic effects from highway investments, whereas states with intermediate highway stock reap the largest investment benefits when compared to the declining impact for `congested' states with a significant preexisting interstate highway network.

Aside from these studies set in the context of the U.S. and other developed nations, recent research on the economic impact of transport infrastructure investment in developing countries has made critical contributions to this field of study. Focusing on the effect of railroads in India, seminal work by Donaldson (2018) shows that access to railroads increases agricultural income by about 17 percent, equivalent to about 40 years of economic growth in India between 1870 and 1930 according to the author's calculations. For the more recent Indian history, Datta (2012) shows that the construction of the `Golden Quadrilateral' (GQ), a 5800 kilometer (km) highway system connecting four major metropolitan areas in India, is associated with a significant reduction in the perception of transport as a major obstacle to production. Using World Bank survey data and a difference-in-differences methodology, Datta (2012) further estimates that firms in treated cities with new access to the GQ reduce inventory and are more likely to switch suppliers than firms in the control group unaffected by the construction of the GQ. Findings by Asturias et al. (2016) complement Datta's research and estimate that the GQ and the associated reductions in transport costs has increased aggregate income by 2.71 percent or roughly $4.1 billion per year.

In the case of China, Banerjee et al. (2012) find that a 10 percent increase in distance to road or railway infrastructure, instrumented for via a hypothetical network, reduces Chinese county-level income by around 7 percent during their 18-year sample period from 1986 to 2003. Moreover, the authors find that this effect is largely generative, rather than a redistribution of economic activity from more distant counties.[18] Separately identifying the effects of land, air, and water transport infrastructure on regional Chinese economic development, Hong et al. (2011) produce consistent evidence that suggests that land and water infrastructure are the principal determinants of economic growth, while air transport infrastructure seems less relevant. Faber (2013) provides direct evidence to the contrary of Banerjee et al. (2012) and Hong et al. (2011) suggesting that rural Chinese counties experience a significant decline in industrial and total GDP in response to an improved connection to the trunk highway system. Faber's results point to the redistribution of economic activity through highway investments in China.

Considering Sub-Saharan Africa, Storeygard (2016) illustrates that motorway network distance has a significant impact on economic activity. To identify economic activity when direct estimates of GDP at the MSA level are unavailable, the author takes a novel approach and relies on the `lights at night data'. Moreover, Storeygard (2016) uses variation in global oil prices interacted with road network distance to approximate temporal changes in transport costs. The author estimates that a 1 percent increase in transport costs reduces urban light intensity by 0.28 percent in cities at a distance of 500 km from a Sub-Saharan African port-city and that urban areas in closer proximity to seaports are much more resilient to changes in global oil prices.

While each of these studies has advanced our understanding of the economic impact of transport infrastructure investments on a geographically dispersed set of countries with varying levels of prior development, we note that relatively few studies explicitly account for the associated externalities of these investments. Examples of these side effects to public capital expenditures include issues of congestion, infrastructure damages, and air pollution due to greater rates of

[18] Given the fact that the authors are restricted to one instrumental variable, they are unable to separately identify the effect of road and rail infrastructures.

utilization (Winston, 1991, De Borger et al., 2008; Redding and Turner, 2015). Duranton and Turner (2011) provide direct evidence of the congestion externality and coin the `fundamental law of road congestion', which suggests that a 1 percent increase in roadway infrastructure raises congestion by 1 percent in response. Both Winston (1991) and De Borger et al. (2008) make the argument that these negative externalities of transport infrastructure investment are significant and can be internalized via efficient infrastructure pricing strategies. To implement optimal pricing strategies, however, further research should clearly delineate the direct investment effects from these externalities and quantify the potential public burdens that should be internalized.

Moreover, the previous research has produced comparatively little evidence on the dynamics of the economic impact of transport infrastructure investments or deeply considered the potentially decreasing returns to scale deriving from these public capital expenditures. A second highway network, for example, duplicated the existing public capital stock would not be expected to have the same benefits as the first. To this date, we observe a significant lack of evidence concerning the rate at which economic benefits of transport infrastructure investments diminish. Yet, from a policy perspective, this statistic is a critical element in forecasting the anticipated economic impact of any transport infrastructure investment expanding upon the existing capital stock and particularly relevant in the developed country case.

