How Public Capital Affects Private Production

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Abstract

In this study, I analyze the effects of public capital on private production under a vector autoregressive framework. Empirical results suggest that, first, the effects of public capital on the private economy are time-varying, in particular, the total effects of public capital on private output in pre-1980 period is positive while in post-1980 the effects are insignificant negative, and the public capital productivity diminishes across these two subsamples. Second, public capital presents crowding-in effects on private inputs before 1980 while it shows crowding-out effects on private inputs in recent decades. Accordingly, a decrease in public capital productivity might account for different behaviors of the private sector across time. Third, most components of public capital demonstrate lower productivity in the later period, thus provide lower aggregate public capital productivity in recent years.

1 Introduction

Effects of public capital on the private economy have been at the center of the academic and policy debate for a long time. According to one view, public capital should contribute to the private sector since public capital can generate positive externalities, contributing to the well-being of households and the productivity of the firm, further may attract more private inputs and yield more private production in the economy. For instance, after a new public highway is constructed in the area without any highways, private investors might have incentives to build their new firms or enlarge their current firms to increase production in this area, especially along the new highway. Because the more safe and faster transportation may lower the production cost and increase the marginal productivity of their firms. In this example, public capital raises the productivity of this area and encourages more private inputs which may lead to a higher production level of this area. This view is often referred to as "the public capital hypothesis". According to Tatom (1991), the public capital hypothesis indicates that public infrastructure, directly and indirectly, affects the productivity of the private economy in a positive way. The direct effect arises, because public capital provides intermediate services to private sector firms, or the marginal product of public capital services in the private sector is positive. The indirect effect arises from an assumption that public and private capital are "complements" in production.

Other economists oppositely believe that, although pubic capital can be productive since public capital is accumulated from government investment, the increased public capital from additional government investment might crowd out the private investment on private capital. In the end, it may lead to negative or insignificant effects on private production. This view means the indirect effect of a rise in public capital on private output is not necessarily positive. This effect is negative when public and private capital are "substitutes". In addition, some people argue that the public capital might have a diminishing return on productivity. In Fernald (1999) about assessing the link between public roadbuilding and productivity, Fernald states that building the interstate network may have been very productive, but building a second interstate system may not be. As a result, the added public capital is less productive when the stock of capital is already large.

The main debate on the size and direction of effects of public capital on private output yielded mixed results among literature. The pioneer of the literature on the effects of public capital on economic performances is the work of Aschauer (1989a). Aschauer (1989a) estimates an aggregate Cobb-Douglas production function for private output as a function of employment, private capital, and the government capital stock, by using annual data 1949-1985, his results indicate that the elasticity of private output with respect to nonmilitary public capital is 0.39 which is large and significant. Pereira and Frutos (1999) uses 1956-1989 annual data and apply VAR with public capital, private capital, labor input, and private output, and also obtains a large and significant long-run result of 0.64. A few papers have challenged these views, they conclude the small or insignificant results. Tatom (1991) estimates an OLS regression production function including energy as an input, with the first difference of variables, and 1949-1989 annual data, the result is small and insignificant 0.04. Kamps (2005) uses 1960-2001 data, applies VAR and VECM with public capital, private capital, labor input, and GDP to estimate for OECD countries, the result for the U.S. is 0.33, but insignificant. Bouakez et al.(2017), instead of an OLS estimation of a standard production function, estimates total factor productivity as a function of employment, private capital, public capital, human capital, and Technology with 1960-2014 annual data, and finds the elasticity of productivity respect to public capital is significant 0.065. Using panel data for the 48 contiguous U.S. states in each year between 1970 and 1986, Evans and Karras (1994) estimates production function with different categories of government capital and current government services, finds government capital often has insignificant positive productivity or significant negative productivity.

Utilizing different methodologies and control variables, with different data from different sources or different periods, economists obtained various results of effects of public capital on private output, from negative to positive, from small to large. It is hard to summarize the main points that bring in such different results. However, I notice that among all these papers, Kamp (2005) and Pereira and Frutos (1999) apply a similar method with similar OECD data, but have different estimation results for U.S. public capital elasticity of output. Kamp (2005) with more recent data estimates a smaller public capital effect than Pereire and Frutos (1999), the paper with an earlier sample. This discovery enlightens me that the public capital effects on output may change over time. As a result, the different sample periods might be the key determinant for the different estimation results. This is in line with the main findings of my previous paper about government spending effects on the private sector: in the previous paper, I find government spending shocks significantly crowd in private investment in pre-1980 and significantly crowd out private investment in post-1980. And in the context of a structural model, one main driver of these different effects is the different magnitude of government spending productivity: Large government spending productivity is found from pre-1980 periods (0.38), while smaller government spending productivity is found in more recent periods (0.03). These findings motivate me to investigate whether the stock of public capital exhibits a similar pattern across time.

The ultimate goal of this paper is to study the effects of public capital on private output, and, to check whether they are consistent for two different subsamples. And if the effects are different across time, then how does public capital affect private production differently, i.e. whether public capital has different productivity across time; between public capital and private inputs, which effects dominate: complementary effects or substitutionary effects.

In this study, I apply the recursive SVAR model with 1949-2014 annual data while Aschauer (1989a) and much earlier literature are using OLS estimation. OLS estimates of a single equation suffer from simultaneity bias. When investigating the public capital effect on output by OLS estimates, we are holding other variables including private inputs constant. In reality, as a positive externality, when public capital changes, it may change private capital and labor, and further affect output. Therefore, a dynamic multivariate system that allows us to have simultaneous relationships among variables is needed. Compare to a univariate static OLS estimation, an estimate using the VAR model can capture the dynamic feedback. Moreover, total effects of public capital on private production from two parts: one is public capital affects private productivity; the other is complementary and substitutionary effects: on the one hand, the public capital promotes the productivity then increases the marginal productivity of private input, thus attracts more investment on private capitals, finally lead to higher private output level; on the other hand, public capital accumulated from government investment crowds out private capital that accumulated from private investment. By utilizing a two step SVAR estimation, I can separate the total effects of public capital into two parts: the direct effect of public capital which is public capital productivity (i.e. public capital effects on private productivity), and the indirect effect which is a part of the total effects via private inputs changes caused by public capital. The direction and size of indirect effects can quantitatively estimate which effects dominate the relationship between public capital and private inputs: the complementary or substitutionary effects.

Main findings and contributions of my empirical analysis are: Firstly, I find the time-varying effects of public capital effects on the private economy. In particular, by investigating different subsamples: I find that adding public capital has significant positive total effects on the private output before 1980, whereas after 1980, public capital has large but insignificant negative effects. The productivity of public capital diminishes across two subsamples. Secondly, I provide a new method to measure how public capital affects output through major private inputs changes, and I find valid evidence that public capital can affect output summarily by crowding in private inputs before 1980, and by crowding out private inputs recently. Therefore, a decrease in public capital productivity might be the main factor of different behaviors of the private sector across time. Thirdly, I verify that the effects of public investment show a similar pattern. Fourthly, I further study disaggregate effects of the components of public capital on private production. The estimates confirm that most parts of public capital have positive effects before 1980 meanwhile they have negative effects after 1980, which are consistent with the heterogeneity aggregate public capital effects. And structures category which accounts for more than 75% of public capital might be the main driver of the heterogeneous effects across time since its effects flip from largely positive to large negative after 1980. Lastly, I show that the age of capital does not significantly affect its effects on private output. But the diminishing return of public capital might be one of the potential reasons for its heterogeneous effects.

The paper proceeds as follows: Section II introduces the methodology, including a simple theoretical model and two step recursive SVAR model. Section III provides an empirical analysis of public capital effects on the private section. Section IV reports the estimates regarding effects of components of public capital. Section V discusses two more potential reasons for the discovered heterogeneous effects. Section VI summarizes the main findings.

