World Transactions on Engineering and Technology Education
Vol.7, No.1, 2009

Causality analysis between public capital and economic growth

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ABSTRACT: Public capital has been considered to be the wheels of a nation's or a region's economic activity. The reverse effects, the contributions of economic growth to public capital, are also worth analysing. Non-structural approaches in econometrics were implemented for the Australian economy using yearly data for the period from 1960 to 2008. A co-integration test was carried out to investigate whether there are long-term equilibrium relationships between each pair among public capital, private output, private capital and labour. The Ganger causality test was further employed to determine whether public capital contains useful information to predict a private production variable and vice versa. The results will provide historical evidence for Australia's federal and regional governments to assist in estimating the effects among these production variables, in particular, the effect of infrastructure spending on gross domestic product.

INTRODUCTION

Public capital, and especially infrastructure, is central to the activities of households and firms, which represents the wheels, if not the engine, of the economic vehicle. Theoretical arguments and historical evidence have shown strong linkages between public capital and economic growth. When the 2008-09 global economic recession was verified, most governments immediately launched infrastructure spending in their stimulus packages. For instance, the Australian Government planned to spend $28 billion out of the $42 billion stimulus package for infrastructure projects and school improvements commencing from March 2009. This was to lift the country out of a deepening slowdown and to protect against a full-blown recession, which might have sent the budget into the red for the first time in nearly a decade.

Notwithstanding this, it was not until the late 1980s that economists started to develop quantitative measures of such linkage by building macro-economic model, which was pioneered by an economist, David Aschauer [1]. Aschauer's pioneering paper employed aggregate time series data to investigate the relationship between public capital and economic growth by expanding the conventional production function to include public capital or its components. That publication started an important debate in economic literature about the effect of public capital on economic activity. The main motivation behind that seminal paper was to test empirically the existence of a relationship between public capital and private production. The empirical strategy that the author followed consisted of estimating an aggregate production function of the US economy. The author defined core infrastructure as the federal, state, and local capital stock of non-military equipment and structures. The paper found that non-military public capital had a positive and significant effect on aggregate output. The empirical strategy followed by that paper is now a common methodology in economic literature to the point of being known as the production function approach.

Serious attempts to review this empirical strategy first focus on the estimation of aggregate production functions at the US state level [2-5]. Conceptually, these papers follow the same empirical strategy and in most cases use the same definition of public capital. The main advantage of this panel data approach, in comparison to time series, is that state-level samples are large enough to produce reliable estimates. The most significant problem is the lack of primary data on public capital stock at the state level, and hence these studies have to use estimated figures for this variable. In general, the estimated magnitude of the effect of public capital on production tends to be considerably smaller or even negligible under this approach. Subsequent studies were also taken place on other countries, for instance, China [6], France [7], Germany [8]. Under some empirical strategies, the results not only estimate smaller returns to public capital, in comparison with the findings from the pioneering work, but also contradict the idea of public capital as a productive input. The research results raise several questions that initiated a boom in the study of the effects of public infrastructure on the economy. Although, from a theoretical point of view, few researchers would question that infrastructure has impacts on production, the magnitudes of estimated effect in that seminal paper, have been questioned [9]. Furthermore, the aggregate correlation that does not imply any causal relationship between production and infrastructure has been criticised by researchers [2][3][5].

One of the most frequently mentioned problems is the spurious correlation between economic growth and endogenous factors. This is because many macro-economic time series demonstrate the characteristic of non-stationarity even though they may trend in similar directions over time in the long-term analysis. If public capital and private production variables are non-stationary, their estimated relationship might be reflecting only a spurious correlation. A more severe critique lies in the actual causal direction of this correlation. The issue is whether public capital increments actually cause economic growth or whether the causality operates in the opposite direction. An alternative research line in the study of this topic is the estimation of models that do not impose any *a priori* assumption about causality on the data. There have been several examples in the literature, which use econometrics models as an alternative approach to the traditional production function estimations. Besides the flexibility that they offer, an advantage of econometrics models is that they allow testing for the presence of effects between all the variables of interest, even those which theory may not usually consider. The present research takes the advantages of non-structural approaches in economics models to study the Ganger causality among public capital and private output, private capital and labour for the Australian economy, using yearly data for the period 1960 to 2008.