Tables

Table A1: Macroeconomic effects

Source	Methodology	Type of Infrastructure	Area of Study	Time Horizon	Elasticity Range	Summary
Mera (1973)	Production function	General public capital spending	Japanese Prefectures-Industry	1954-1963	0.12-0.50	Output elasticity with respect to (wrt) public capital is estimated at 22% in the primary, 50% in the secondary, and 12% to 18% in the tertiary sectors.
Aschauer (1989)	Production function	Multiple infrastructures	U.S. National	1949-1985	0.25-0.56	The preferred elasticity of income wrt public capital is 0.39 suggesting a higher return to public capital than private investments.
Aschauer (1990)	Output growth equation	Highway infrastructure	U.S. State	1960-85	0.22-0.38	One standard deviation increase in highway capital increases income growth by at least 0.13 percentage points.
Hulten & Schwab (1991)	Production function	Multiple infrastructures	U.S. State	1970-1986	-0.344 to 0.054	Regressions evaluate the impact of public capital on multi-factor productivity and evidence insignificant effects.
Garcia-Mila and McGuire (1992)	Production function	Highway and education spending	U.S. State	1969-1983	0.044-0.165	Output elasticity wrt highway capital ranges between 0.044 and 0.045 and wrt education capital it ranges between 0.072 and 0.165.
Holtz-Eakin (1994)	Growth accounting	General public capital spending	U.S. State	1969-1986	-0.115 to 0.203	Results of insignificant public infrastructure effects hold at regionally aggregated level.
Evans and Karras (1994)	Production function	Multiple infrastructures	U.S. State	1970-1986	-0.110 to 0.102	Output elasticity wrt public educational services is estimated at 0.033 and statistically significant.

Table A2: Spatial spillover effects

Source	Methodology	Type of Infrastructure	Area of Study	Weight Matrix	Time Horizon	Summary
Forkenbrock and Foster (1990)	Cost-Benefit Analysis	Highway infrastructure	U.S. County	Contiguity	1988	Benefit/Cost ratio estimates for highway construction between Saint Louis, MO and Saint Paul, MN range from 0.8 to 2.8
Boarnet (1998)	Production function	Highway infrastructure	U.S. County	Similarity	1969-1988	Cumulative effects include direct effects (0.236-0.300) and indirect spillover effects (-0.806 to 0.125)
Chandra and Thompson (2000)	Earnings equation	Highway infrastructure	U.S. County-Industry	Contiguity	1969-1993	Earning effects from highways (%): Manufacturing 2-10; Retail -3 to -6; Farming -10 to -30
Cohen & Morrison Paul (2004)	Cost function	Highway infrastructure	U.S. State	Economic Integration	1982-1996	Inter- and intrastate highway infrastructure reduces manufacturing costs (combined cost elasticity: -0.24).
Cantos et al. (2005)	Production function	Multiple transport infrastructures	Spanish Region-Industry	Economic Integration	1955-1996	Output elasticity estimates range by infrastructure (ports: -0.017; roads: 0.088) and industry (constr.: -0.025; agric.: 0.072).
Moreno and López-Bazo (2007)	Production function	Multiple infrastructures	Spanish Provinces	Multiple	1965-1997	Direct output elasticities wrt to local and transport infrastructure vary from 0.065 to 0.121 and -0.001 to 0.051, respectively.
Ozbay et al. (2007)	Production function	Highway infrastructure	U.S. County	Contiguity	1990-2000	Direct and indirect elasticity estimates wrt to highway capital range from 0.017 to 0.057 and -0.017 to -0.051, respectively.
Crescenzi and Rodríguez-Pose (2011)	Output growth equation	Highway infrastructure	EU Regions (NUTS 1 & 2)	Nearest Neighbors	1990-2004	Insignificant highway capital effect on output growth.

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Table A2 – *Continued from previous page*

Source	Methodology	Type of Infrastructure	Area of Study	Weight Matrix	Time Horizon	Summary
Yu et al. (2013)	Production function	Transport infrastructures	Chinese Regions	Contiguity	1978-2009	Integrating the Spatial Durbin Model into the common production function, the authors find diminishing direct and increasing regional spillover effects over the sample period.
Arbués et al. (2015)	Production function	Multiple transport infrastructures	Spanish Provinces (NUTS 3)	Multiple	1986-2006	Total elasticity estimates wrt to transport infrastructure vary greatly (seaports: -0.043 to -0.012; motorways: 0.080 to 0.119) and are largely insignificant, except for motorway capital.