2 Methodology

2.1 Theoretical Model

The thoery behind the empirical analysis is based on the aggregate production technology. I consider a basic framework of an aggregate production function following Aschauer (1989a) and Fernald (2014) with modification.

$$Y = f(TFP, K^P, L) = TFP * f(K^P, L) \tag{1}$$

And,

$$TFP \equiv f(K^G, TECH, HC, CU) \tag{2}$$

Y is the output of goods and services of the private sector. K^P and L are the stock of productive capital and employment of labor services in private sector respectively. TFP is the total factor productivity. Under this production technology, growth in TFP is the portion of growth in output not explained by growth in traditionally measured inputs of K^P and L used in production, and it depends on public capital stock, techology, human capital and capacity utilization. K^G is the public capital stock. $TECH$, HC and CU stands for Technology, Human Capital and Capacity Utilization respectively.

2.2 Empirical Model

2.2.1 Univariate estimation vs. dynamic multivariate estimation

In previous literature on public capital effects on private sectors, based on the aggregate production function, two methodologies have been proposed: single equation estimation and dynamic multi-equations estimation. Both methods have a common goal that is to evaluate the changes of output (or TFP) with respect to changes of public capital based on an aggregate production function in which the stock of public capital enters. In the meantime, these two methods have different implementations.

Single equation is the static univariate estimation. For instance, when we regress private output on K^G, K^P, L and other relevant control variables, the estimated parameter before K^G measures that how many units changes of private output will respond to one unit change of K^G, while holding K^P and L and all other variables in the equation constant. Thus, the single equation framework excludes the likely presence of feedbacks, especially the dynamic feedback effects among the relevant variables. However, dynamic feedbacks are essential to understanding the relationship between public capital and private sector performances. For one thing, public capital can affect output directly. Based on our theoretical model, public capital is one of the factors in the production function that can directly affect the total factor productivity of private production. As a factor of private productivity, public capital should, centrist paribus, affect private production. For another, public capital affects private production indirectly via its substitutionary or complementary effects on private inputs, especially private capital and employment. For instance, higher availability of public input could reduce the demand for private inputs, which is a substitutionary effect or crowding-out effect. Contrarily, higher productivity of public capital may increase the marginal productivity of the private inputs and thereby, lowers the marginal costs of production and induce more private inputs, ultimately raise the levels of private production, which is a complementary effect or crowding-in effect. In addition, the evolution of private output and private inputs can affect public capital formation. In particular, a growing private output provides a growing tax base and the potential for greater public investment. Therefore the total effect of public capital on private output is the results of several different channels, all developing over time: direct and indirect effects of public capital on private sector variables and feedbacks from private sector variables on the evolution of public capital accumulation. To summarize, in the presence of these dynamic feedback relationships, the size of the effect of public capital on output obtained from the static univariate single equation does not answer the question of whether or not public capital is productive since it does not measure the dynamic feedbacks. In short, a multivariable dynamic approach is necessary.

In this paper, I analyze the effects of public capital in a vector autoregressive framework which is a multivariable dynamic approach, including variables in the aggregate production function. This approach allows for feedbacks between public capital and private sector variables, even include the possibility of reverse causation from output to public capital. Last but not least, it does not require a detailed specification of the production function.

2.2.2 The VAR estimation model

In order to estimate the effects of public capital on the private economy, I need to estimate the impulse response functions (IRFs) from the SVAR model. Follow Blanchard and Perotti (2002), which developed the recursive identification for SVAR approach to the analysis of fiscal policy, the basic framework of the SVAR is as follows:

$$B_0 Y_t = B(L) Y_{t-1} + \omega_t$$

Its corresponding reduced form:

$$Y_t = A(L) Y_{t-1} + u_t$$

Where B_0 is the matrix of coefficients of the endogenous variables, $A(L) = B_0^{-1} B(L)$, $u_t = B_0^{-1} \omega_t$, and $\omega_t \sim N(0, \Sigma_\omega)$ and $u_t \sim N(0, \Sigma_u)$. Y_t in the baseline VAR model consists of the stock of public capital, private capital, labor hours, private output (GDP for short, but it only include production by the private sector) or TFP, capacity utilization, technology, and human capital. In section IV, I use government investment other than public capital, to check whether the flow of public capital also has similar results. And $A(L)$ is a polynomial in the lag operator, I include 1 lag of each variable chosen by AIC. U_t is the residual matrix. In addition, I include the constant and linear time trends in the VAR system for each variable. ω_t is the structure residuals and u_t is reduced from residuals. In addition, I include the constant and linear time trend in the VAR system for each variable.

Notice that the recursive identification of SVAR approach, which assumes B_0 is a lower triangular matrix of coefficients, relies on identifying assumptions to identify shocks and investigate the policy effects. In the relevant empirical literature, e.g. Pereira (2000), Pereira and Fruto (1999), and Kamp(2005), etc., public capital shocks or public investment shocks have been identified on the assumption that public capital is not contemporaneously affected by the other variables included in the VAR model and allow all other variables in the VARs to respond contemporaneously to public capital shocks in order. These assumptions ensure that public capital shocks can be identified using the Choleski decomposition method in a VAR system where public capital is ordered before the other variables. I rely on the same identifying assumptions so that I estimate a recursive VAR where public capital is ordered first, and other interested variables are following behind. Before clarifying the order of other variables, I will firstly introduce the innovation of my estimation.

As I discussed earlier, public capital affects private output mainly through two different channels: One is the direct effects. That is, public capital provides intermediate services to private sector firms that can directly raise the productivity of the private sector. The other one is the indirect effects. That is, complementary effects arise because the marginal product of public capital services in the private sector is positive. Or the substitutionary effects arise because the public investments crowd out private investment. Mathematically, the direct productivity effect measures that when primary private inputs such as private capital and labor are constant, how the growth of public capital impacts output; while the indirect effect measures how the growth of public capital impacts output through complementary or substitutionary effects on private inputs. And the total effects of public capital on private output is the sum of direct and indirect effects.

My innovative method is using a two-step VAR to estimate the total effects and direct effects of public capital respectively, further subtracting direct effects from total effects to obtain the indirect effects.

In step one, the VAR model includes the variables ordered as: public capital, private capital, labor hours, GDP, capacity utilization, human capital, and technology. Obviously, the impulse response functions of public capital and GDP to public capital shocks provide us the total effects of public capital on output. I ordered public capital first since identification assumptions need public capital shocks cannot be affected by other variables within a year. I argue that it is a rational assumption, because public capital is accumulated from government investment which is determined by the Congressional policy. The changes of government investment usually need to pass the legislative procedure, and the approved investment proposal still needs time to transform or construct into the capital from investment. Therefore, the assumption of the private economy has lag effects on public capital is reasonable. Private capital ranks second since as public capital it also needs time to build, but the deterministic procedure in private firms might be easier and faster than government, and it can affect private outputs and other private inputs in the same period. About labor and output, the granger causality test by using quarterly data shows that within one year, GDP growth does not granger cause labor change at 95% confidence level, while labor input obviously affects private output within one year. Capacity utilization is the percentage of sources used to produce goods which indicates how efficiently the factors of production are being used. It also measures the fluctuation of the business cycle, so same as previous literature, I use it to control the business cycle effects on output. Similar to Bouakez et al.(2017), technology is proxied by patents issued, and human capital is proxied by expenditure on education, I order them at the end of the model since both of them are important determinants of production but need time to contribute to production.

In step two, the VAR model includes the variables ordered as: public capital, total factor productivity, private capital, labor hours, capacity utilization, human capital, and technology. Instead of GDP, this VAR system contains TFP. The growth in TFP is measured as a residual of growth of GDP, i.e. that part of GDP growth that cannot be explained by changes in primary private inputs such as private capital and labor inputs. Thus, the public capital impacts on TFP measure the direct productivity as changes in TFP does not correlate with changes in two major private inputs. Therefore, the impulse response functions of public capital and TFP to public capital shocks provide us the direct effects of public capital on output. TFP is ordered in the second place, because other variables do not influence it in the same period except public capital.