PUBLIC CAPITAL AFFECTING ECONOMIC GROWTH

Public capital has two potential ways of leading to long run economic growth effects, mainly in terms of the production process [1][10] and service function [11-14].

Macro-economic Perspective

In the early literature, it is generally assumed that public capital forms an element in the aggregate production function. The linkage between public capital and economic activity can be modelled with a standard neoclassical framework from a macro-economic perspective, considering public capital stock as an argument in the production function *f* as shown below:

$$Y_t = f(K_t^G, K_t^P, L_t, A_t) \tag{1}$$

where, sub-index *t* gives the period of time, *Y* represents aggregate production, K_t^G is aggregate public capital stock, K_t^P is private capital stock, L_t means labour, and A_t is a technical parameter. Public capital can have different short-term and long-term effects on production depending on the functional form of the production function. The effects of a variation in public capital are given by the partial derivation of *Y* with respect to K_t^G. Under the assumption that public capital is productive, this derivate is positive, and its effect in the long run is reflected in an increased production level.

Another possibility is that public capital may have a positive effect on the technological growth process, facilitating the transit and access to technological innovations [10]. In that case, an expansion of public capital may affect the technological parameter *A* in Equation (1) positively. Following this case, public capital can be interpreted as being one of the technological constraints of total factor productivity and the above equation can be revised as follows:

$$Y_t = A(K_t^G) f(K_t^G, K_t^P, L_t) \tag{2}$$

In addition, the effects of public capital on economic growth also crucially depend on the extent to which private and public capital are substitutes. For instance, firms may build a road on their own, thereby allowing the government to withhold from this investment [15]. Research findings indicate that both crowding-in and crowding-out effects of public investments on private investments by using time series and probit analysis in a sample of twenty-five developing countries [16]. Public capital and private employment are found to be substitutes too [17], and the research also indicates that a clear negative effect of public capital on employment remains after taking into account the effects of public investment on aggregate demand, productivity and wage formation.

Micro-economic Perspective

The second way to model the growth effect of public capital is by focusing explicitly on the services provided by the assets. The macro-economic models described above link public capital to the production function, but do not specify the process by which the capital leads to growth. Those models present an idea of the existence and extent of the effect of public capital, but give no satisfying answer to how, and thus have limited use in directing future public capital. Therefore, the most important problem when using a pecuniary value of public capital for studying its linkage with economic activity is that this methodology may not be appropriate for studying spatially interconnected networks. In fact, the internal composition stock does matter since the marginal productivity of any link depends on the capacity and configuration of all the links in all the networks. An aggregate monetary measure of public capital fails to capture these effects allowing only the estimation of the average marginal product of the network in the past. This problem is of particular interest since most of the public capital stock is associated with networks, such as roads, water systems, sewers, and electric grids among others. Therefore, other approaches have tried to incorporate micro-economic based processes into the model, for example, through reduced travel times and costs which lead to economies of scale and specialisation, and thus to economic growth. For instance, for each industry *i*, the transport services (T_i) produced within that particular sector may be included into the above production function for a sector as follows [11]:

$$Y_i = A_i f(K_i^G, K_i^P, L_i, T(V_i, K_i^G)) \tag{3}$$

where, the transport services, in turn, depend upon the flow of services provided by the aggregated stock of government capital K_i^G as well as the stock of vehicles in the sector V_i. This way of modelling the growth effects of public capital also makes it possible to introduce the effects of congestion and network externalities. Most services provided by the stock of public capital may be subject to congestion and an example is that more vehicles on one road lower the productivity of this road and more roads will reduce congestion and, therefore, improve productivity. Above a certain threshold, however, marginal increments will no longer affect output since they no longer cause a decline in congestion and so congestion will give rise to nonlinearities in the relationship between public capital and economic growth [12].