Table A3: Spatial weight specifications

Label	Spatial Weight (w_{ij})	Input Variables	Source
Contiguity	$\omega_{ij} = \begin{cases} 1 & \text{if i and j are neighbors} \\ 0 & \text{otherwise} \end{cases}$	N/A	Forkenbrock & Foster (1990), Eberts (1991), Dalenberg (1998), Chandra & Thompson (2000), Moreno & López-Bazo (2007), Ozbay et al. (2007), Jiwattanakulpaisarn et al. (2009), Gómez-Antonio & Fingleton (2012), Yu et al. (2013), Shan et al. (2014), Song & van Geenhuizen (2014), Fageda & Gonzalez-Aregall (2017)
k^{th} Nearest Neighbor	$\omega_{ij} = \begin{cases} 1/k & \text{if } k < K \\ 0 & \text{otherwise} \end{cases}$	k: order of contiguity between i & j and K: arbitrary threshold assuming no spillover effects beyond the K^{th} order of contiguity	Crescenzi & Rodríguez-Pose (2011)
Inverse Distance	$\omega_{ij} = 1/d_{ij}$	d_{ij}: (Squared) Distance between centroids of regions i and j	Moreno & López-Bazo (2007), Jiwattanakulpaisarn et al. (2009), Bottasso et al. (2014)
Proximity	$\omega_{ij} = \begin{cases} 1 & \text{if } d_{ij} < 100 \text{ miles} \\ 0 & \text{otherwise} \end{cases}$	d_{ij}: Distance between centroids of regions i and j.	Arbués et al. (2015), Fageda & Gonzalez-Aregall (2017)
Market Potential	$\omega_{ij} = x_j/d_{ij}^2$	x_j: Value added in region j d_{ij}^2: Squared distance between the centroids of regions i and j.	Moreno & López-Bazo (2007)
Region Similarity	$\omega_{ij} = \dfrac{1/\lvert x_i - x_j \rvert}{\sum_j 1/\lvert x_i - x_j \rvert}$	x_i: Population Density, Per Capita Income, Employment Share Manufacturing or Finance, Insurance, and Real Estate (FIRE) industries	Boarnet (1998)

Notes: For the k^{th} nearest neighbor spatial weights, first order contiguity is defined through sharing a common border between region i and j. Second order contiguity is based on sharing a common border between region i's first-order neighbors and region j. Higher orders of contiguity are defined accordingly.

Table A4: Labor market effects

Source	Methodology	Type of Infrastructure	Area of Study	Time Horizon	Summary
Carlino and Mills (1987)	Steinnes and Fisher model	Highway infrastructure	U.S. County	1970-1982	Elasticity estimates of employment and population wrt highway infrastructure equal 0.061 and 0.028, respectively.
Deno (1988)	Translog profit function	Multiple infrastructures	U.S. MSA	1970-1978	Elasticity estimates of manufacturing output, employment, and private capital wrt total public capital range from 0.613 to 0.815 and vary greatly across individual types of infrastructure (Water: 0.019; Highway: 0.571).
Munnell and Cook (1990)	Production function	General public capital spending	U.S. State	1970-1986	Elasticity estimates of output vary across infrastructure (water and sewer: 0.12; highway: 0.06) and exceed those of employment (0.0001 to 0.0002).
Eberts (1991)	Employment growth equation	General public capital spending	U.S. MSA	1976-1986	A 1 % point increase in public capital expenditure raises employment growth by 5.78 % points for small firms and 2.41 % points for large firms.
Berndt & Hansson (1991)	Dual cost function	General public capital spending	Sweden	1960-1988	Elasticity estimates of labor demand wrt public capital exhibit positive and negative employment effects over the sample period. No preferred estimate is provided.
Eberts and Stone (1992)	Labor supply and demand equations	General public capital spending	U.S. MSA	1958-1987	A 1% point increase in infrastructure raises employment growth by 0.346 % points and lowers wages by 0.318 % points.
Duffy-Deno and Dalenberg (1993)	Labor supply and demand equations	General public capital spending	U.S. MSA	1970-1980	Elasticity estimates of employment wrt public capital equals 0.067, while the estimated wage elasticity wrt to public capital is insignificant.
Nadiri and Manumeas (1994)	Dual cost function	Infrastructure & R&D spending	U.S. - Industry	1953-1986	The elasticity of labor demand wrt infrastructure exhibits substitutability (-0.0986 to -1.6196) and wrt publicly financed R&D it exhibits complementarity (0.651 to 0.444).