Subtract direct effects from total effects, the indirect effects of public capital on output via changes of private inputs are obtained. The positive results represent crowding-in and complementary effects between public capital and private inputs while negative results represent crowding-out and substitution effects.

3 Effects of Public Capital on Private Output

3.1 Data and Sources

In the empirical analysis, historical series used are annual data from 1949-2014. The raw database is comprised by 10 varialbes: 4 variables are from BLS including real output for private business, multifactor productivity (TFP), the aggregate worked hours and private capital service. The net stock (aggregate and disaggregate) of government fixed asset and gross government investment are from BEA. The stock of issued patents is computed based on the flow of issued patents data from USPTO by perpetual inventory method. The remaining 3 variables are downloaded and constructed from FRED: personal spending on education constructed from flow of personal consumption expenditure on education by perpetual inventory method; capacity utilization of manufacture; GDP deflator which is used to transform nominal variables to real level.

All the log-level of variables follows I(1) process according to ADF test. This is in line with many previous literature. And for two subsamples, the data cannot pass the cointegration test. To sum up, the data suggests that the first differences of variables should be used.

3.2 Empirical Results

3.2.1 The rolling window results

Recall that in Kamp (2005) and Pereira and Frutos (1999), they apply the similar VAR method with similar OECD data, but obtain the different estimation results for U.S. public capital elasticity of output. Kamp (2005) with more recent data estimates a smaller public capital effect than Pereire and Frutos (1999), the paper with an earlier sample. It enlightens that the public capital effects on output may change over time. The different sample periods might be one of the key determinants for the different estimation results. This is in line with the main findings of my previous paper: I find government spending shocks significantly crowd in private investment in S1:1947Q1-1979Q2 and significantly crowd out private investment in S2:1983Q1-2018Q1. In the context of a structural model, one main driver of these different effects is the different magnitude of government spending productivity: Large government spending productivity is found from pre-1980 periods (0.38), while smaller government spending productivity is found in more recent periods (0.03). These findings motivate me to investigate whether public capital exhibits a similar pattern across time.

Accordingly, instead of focusing on the full sample analysis, I estimate two subsamples S1:1949-1979, and S2:1983-2014 to study the different effects of public capital across time. S1 and S2 are the appropriate subsamples for our study, because the time-varying rolling window estimation of the VAR model in Figures 1A and 1B shows that there exist time-varying effects of public capital on private output. In 1981, the short-run effects of public capital on private output changes from positive to negative; and starting from around 1970, the long-run effects of public capital on private output becomes more and more negative.

Figure. 1A is the impact response of private production to public capital shock, which indicates the short-run effects. The X-axis presents the starting period of each 30 years window. For instance, the value of 1950 is estimated from 1950-1980. Figure 1A illustrates the time-varying effects of public capital, and after 1980, public capital turns to have a negative short-run effect on private output.

Figure.1B shows the 5 years cumulative effects of public capital on output, which is the long-run effects calculated from the 5 years cumulative private production responses divided by 5 years cumulative public capital responses. The reason to report the 5 years cumulative responses is, in the end, I want to study the total effect of public capital on private output until the impulse

Figure 1A. Impact response of private output to public capital

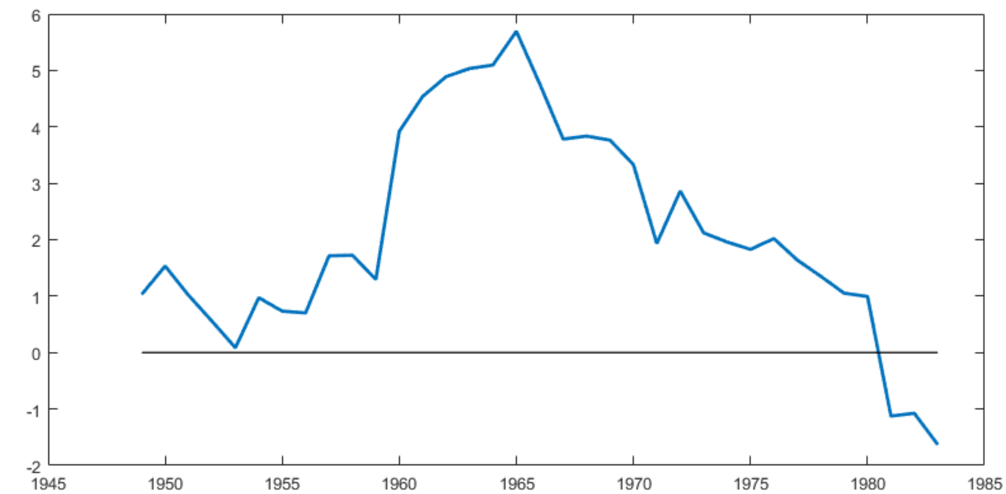
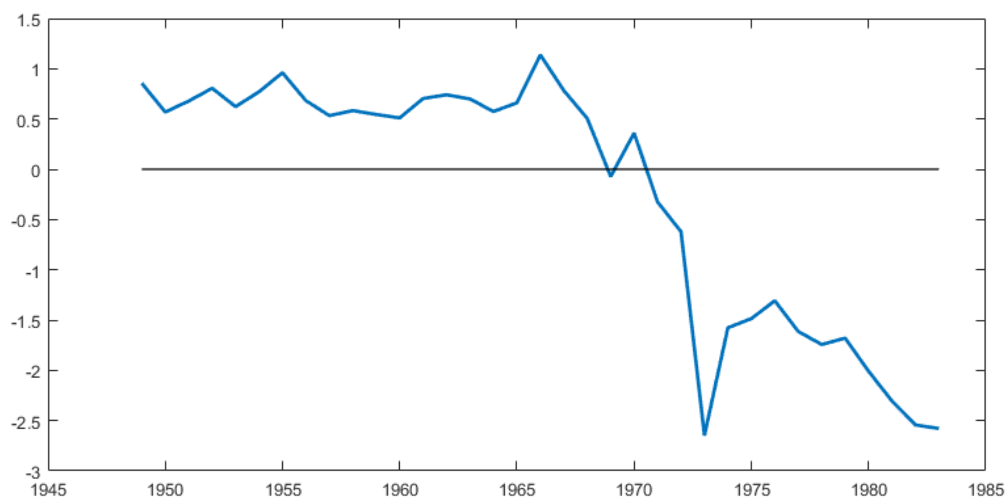


Figure 1B. 5-yr cumulative responses of private output to public capital



NOTES: Y axis presents 1-year (1A) and 5-yr (1B) cumulative effects of private output to public capital. Each year marked on X axis corresponds the starting time of every 30-years rolling sample. For instance, the value for 1950 is estimated by 1950-1979 period.

responses of the growth effects of public capital disappear, and the followed figures for impulse response functions show that the impulse responses of GDP usually converge to insignificant within 5 years. Figure 1B shows that starting from around 1970, the long-run effects of public changes from positive to negative.

Summarily, Figure 1 can give us a visualized evidence that the private output responses flip over from positive to negative at around 1970-1980. The reasons that I cut the sample at 1980, firstly impact response of private production come to negative in 1981; secondly, the previous paper provides that 1980 is the reasonable cutting point; thirdly, the short-run and long-run effects of the flow of public capital which is the government investment also shows the turning point is at 1980.

Moreover, the basic reasons for abandon the period from 1979Q2 to 1982Q4 are similar to Bilbiie et al.(2008): the severe monetary policy change brought by Volcker, the financial liberalization, and the dramatic changes in business-cycle during 1980-1982.

3.2.2 The IRFs of variables to public capital shock

Figure 2 to Figure 4 display the impulse response functions of variables in VAR models to a 1% increase in real public capital. The solid line indicates point estimates, the area between two dashed lines represents symmetric 68% confidence intervals computed by bootstrapping based on 1000 replications.