A somewhat different reason why public capital may affect economic growth is suggested by the new economic geography, which considers transport costs a central determinant of location and scale of economic activity and of the pattern of trade. More transport infrastructure has a profound impact on the size of the market, so producers can cluster together in one central region. This clustering of activities leads to specialisation and economies of scale. In these theoretical models, it is common to model transport costs as iceberg costs [13]. The producer of a particular good sells a certain quantity and, during transport, a fraction of the shipped quantity melts away. The longer the distance, the larger the fraction that melts and the higher the transport costs are. The transport costs can also be defined according to the land area of the region and its public capital stock [14].

METHODOLOGIES

Correlation analysis has been widely used to present the strength and direction of the relationship between two random variables by several coefficients, measuring the degree of correlation, adapted to the nature of the data in academic research. Correlation does not necessarily imply causation in any meaningful sense of that word. The econometric field is full of magnificent correlations, most of which are simply spurious or meaningless, and econometrists debate correlations which are less obviously meaningless. In addition to correlation analyses, the causalities between or within public capital and economic growth of a country or region may be estimated by econometric techniques, such as the unit root test, the co-integration test, the Granger causality test and others. The remainder of this section will provide a brief outline of the basic features of these techniques as original sources and standard references available widely, provide the details.

Stationarity Test Based on Unit Root Theory

Testing stationarity is significant for a regression analysis based on a time series, as the useful information or the characteristics are unlikely to be caught in a non-stationary time series. Therefore, a non-stationary time series would lead to a spurious or meaningless regression. In fact, most economic time series are non-stationary in practice, but time series can be made to be stationary after differencing the first or second time. Useful information of the characteristics are still caught in the time series after the undertaking the first or second difference of the series. Moreover, if two or more variables are non-stationary and have the same order of integration, they can be constructed in a co-integration model. Therefore, the stationarity test should be carried out prior to the co-integration test. A time series is considered to be stationary if its mean and variance are constant and the co-variances depend upon the distance of two time periods.

The stationarity can be confirmed if a time series contains a unit root. In other words, the unit root test is used to test the variables' stationarity and the order of integration. Econometric theory has provided a variety of powerful tools for testing a series, or the first or second difference of the series, for the presence of a unit root. If these variables are non-stationary and have the same order of integration, they can be constructed into a co-integration model. The Augmented Dicky-Fuller (ADF), Phillips-Perron (PP), GLS-detrended Dickey-Fuller (DF), Kwiatkowski, Phillips, Schmidt, and Shin (KPSS), Elliott, Rothenberg, and Stock Point Optimal (ERS), and Ng and Perron (NP) unit root tests are the most popular tests for whether the series in the group, or the first or second differences of the series, are stationary. The ADF and PP tests were used in this study[18][19]. There are three forms of the ADF and PP unit root test models to choose the exogenous regresses, namely including no intercept (a constant) or trend (a linear time trend), intercept but no trend, and intercept and trend, in the test regression. Recent literature suggests that panel-based unit root tests have higher power than unit root tests based on individual time series. While these tests are commonly termed panel unit roots, theoretically, they are simply multiple-series unit root tests that have been applied to panel data structures, where the presence of cross-sections generates multiple series out of a single series. Panel unit root tests are similar, but not identical, to unit root tests carried out on a single series.

Engle-Granger Co-integration Test

The finding that many macro time series may contain a unit root has spurred the development of the theory of non-stationary time series analysis. It was pointed out that a linear combination of two or more non-stationary series may be stationary [20]. If such a stationary linear combination exists, the non-stationary time series are said to be co-integrated. The stationary linear combination is called the co-integrating equation and may be interpreted as a long-term equilibrium relationship among the variables.