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Table A4 – *Continued from previous page*

Source	Methodology	Type of Infrastructure	Area of Study	Time Horizon	Summary
Dalenberg and Partridge (1995)	Disequilibrium framework	Highway & non-highway public capital	U.S. MSA - Industry	1966-1981	The estimates of the effects of highways (-0.018 to -0.116) and more broadly defined infrastructure (-0.003 to -0.007) on labor suggest the substitutability between these factors of production.
Haughwout (1996)	Urban equilibrium model	General public capital spending	U.S. MSA	1974-1985	Elasticity estimates of employment, land values, and wages wrt public infrastructure equal 0.099, 0.035, and -0.014. The wage effect, however, is indistinguishable from zero.
Clark and Murphy (1996)	Steinnes and Fisher model	Multiple infrastructures	U.S. County - Industry	1981-1989	Total employment growth responds positively to defense and police spending as well as property taxes. At the industry level, however, these responses vary drastically.
Dalenberg and Partridge (1997)	Urban equilibrium model	Multiple infrastructures	U.S. State-Industry	1972-1991	Elasticity estimates of wages wrt highway infrastructure equals -0.015 for all industries and 0.013 for manufacturing. Wage elasticity estimates wrt other public capital expenditures are statistically insignificant.
Dalenberg et al. (1998)	Employment growth equation	Highway & non-highway public capital	U.S. State	1972-1991	A 1% increase in highway expenditures raises local employment growth by 0.04 to 0.07% points and has positive spillover effects, whereas other public expenditures have smaller effects (0.00035 to 0.005).
Wu and Gopinath (2008)	Urban equilibrium model	Multiple infrastructures	U.S. County	2000	The structural estimates suggest a simultaneous determination and positive effect of road density on labor demand, as well as the supply and demand of land development.
Michaels (2008)	HO Model	Highway infrastructure	U.S. County	1967-1982	The development of highways in rural counties increases the skill premia in skill abundant locations and reduces the wages in less educated counties.

Continued on next page

Table A4 – *Continued from previous page*

Source	Methodology	Type of Infrastructure	Area of Study	Time Horizon	Summary
Jiwattanakulpaisarn et al. (2009)	Employment growth VAR model	Highway infrastructure	U.S. State	1984-1997	Interstate highway infrastructure is estimated to have a positive agglomeration effect that drives lagged local employment growth.
Duranton & Turner (2012)	Urban growth model	Highway infrastructure	U.S. MSA	1983-2003	The preferred elasticity estimate of employment wrt intracity highways equals 0.15.
Gòmez-Antonio and Fingleton (2012)	NEG wage equation	General public capital spending	Spain - Provinces	1985-2005	Direct elasticity estimates of wages wrt to public capital range from 0.051 to 0.213, whereas the indirect estimates range from -0.008 to -0.373 and point to negative spatial spillovers and redistribution of economic activity.
Matas et al. (2015)	Wage equation	Road infrastructure	Spain - NUTS 3	1995, 2002, 2006	Elasticity estimates of wages wrt travel time, controlled for via transport infrastructure, range from 0.059 to 0.076 via two-stage least squares.
Möller and Zierer (2018)	Employment growth equation	Highway infrastructure	Germany	1994-2008	The key finding suggests that a one standard deviation increase in highway growth raises employment and wage growth by 2.7%-3.4% and 3.0%-3.7%, respectively.
Heuermann and Schmieder (2018)	Gravity model	Rail infrastructure	Germany - NUTS 3	1994-2010	The elasticity estimate of commuter supply wrt commuting time equals 0.25 and is driven by urban residents seeking employment in more rural areas.

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