The full sample results in figure 2A and 2B shows that, in step one, for the total effects of public capital, output has the insignificant negative impact response, and 5-year long-run effects can be calculated as 0.13; in step two, for direct effects, output has the insignificant positive impact with a positive long-run effect on productivity. As we can see, for the full sample, the responses of output with respect to public capital are insignificant for most of the time. This might be attributed to the heterogeneity across time bias that is caused by neglecting the true heterogeneous effects of public capital across time–the positive effects in the first half of the full sample and the negative effects in the second half of the full sample somehow canceled out. And the step two estimation also suffers from this heterogeneity bias.

Figure 3 and 4 are the subsamples estimates for two-step VAR models. Figures 3A and 3B are for S1 period, and Figures 4A and 4B are for S2 period.

Compare Figure 3A to Figure 4A, both are for step one estimates which are for total effects of public capital, but different subsamples. Output (second row first subplot) in S1 has a large and significant positive impact response, and in S2 it shows the large and insignificant impact and long-lasting negative responses. The private capital and labor (first row second and third subplot) in Figure 3A show some significant positive responses to public capital shock within 5 years, while the private capital and labor in Figure 4A show large negative effects, these pieces

Figure 2A. Step 1 IRFs to public capital shock (Full sample)

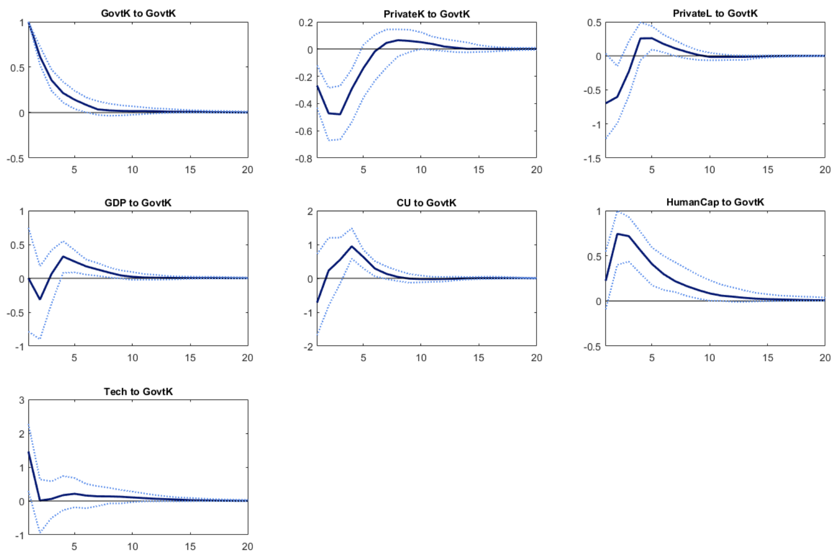
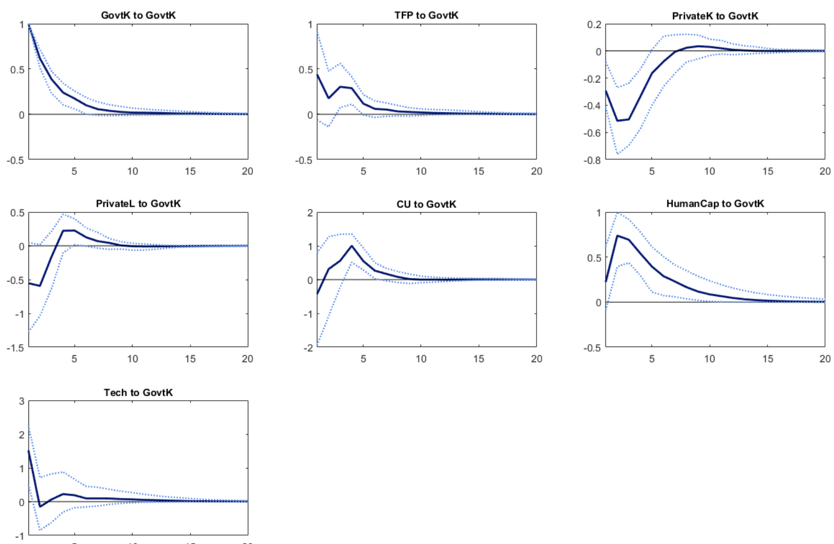


Figure 2B. Step 2 IRFs to public capital shock (Full sample)



NOTES: Figure 2A and 2B shows the responses of public capital, private capital, private labor, private output, TFP, capacity utilization, human capital, and technology to a public capital shock and its corresponding 68% confidence interval for the 20 year horizon using full sample 1949-2014. The X-axis shows years. The Y-axis is the impulse responses (deviation from steady state) of each variable to 1 unit change of shock. And these impluse responses are standarized by the first period responses of public capital for all following IRFs' figures.

Figure 3A. Step 1 IRFs to public capital shock (S1: 1949-1979)

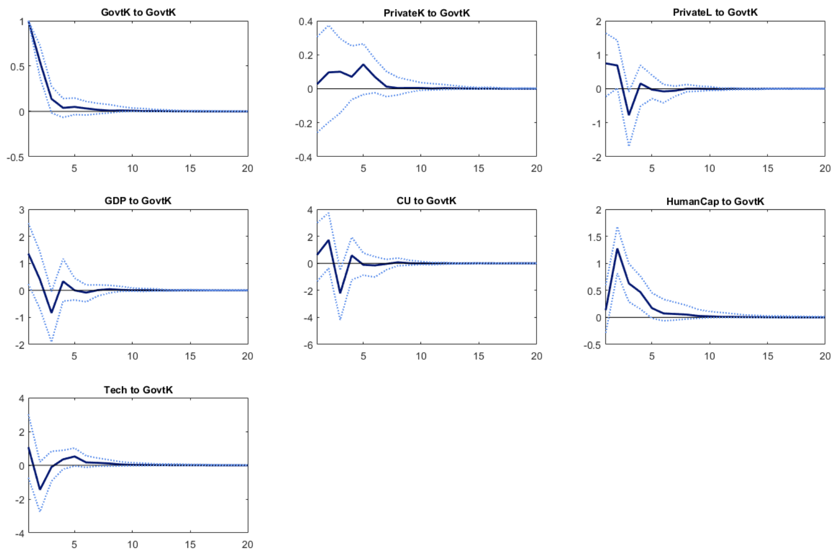
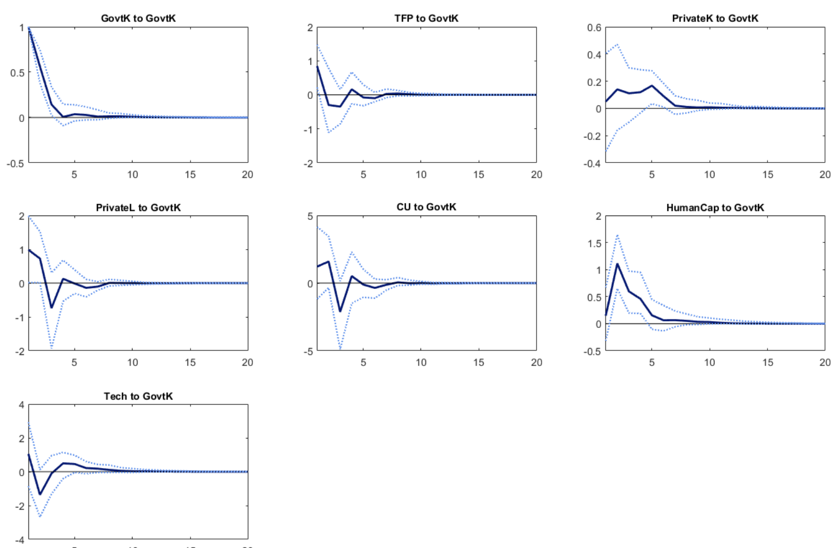


Figure 3B. Step 2 IRFs to public capital shock (S1: 1949-1979)



NOTES: Figure 3A and 3B shows the responses of public capital, private capital, private labor, private output, TFP, capacity utilization, human capital, and technology to a public capital shock and its corresponding 68% confidence interval for the 20 year horizon using S1: 1949-1979. The X-axis shows years. The Y-axis is the impulse responses (deviation from steady state) of each variable to 1 unit change of shock.