The theory of co-integration was developed by [21]. The Engle-Granger (EG) co-integration test is used to determine the pairwise co-integration relationships between two variables. Once the two variables are tested to be non-stationary and the orders of integration are tested to be the same order, the EG test can be used to test the co-integration relationship between each pair of variables [20]. The co-integration regression can rule out the possibility of a spurious regression. It was further demonstrated that the co-integration is evidence of causality [22]. If the co-integration relationship is found, the causal relationship can be detected by the co-integration equation. There are two types of EG test regression, without trend and with trend as presented in Equations (4) and (5) respectively,

$$Y_t = \hat{Y}_t + e_t = \hat{\alpha}_0 + \hat{\alpha}_1 X_t + e_t \quad (4)$$

$$Y_t = \hat{Y}_t + e_t = \hat{\alpha}_0 + \beta t + \hat{\alpha}_1 X_t + e_t \quad (5)$$

The product of β and t is a time trend. After the ordinary least square (OLS) regression of Y on X, the residual series is made as follows:

$$e_t = Y - \hat{Y}_t \quad (6)$$

Using the unit root test to test the stationarity of e_t, if e_t is stationary, Y_t and X_t are co-integrated. In the application of the Engle-Granger co-integration test, first, regress Y on X shown as Equations (4) or (5), and then the residuals series is generated from the regression shown as Equation (6) and a stationary residual series will determine a co-integration relationship between Y and X. This Engle-Granger two-stage co-integration test is performed on the error term from the regression of public capital against economic growth and vice verse at current prices in the present research.

Granger Causality Test

Since the Granger causality was first introduced, it has been widely used by various researchers [23]. It can detect the causal relationship between the research objects mathematically and can be applied easily. The Granger causality approach to the question of whether the variable *X* causes the variable *Y* is to see how much of the current *Y* can be explained by past values of *Y* and then to see whether adding lagged values of *X* can improve the explanation. The variable *Y* is said to be Granger caused by the variable *X* if *X* helps in the prediction of *Y*, or equivalently if the coefficients on the lagged *X*'s are statistically significant. The statement style adopted to report the Granger causality test is *X Granger cause Y*. It is important to note that the statement *X Granger cause Y* does not mean that *Y* is the effect or result of *X*. It means that *X* contains useful information to predict *Y*. Granger causality measures precedence and information content and does not relate to the meaning of causality in the more common use of the term.

The Granger causality between investment in public capital and economic grows is investigated in this research to show whether public capital contain useful information for explaining or predicting the economic growth and vice verse. Once the stationarity is validated by a unit root test and the optimal lag lengths are selected respectively, these factors can be used in a pairwise Granger causality test as presented in the following

$$Y_t = \sum_{i=1}^{m} \alpha_i X_{t-i} + \sum_{i=1}^{m} \beta_i Y_{t-i} + \mu_{1t} \quad (7)$$

$$X_t = \sum_{i=1}^{m} \lambda_i Y_{t-i} + \sum_{i=1}^{m} \delta_i X_{t-i} + \mu_{2t} \quad (8)$$

where, Y_t and X_t are time series of variables, which can be any pairs of public capital and private economic factors in year t. Y_{t-i} and X_{t-i} are the lagged term of Y_t and X_t respectively. The lag length m corresponds to reasonable beliefs about the longest time over which one of the variables could help predict the other. μ_{1t} and μ_{2t} are the error terms. If $\alpha_i \neq 0$ and $\lambda_i = 0$, *X* Granger causes *Y* and *Y* does not Granger cause *X*. If $\alpha_i = 0$ and $\lambda_i \neq 0$, *Y* Granger cause *X* and *X* does not Granger cause *Y*. If $\alpha_i \neq 0$ and $\lambda_i \neq 0$, *Y* Granger causes *X* each other. If $\alpha_i = 0$ and $\lambda_i = 0$, *Y* Granger does not cause *X* each other.

DATA DESCRIPTION

In the present research, the annual data about the Australian economy have been taken from the Australian Bureau of Statistics (ABS). ABS is an agency of the Australian government and thus its data are considered to be convincing and the most accurate. The period covered is from 1960 to 2008. The basic variables are public capital stock, private capital stock, gross domestic products of Australia and total employment.

The three monetary variables are measured in million dollars at their current prices. The time series of public and private capital and output are all taken from the Australian System of National Accounts (ASNA) annually estimated and published by the ABS [24]. The estimates of capital stock and consumption of fixed capital are prepared using the perpetual inventory method (PIM). Estimates of gross capital stock are derived by accumulating past investment flows and deducting the estimated value of retirements from the stock. Estimates of consumption of fixed capital, and hence net capital stock, are derived using a depreciation function based on the expected economic life of the various assets. The ASNA forms a body of statistics that incorporates a wide range of information about the Australian economy and its components. In addition to the long-standing statistics of national income, expenditure and product, the accounts include the financial accounts, input-output tables, balance sheet statistics (including capital stock statistics), multifactor productivity statistics, and state accounts.

The labour data are drawn from the ABS monthly document Labour Force, Australia [25]. This publication contains estimations of the civilian labour force derived from the Labour Force Survey component of the Monthly Population Survey, conducted by the ABS staff. The estimation method used in the Labour Force Survey is composite estimation, which combines data collected in the previous six months with the current month's data to produce the current month's estimates, thereby exploiting the high correlation between overlapping samples across months in the labour force survey. The composite estimator combines the previous and current months' data by applying different factors according to length of time in the survey. After these factors are applied, the seven months of data are weighted to align with current month population benchmarks. Labour is measured as the number of employees in thousands.

Before data are pooled into the analytical models, all four variables are transformed into their natural logarithms to stabilise the variances and to normalise their distributions.

EMPIRICAL RESULTS

Testing Stationarity

In order to determine the order of integration of the four selected variables, the null hypothesis of a unit root on the natural logarithm is first tested for each of them. The stationary process plays an important role in time series analysis. A stationary time series process has a stable probability distribution over time. Its mean and variance are constant, or the value of covariance between two time periods is affected by the lag rather than the time. If a time series is non-stationary, its behaviour can only be studied in a particular time period. For other time periods, it is difficult to generalise valuable information from its behaviour. Another problem is that regression of non-stationary time series would lead to a phenomenon of spurious regression.

Table 1 shows the unit root test results of four variables using the Augmented Dicky-Fuller (ADF) unit root test and the Phillips-Perron (BB) unit root test. The ADF test approach was introduced in [18] and the PP test in [19].

Table 1: Testing for unit roots.

		ADF test at levels			ADF test in first difference			PP test in first difference		
		t-statistic	Prob.*	lag	t-statistic	Prob.*	lag	t-statistic	Prob.*	lag
Intercept	Public capital	-1.350445	0.5983	1	-4.594219	***0.0005***	0	-4.636900	***0.0005***	1
	Private capital	-0.411024	0.8988	0	-5.814404	***0.0000***	0	-5.739920	***0.0000***	7
	Private output	-1.490101	0.5301	0	-5.230692	***0.0001***	0	-5.225579	***0.0001***	1
	Labour	-0.358555	0.9075	2	-5.108097	***0.0001***	1	-4.300206	***0.0013***	12
Critical values		1% level- 3.581152 5% level- 2.926622			1% level-3.581152 5% level-2.926622			1% level- 3.577723 5% level- 2.925169		
Intercept & trend	Public capital	-1.816935	0.6806	1	-4.701890	***0.0023***	0	-4.645687	***0.0027***	3
	Private capital	-1.560819	0.7937	0	-5.759555	***0.0001***	0	-5.675444	***0.0001***	8
	Private output	-2.007951	0.5822	0	-5.387679	***0.0003***	0	-5.339495	***0.0003***	3
	Labour	-3.712441	**0.0312**	1	-5.044473	***0.0009***	1	-4.233640	***0.0084***	12
Critical values		1% level- 4.165756 5% level- 3.508508			1% level-4.170583 5% level-3.510740			1% level- 4.165756 5% level- 3.508508		
None	Public capital	3.041793	0.9992	1	-2.768017	***0.0066***	0	-2.696333	***0.0081***	1
	Private capital	7.699182	1.0000	0	-3.161603	***0.0022***	0	-3.161603	***0.0022***	0
	Private output	13.15487	1.0000	0	-1.227595	0.1984	1	-1.610800	0.1003	7
	Labour	4.310941	1.0000	2	2.337195	**0.0203**	0	-2.213729	**0.0273**	8
Critical values		1% level- 2.616203 5% level- 1.948140			1% level- 2.615093 5% level- 1.947975			1% level- 2.615093 5% level- 1.947975		