Figure 4A. Step 1 IRFs to public capital shock (S2: 1983-2014)

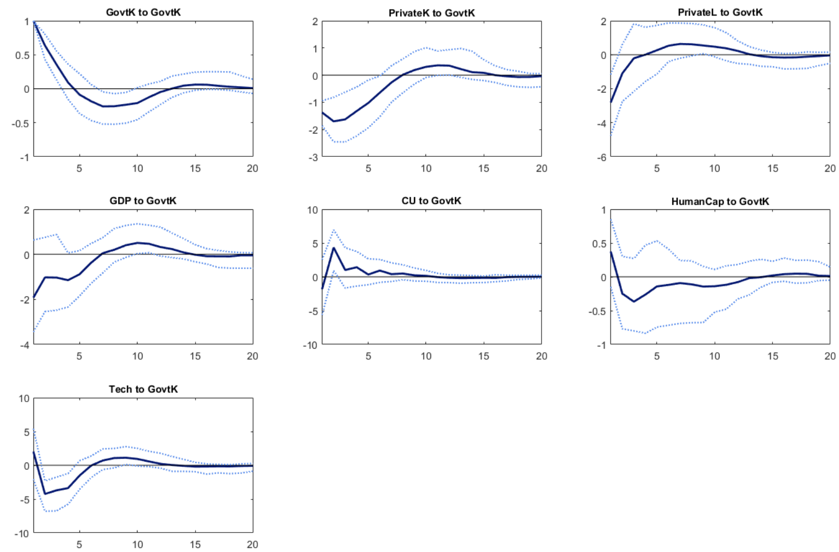
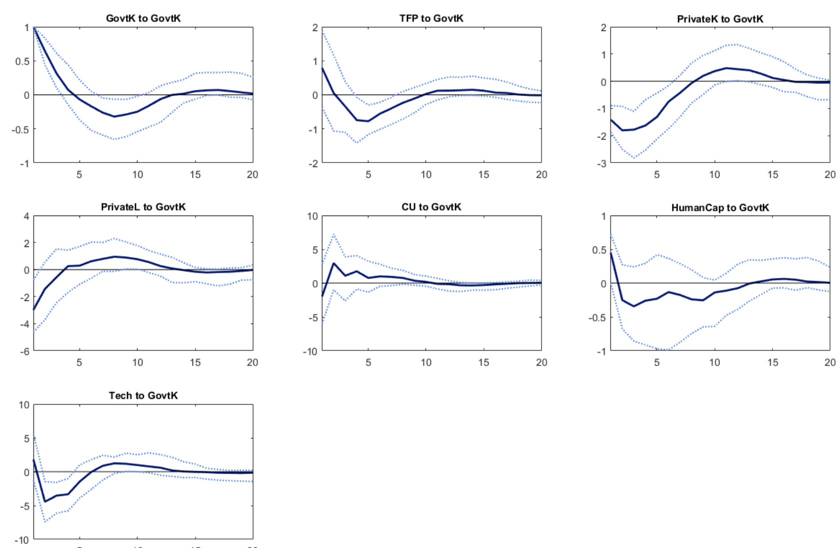


Figure 4B. Step 2 IRFs to public capital shock (S2: 1983-2014)



NOTES: Figure 4A and 4B shows the responses of public capital, private capital, private labor, private output, TFP, capacity utilization, human capital, and technology to a public capital shock and its corresponding 68% confidence interval for the 20 year horizon using S2: 1983-2014. The X-axis shows years. The Y-axis is the impulse responses (deviation from steady state) of each variable to 1 unit change of shock.

of evidence may indicate crowding-in effects of public capital weakly dominate crowding-out effects in S1 whereas crowding-out effects strongly dominate in S2.

Next, compare Figure 3B to Figure 4B, both are for step two estimates which are for direct effects of public capital, but different subsamples. Total factor productivity (first row second subplot) in S1 has a large and significant positive impact response, and the response in S1 is slightly larger than S2. Soon the TFP response in S1 converges to insignificant. In the meantime, TFP response in S2 is positive but insignificant at the beginning, then turns to large and significant long-lasting negative responses. As long as the private capital and labor do not affect the TFP variable, the impact and cumulative responses of TFP can reflect the short-run and long-run direct effects of public capital on the private output which is the influence on private productivity. The main takeaways of these two pictures are that for both subsamples, the public capital has a positive effect on private productivity at the beginning, and these positive effects become smaller in the first period in the long run while in the second period, the public capital, in the long run, may have even negative externality on private productivity (ex: congestion).

To sum up, in the pre-1980 period, the public capital shows a large positive effect on the private economy, it might be because of the larger private productivity responses to the change of public capital in this period which can further induce private inputs and finally boost the private output; while in the post-1980 period, the public capital shows insignificant negative effect on the private economy. This phenomenon might be because the public capital does not have as many positive productivity effects as earlier period, even has negative productivity effects years later, therefore, the additional public capital that comes from government investment reveals crowding-out effects on private inputs, and lead to the insignificant total effects on private output.

3.2.3 Effects of public capital on private sector

Table 1 lists the short-run and long-run effects of public capital on private output. The upper panel is for short-run effects which are computed from impact response of output and TFP to public capital shock. For S1, the total effect is 1.75 means one percent change in public capital can lead to 1.75 percent change in private output. The direct effect of public capital on private productivity is 0.87. And by subtracting direct effects from total effects, can have indirect effects as 0.88 which indicates the crowding-in effects. For S2, the total effect is negative but not significant, and the direct effect is smaller than the previous period, but also not significant, leading to insignificant negative indirect effects, the results mean in the short run, public capital in the later period has no effects on the private economy.

The lower panel is for long-run effects which are computed by 5 years cumulative responses. For S1, the total effect is 0.84. And the direct effect is 0.36, which is pretty similar to the previous paper results for the productivity of government spending. The indirect effect is 0.48 which also reveals the complementary effects of public capital and private inputs. Therefore, in

Table 1: Effects of Public Capital on Private Output

	Short-run effects (1yr)					
	Total (GDP)		**Direct (TFP)**		**Indirect (GDP-TFP)**	
S1: 1949-1979	1.7549	*	0.8718	*	0.8831	*
S2: 1983-2014	-2.0045		0.6718		-2.6763	
	Long-run effects (5yrs)					
	Total (GDP)		**Direct (TFP)**		**Indirect (GDP-TFP)**	
S1: 1949-1979	0.8398	*	0.3569	*	0.4828	*
S2: 1983-2014	-3.0137		-0.4927	*	-2.5210	*

NOTES: Table 1 reports the short-run and the long-run total effects (private output), direct effects (TFP) and indirect effects (Total-direct) of public capital on private output, and the stars means it significant at 68% confidence level.

pre-1980 period, both in the short-run and long-run, public capital has high productivity in private sectors, and the complementary effects dominants the relationship between public capital and private inputs. For S2, the results are vague. the total effect is large but insignificant, and the direct effect is -0.5 and the indirect effect is also large and negative. Therefore in post-1980 period, both in the short-run and long-run, total effects are insignificantly negative. The direct effect is significantly negative in the long run which indicates that in the short-run public capital may not affect private inputs, but in the long run, public capital may crowd out the private inputs.

4 Effects of Components of Public Capital

4.1 Components of Public Capital

One of the potential reasons for the heterogeneous effects of public capital might comes from the change of components of government capital across two samples. In table 2, I report the components of government capital as the percentage of total government capital or as the percentage of total output. The first two columns in table 3 display the disaggregate government capital as the percentage of total government capital for S1 and S2, respectively. Compare these two columns, the equipment category is significantly decreased from 17% to 10% while the structure category increases to almost 80% from 75%. The intellectual property products category also increases 2.5%. In the subcategories under structure, office, educational, transportation increases around 3% each; industrial, military facilities, decreases 3%-5%; residential, commercial, health care, public safety, etc., changes less than 2%.

4.2 Effects of disaggregate public capital on private sector

Intuitively, the change of some of the productive parts of government capital might lead to the aggregate productivity change of public capital across two samples. Then I further examine the extent to which government capital contributes more to private production. In Table 3, I report comprehensively for disaggregate government capital effects on TFP and private output. The upper panel is for S1, overall, most of the effects are positive, especially the long-run effects. In the meantime, the lower panel for S2 shows plenty of negative numbers. Here are some key points in Table 4: First, Equipment has large total effects and direct effects in S2, but it has a smaller proportion in S2. Second, structures, which account for more than 75% of total public capital, have very large positive effects in S1 and negative effects in S2. This might indicates that structures could be the main driver of the heterogeneous effects across samples. Third, the large positive effects of structures in S1 might mainly comes from 3 large subcategories: Education, highways and streets (The impact response of highway and streets is insignificantly negative and then responses become significant and positive), and other structures which is consists of lodging, religious, communication, sewage and waste disposal, water supply structures, and manufacturing.

Table 2: Components of Public Capital

	% of Government Capital		**% of Total GDP**	
Components of government capital	**S1:1949-1979**	**S2:1983-2014**	**S1:1949-1979**	**S2:1983-2014**
Equipment	17.14%	10.24%	13.12%	7.13%
Structures	75.18%	79.58%	58.14%	55.83%
Residential	2.72%	3.33%	2.10%	2.32%
Industrial	4.24%	1.03%	3.22%	0.72%
Office	2.14%	5.10%	1.68%	3.58%
Commercial	0.69%	0.53%	0.53%	0.37%
Health care	2.48%	2.51%	1.91%	1.75%
Educational	11.44%	14.66%	8.88%	10.32%
Public safety	0.83%	2.09%	0.65%	1.46%
Amusement and recreation	1.14%	1.85%	0.89%	1.30%
Transportation	1.84%	4.18%	1.44%	2.95%
Power	2.08%	2.77%	1.61%	1.94%
Highways and streets	22.43%	22.85%	17.39%	16.07%
Military facilities	10.13%	5.48%	7.78%	3.82%
Conservation and development	5.14%	3.60%	3.96%	2.52%
Other structures	7.88%	9.60%	6.10%	6.73%
Intellectual property products	7.68%	10.18%	6.01%	7.10%
Research and development	7.58%	9.42%	5.94%	6.57%

NOTES: Table 2 reports components of public capital as % total public capital or total GDP in two samples.

Table 3: Effects of Components of Public Capital on Private Output

	Total effects (S1:1949-1979)		Direct effects (S1:1949-1979)	
Components of government capital	**Impact**	**5yrs**	**Impact**	**5yrs**
Equipment	0.3375	0.1244	0.1092	-0.0380
Structures	1.2156	0.7118	2.2836	0.6993
Residential	-0.5180	-0.0916	-0.3353	0.1133
Industrial	0.2071	0.0290	0.2670	0.0086
Office	-0.7201	0.0940	-0.2366	0.2017
Commercial	-0.4959	0.0881	-0.0675	0.1937
Health care	-2.3060	-0.2787	-0.9162	-0.1030
Educational	0.0869	0.0460	0.6859	0.1112
Public safety	-0.1462	0.4184	-0.0478	0.3447
Amusement and recreation	-2.1116	0.3286	-0.9952	0.5971
Transportation	-0.3198	0.0234	-0.0776	0.0125
Power	-0.1600	0.2985	-0.0844	0.1907
Highways and streets	-0.7842	0.2142	0.5045	0.3652
Military facilities	0.0409	-0.0604	-0.2959	0.1107
Conservation and development	1.1269	0.9169	0.6993	0.4581
Other structures	2.1203	1.0032	0.9091	0.4073
Intellectual property products	0.6569	0.1998	0.5213	0.2216
Research and development	0.6313	0.2166	0.4743	0.1947
	Total effects (S2:1983-2014)		**Direct effects (S2:1983-2014)**	
Components of government capital	**Impact**	**5yrs**	**Impact**	**5yrs**
Equipment	0.3163	-0.4289	0.5965	-0.0207
Structures	-2.8226	-1.9901	-0.4867	-0.1152
Residential	-2.4669	-2.7928	0.3235	-0.3373
Industrial	-5.2079	-1.3766	-0.9659	-0.3275
Office	0.1350	0.4898	0.1602	0.3941
Commercial	-0.0173	0.0607	0.0024	-0.0298
Health care	-3.3762	0.0956	-1.1449	-0.7019
Educational	0.1367	-0.2996	-0.4110	0.1073
Public safety	-1.3855	-0.4900	-1.0302	-0.5620
Amusement and recreation	-1.6312	-0.8719	-0.9642	-0.0606
Transportation	-0.7537	-0.3790	-0.7286	-0.2010
Power	-1.6408	-0.8881	-0.0870	-0.1157
Highways and streets	0.2120	0.0155	0.7605	0.3679
Military facilities	-1.5665	-0.6670	-0.2109	-0.3854
Conservation and development	0.3307	0.2004	0.0460	-0.0579
Other structures	-2.7806	-2.5983	-0.8482	-1.0018
Intellectual property products	0.7846	-0.1801	1.1838	0.1258
Research and development	-0.2966	-0.4448	0.4970	-0.0435

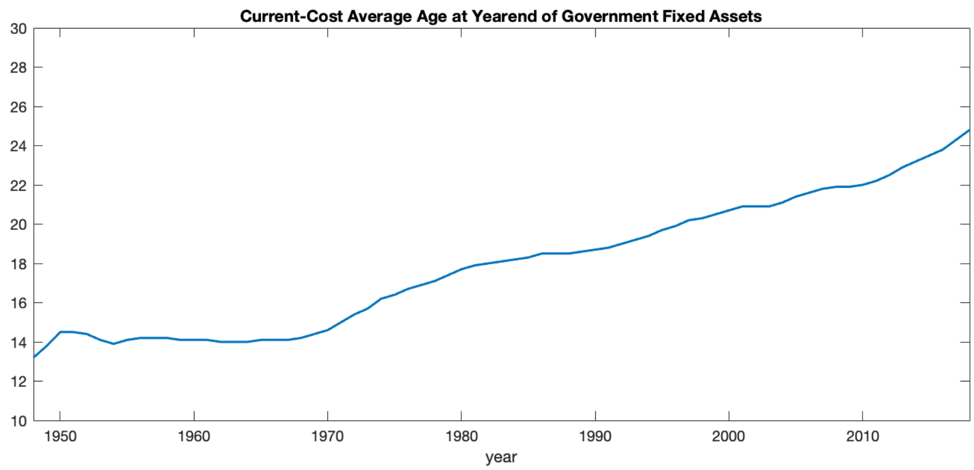
NOTES: Table 3 reports the short-run and the long-run total effects (private output), direct effects (TFP) and indirect effects (Total-direct) of components of public capital on private output

5 Other Potential Reasons for Heterogenous Effects

5.1 Vintage Effects of Capital

Woff (1996) defines a "vintage effect" as that new capital is more productive than old capital per dollar of expenditure. And vintage effects can be measured by the average age of capital – a negative correlation should be observed between the rate of productivity gain and the change in the average age of capital. Therefore, one potential reason for the low productivity shown in more recent years could be the higher average age of capital stock. Figure 5 plots the average age at yearend of government fixed assets, which shows that the average age of public capital indeed keeps increasing from less than 15 to around 25 in 2019, in 2014 the value is 23.2.

Figure 5. Average age of public capital



NOTES: Figure 5 plots the current-cost average age of public capital from 1948-2019.