*MacKinnon (1996) one-sided p-values.

The null hypothesis of non-stationary was performed at the 1% and 5% significance levels. There are three different null hypotheses of the time series processes in this test: process as a random walk, process as a random walk with drift, and process as a random walk with drift around a deterministic trend. They are shown in Table 1 respectively: no trend and intercept, intercept without trend and, intercept and trend. The test critical values vary according to the test methods in level and difference forms, and on whether trend and/or intercept is included in the test equation. The results show that these four data series are not stationary at the level form but stationary after the first difference at the 1% and 5% significance levels. That is, all the four data series are I(1), which denotes that the time series is integrated at the first difference level.

Pairwise Co-integration Relationship

Co-integration test was employed to detect the long run equilibrium relationships between each pair of the four economic factors in order to reveal the causal relationships between them. Two variables are said to be co-integrated if they share a common trend or tie together in a long run equilibrium relationship. The Engle-Granger test was used in this study. The EG test first regresses one variable on another and obtains a least squares regression. Then, a unit root test is performed on the residuals obtained from the least squares regression to test the stationarity (see Equation 6). If the series of the residuals is stationary, the two variables are said to be co-integrated; that is, they share a common trend in the long term. In addition, the regression is not considered as spurious. There are two types of co-integrating regression models in this test, without trend and with trend. They were formulated as Equations (4) and (5).

Table 2 shows the pairwise co-integration test results of the four economic variables based on the co-integrating regression without trend.

Table 2: Engle-Granger co-integration test without trend.

		Public capital	Private capital	Private output	Labour
Public capital	$\hat{\alpha}_0$		-0.601506	-22.76931	-31.39683
	$\hat{\alpha}_1$		0.875715	2.388540	4.520777
	R square		0.980596	0.968587	0.962736
	DW		0.403882	0.178283	0.197511
	ADF on residuals		**-3.477317 (0.0130)**	**-2.004203 (0.0442)**	**-1.978854 (0.0467)**
Private capital	$\hat{\alpha}_0$	0.875200		-25.15214	-35.10068
	$\hat{\alpha}_1$	1.119766		2.715171	5.154992
	R square	0.980596		0.978822	0.978977
	DW	0.402750		0.105743	0.135905
	ADF on residuals	**-3.316304 (0.0197)**		-1.500184 (0.1237)	-1.185027 (0.6735)
Private Output	$\hat{\alpha}_0$	9.644510	9.344618		-3.628690
	$\hat{\alpha}_1$	0.405514	0.360501		1.894581
	R square	0.968587	0.978822		0.995941
	DW	0.176034	0.104627		0.427922
	ADF on residuals	-1.939066 (0.0510)	-1.618908 (0.0988)		**-2.196257 (0.0284)**
Labour	$\hat{\alpha}_0$	7.015066	6.851449	1.943349	
	$\hat{\alpha}_1$	0.212958	0.189909	0.525679	
	R square	0.962736	0.978977	0.995941	
	DW	0.197152	0.136680	0.429812	
	ADF on residuals	-1.867109 (0.0595)	-1.201786 (0.2069)	**-2.135560 (0.0327)**	

Note: ** and *** denote the rejection of null hypothesis at the 5% and 1% significance level respectively.