I revisit the VAR system by controlling the age variable (in log difference form), to check whether the age of public capital can significantly affect the public capital effects on private output. [1] The impulse response functions are in Figure 6 and Figure 7. Compare them to Figure 3 and Figure 4, there are not many differences. Key points are: With controlling age variable, GDP response is significantly positive in S1 but insignificantly negative in S2; the TFP responses are larger in both S1 and S2, but in S2 is still not significant; the crowding out effects on private inputs are still significant in S2, however, the crowding in effects on private inputs are not significant in S1. In short, although the age of capital has some effects on productivity [2], it is not significant at 68% level.

[1] I add the current and lagged age variables in the VAR system to control the age effects, and check whether there would be significant changes in the IRFs to public capital after controlling the age variable

[2] The coefficient of age in GDP and TFP equations are significantly negative.

Figure 6A. Step 1 IRFs to public capital shock controlling age (S1: 1949-1979)

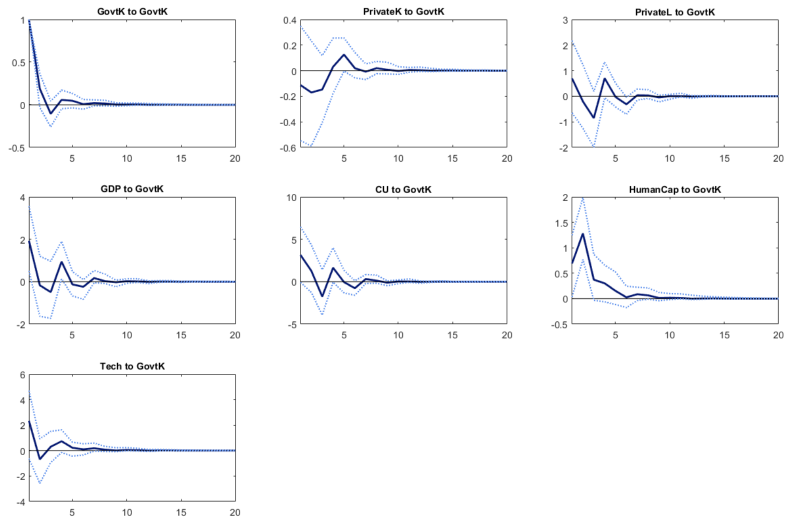
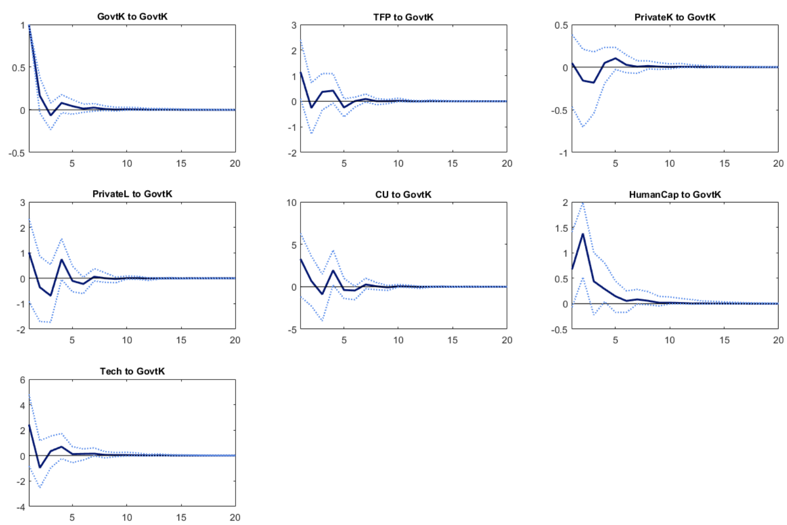


Figure 6B. Step 2 IRFs to public capital shock controlling age (S1: 1949-1979)



NOTES: Figure 6A and 6B shows the responses of public capital, private capital, private labor, private output, TFP, capacity utilization, human capital, and technology to a public capital shock after controlling for age variable, and its corresponding 68% confidence interval for the 20 year horizon using S1: 1949-1979. The X-axis shows years. The Y-axis is the impulse responses (deviation from steady state) of each variable to 1 unit change of shock.

Figure 7A. Step 1 IRFs to public capital shock controlling age (S2: 1983-2014)

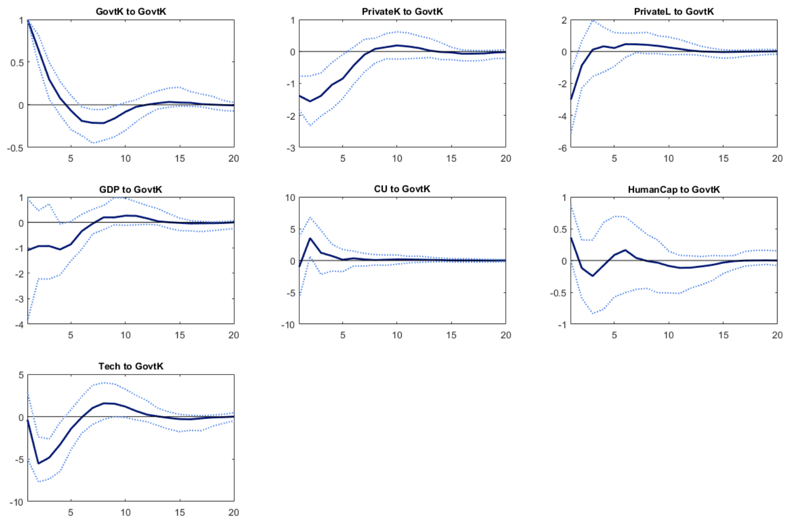
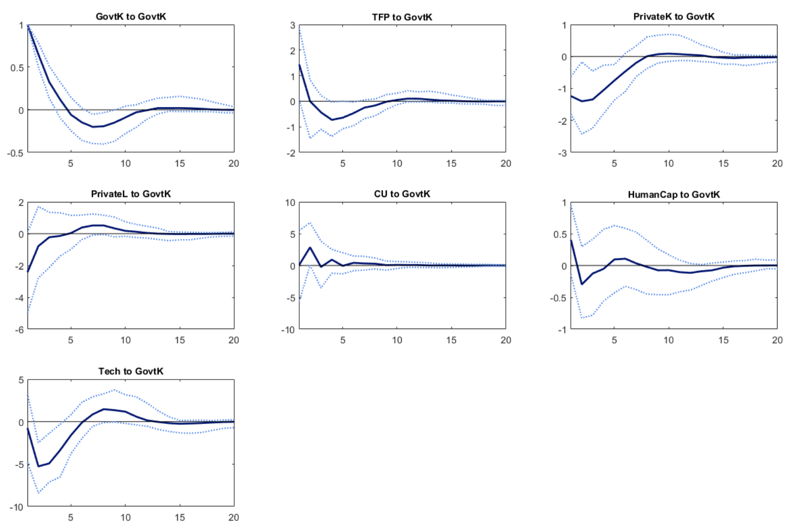


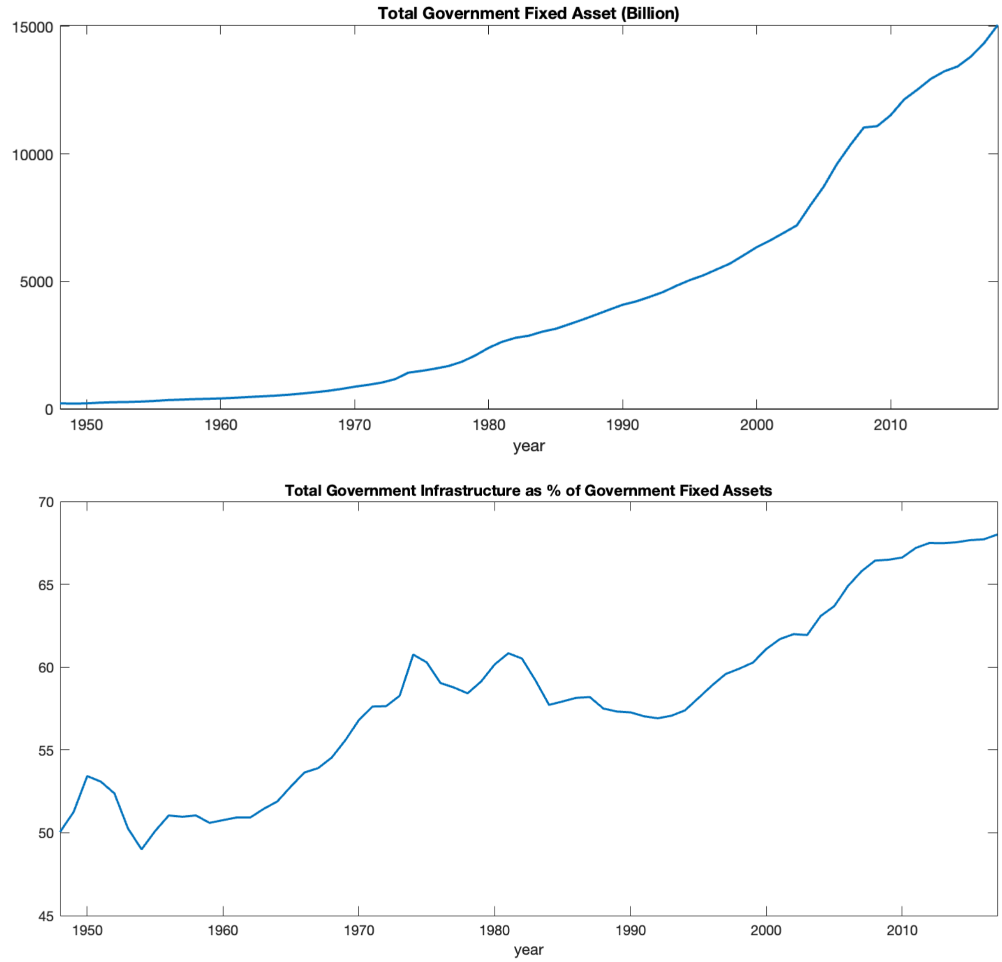
Figure 7B. Step 2 IRFs to public capital shock controlling age (S2: 1983-2014)



NOTES: Figure 7A and 7B shows the responses of public capital, private capital, private labor, private output, TFP, capacity utilization, human capital, and technology to a public capital shock after controlling for age variable, and its corresponding 68% confidence interval for the 20 year horizon using S2: 1983-2014. The X-axis shows years. The Y-axis is the impulse responses (deviation from steady state) of each variable to 1 unit change of shock.

5.2 Diminishing Return of Public Capital

Figure 8. Path of public capital and government-owned infrastructure



NOTES: Figure 8 plots the current-costs of government fixed assets in billion dollars and the government owned infrastructure as percentage of government fixed assets from 1948-2019.

The stock of public capital is more and more built up over the years which can be observed from the upper plot of Figure 8. In addition, Aschauer (1989a) argued that government infrastructure has the most explanatory power for aggregate productivity growth in the United States from 1949 to 1985. While the empirical magnitude of the effect has been a subject of debate, the basic idea stands that infrastructure is an important economic input. Bennett et al. (2020) provides an overview of U.S. infrastructure data in the National Economic Accounts. Based on their dataset, I calculate the government-owned total infrastructure shown in Figure 8: The total public infrastructure as the percentage of total government fixed assets. As expected, a consistently increasing trend, which is 50% at the beginning of the period and more than 65% in the recent period, means that the stock of total government infrastructure is getting larger and larger relative to total government fixed assets. As a result, the diminishing return of public capital can be considered as the other potential reason for heterogeneous effects of public capital across time: If aggregate (or parts of) public capital is subject to a diminishing return on productivity, then adding additional government fixed assets or public infrastructure, there will be less marginal productivity gain in more recent years because of the higher amount of net stock of public capital.

6 CONCLUSION

This study investigates the effects of public capital on private production, in particular, the effects in the different historical periods, pre-1980 and post-1980. I use two step SVAR model with the 1949-2014 annual data and find that public capital has different effects on the private economy across time. Considering the total effects on output, the large positive effects are found from pre-1980 periods, while small or insignificant negative effects are observed in more recent periods. Next, the public capital productivity which is the direct effects of public capital on private output is diminishing across two samples.

From theory, public capital should both have complementary and substitutionary effects on private inputs. Before 1980, the effects of public capital on private inputs are dominated by complementary effects; whereas, after the 1980s, they are dominated by substitutionary effects. The public capital productivity (direct effects) might be the main reason accounting for these different characteristics of two subsamples: the significant large positive public capital productivity may crowd in much more public inputs in pre-1980 periods.

The disaggregate effects of components of public capital for two samples verify that most parts of public capital have positive effects in pre-1980 while having negative effects in post-1980. And effects of the structures category might be the main driver of the heterogeneity due to its flipping signs from plus to minus across two periods. What's more, the diminishing return of public capital could also be the reason for the lower productivity in post-1980 period. Finally, not as expected, there is no evidence to show that the age of public capital can significantly affect its effects on private economy.

The results of this paper demonstrate smaller and smaller effects of public capital on private-sector productivity and GDP growth as time goes on. Both the stock and flow of public capital have similar effects on the private economy. Therefore, a simple increase in any public investment in public capital recently may not be able to raise private productivity or to increase private production, it may even threaten the living standards of future generations, because recent data shows that public capital raise has some negative effects on the private economy in the long-run. If today's policymakers are serious about "winning the future", then having greater public investment and constructing more public capital may not be the best choice.

Reference

Aschauer, D. A. (1989a). Is public expenditure productive?, *Journal of Monetary Economics*, 23, 177-200.

Aschauer, D. A. (1989b). Does public capital crowd out private capital, *Journal of Monetary Economics*, 24, 171-188.

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

Bennett, J., Kornfeld, R., Sichel, D., and Wasshausen, D. (2020). Measuring Infrastructure in BEA's National Economic Accounts (No. w27446). National Bureau of Economic Research.

Bilbiie, F.O., Meier, A. and Muller, G.J., (2008). What accounts for the changes in US fiscal policy transmission?. *Journal of Money, Credit and Banking*, 40(7). 1439-1470.

Blanchard, O., and Perotti, R. (2002). "An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output. " *The Quarterly Journal of economics*, 117(4), 1329-1368.

Bouakez, H., Guillard, M., and Roulleau-Pasdeloup, J. (2017). Public investment, time to build, and the zero lower bound. *Review of Economic Dynamics*, 23, 60-79.

Christiano, L.J., Eichenbaum, M. and Evans, C.L., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of political Economy*, 113(1), 1-45.

Evans, P., and Karras, G. (1994). Are government activities productive? Evidence from a panel of US states. *The Review of economics and statistics*, 1-11.

Fernald, J. G. (1999). Roads to prosperity? Assessing the link between public capital and productivity. *American economic review*, 89(3), 619-638.

Fernald, J. (2014). A quarterly, utilization-adjusted series on total factor productivity. Federal Reserve Bank of San Francisco.

Kamps, C. (2005). The dynamic effects of public capital: VAR evidence for 22 OECD countries. *International Tax and Public Finance*, 12(4), 533-558.

Hulten, C. R. (1992). Growth accounting when technical change is embodied in capital. *American economic review*, 82(4), 964-980.

Pereira, A. M., and De Frutos, R. F. (1999). Public capital accumulation and private sector performance. *Journal of Urban economics*, 46(2), 300-322.

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

Ramey, V. A. (2011). Identifying Government Spending Shocks: It's All in the Timing. *Quarterly Journal of Economic* 126(1), 51–102.

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

Ramey, V. A. (2019). Macroeconomic consequences of infrastructure investment. In *Economics of Infrastructure Investment*. University of Chicago Press.

Tatom, J. A. (1991). Public capital and private sector performance. *Review*, 73.

Wolff, E. N. (1996). The productivity slowdown: the culprit at last? Follow-up on Hulten and Wolff. *American economic review*,, 86(5), 1239-1252.