There are 12 small real line panes, which denote 12 least squares regression equations and the unit root test by the ADF on residuals obtained from each regression equation. The estimated constant value $\hat{\alpha}_0$ means the intercept and $\hat{\alpha}_1$ the long-term accumulated elasticities listed in the left column with respect to each variable in the top row. All R-square values are close to 1, which indicate that the regression line well approximates the real data points. The low Durbin–Watson statistic, which is substantially less than 2, provides evidence of positive serial correlation between the pair of variables. The ADF on residuals, including the t-statistics and probability, present the significant level to reject the null hypothesis. Each of the bold numbers denotes the series of residuals obtained from the individual regression equation is stationary; that is, the two variables in this regression are co-integrated. The results show that there are six pairs of economic variables are co-integrated and each pair of co-integrated variables must have a long run equilibrium relationship.

Further research on pairwise co-integration test of four variables was conducted based on the co-integrating regression with a time trend. Eight pairs of variables were tested to be co-integrated. Details of the test results are available from the authors upon request.

Pairwise Granger Causality

The four variables were investigated to show whether they contain usual information for predicting each other in a pairwise Granger causality test. Table 3 shows the F-statistics probability values at ten lag lengths under each of six null hypotheses. The test results of additional null hypotheses are available from the authors upon request. The bolded p-value indicates the lag length at which there is a minimum probability to reject the null hypothesis given in the first left hand column. There is no doubt that the public capital significantly Granger causes the private capital immediately. Public capital does not Granger cause private output or labour in general although the rejection rates decrease in both scenarios with the increase of lag lengths. The significant level to reject the null hypothesis that private capital, private output or labour does not Granger cause public capital is generally low with a short lag length. Approximately, it can be said that public capital provides usual information to explain private capital for the test period of 10 years, but public capital does not contain much useful information to predict private output of labour after two years.

Table 3: Granger causality tests.

	F-statistics probability with various lags									
Null hypothesis	1	2	3	4	5	6	7	8	9	10
Public capital does not Granger-cause private capital	**0.00801**	0.01447	0.12551	0.11257	0.23391	0.28873	0.40243	0.57868	0.76528	0.86067
Public capital does not Granger-cause private output	0.41694	0.65079	0.67548	0.65571	0.7765	0.76281	0.85602	0.37176	**0.06675**	0.13705
Public capital does not Granger-cause labour force	0.97425	0.76474	0.89183	0.87051	0.88149	0.88004	0.78787	0.63863	0.4938	**0.45222**
Private capital does not Granger-cause public capital	0.27823	**0.07355**	0.07938	0.05982	0.16867	0.08152	0.1815	0.30266	0.15215	0.10138
Private output does not Granger-cause public capital	**0.05246**	0.07976	0.20883	0.16484	0.19804	0.19618	0.36735	0.53351	0.57979	0.30292
Labour does not Granger-cause public capital	0.10737	**0.10483**	0.27849	0.224	0.41344	0.44566	0.59081	0.497	0.63821	0.26415

CONCLUSIONS

This article attempts to examine the co-integration and causal relationships between public capital, private capital, gross domestic products and labour forces in Australia. The co-integration test results suggest that there are long-run equilibrium relationships among several pair of these selected variables. The study uses unit root, co-integration and Granger's causality tests on annual data from 1960 to 2008. The major findings of the study on causal relationships are: a significant causality from public capital to private capital exists; there is no Granger's causality from public capital to private output or labour force; and the causal relationship from private capital, private output or labour to public capital is not significant, especially after a lag of two years. In the context of the major finding that causation runs from public capital to private capital in Australia, an interesting insight has opened up that it may be a strategy for policy maker to influence private capital investment in the Australian economy by controlling public capital management. In the future, this research can be extended though Vector Autoregression (VAR) and Vector Error Correction modelling and the results obtained from co-integration and Granger's causality tests will be further examined with respect to multiple variables. Furthermore, panel data approaches may also be applied once the state level data become available.

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