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Efficiency of Infrastructure Provision: Australia, States and Territories

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Abstract

This paper examines the optimality of the provision of economic infrastructure in Australia using a system of Euler equations to represent intertemporal efficiency conditions. Employing Generalised Method of Moments, our estimation results suggest that dealing with individual types of infrastructure investments at State level is helpful for reaching realistic conclusions about infrastructure provision. In particular, the paper finds that while the efficiency conditions are satisfied at aggregate level, a disaggregate analysis which examines individual components of economic infrastructure reveals sub-optimality in the provision of some types of infrastructure across the States. In addition, contrary to other methods, our efficiency approach produces a quite sensible estimate of the infrastructure effect with an annual average rate of return of about 8 percent.

Keywords: Economic infrastructure, Efficiency conditions, Disaggregate analysis.
JEL Classification Numbers: H54, H42.

1 Introduction

Despite the disagreement on the magnitude of the effect, the majority of empirical research has tended to confirm the beneficial returns from the enhanced economic infrastructure in boosting economic growth and productivity.[1] Having agreed on its essential role in the economy, a second question to arise is whether the investments in economic infrastructure are at an optimal level. In other words, is the provision of economic infrastructure adequate to meet the needs of society, or is there a waste of resources as a result of over-investing in some sectors while under-investing in others, creating bottlenecks that hinder investment and growth? Answering this question

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[1]For a comprehensive review of empirical literature see Elnasri (2013), Bom and Ligthart (2008), Romp and de Haan (2007) and Makin and Paul (2003) among others.

is quite a complex issue bearing in mind the competition that exists between the financing of economic infrastructure (such as transportation, telecommunications, energy and water supply) on one hand and the funding of social infrastructure (such as health, education and community facilities) and the many other projects that are expected to generate welfare gains for society on the other.

In an attempt to shed light on the above question, this study provides empirical evidence by using recent Australian data. Specifically, the study proposes a framework which stems from a constrained optimisation problem in which the theory is employed to conceptualise an optimal level at which the profit of the firm and the utility of the consumer are maximised. Next, the actual level of infrastructure investment is compared with this optimal level to investigate whether there is over- or under-investment in infrastructure.

The analysis presented here is built on an earlier article written by Otto and Voss (1998) in which the authors examined the provision of public and private investment in Australia over the period 1960-1992 and found evidence that both types of investment are optimally provided. Similar to the previous article, a key feature of this study is the implementation of intertemporal efficiency conditions to examine the allocation of resources in the economy. The current analysis departs from the previous one in two dimensions. First, it focuses on a different category of investment projects, namely, economic infrastructure, in comparison to the broad measure of public capital presented by Otto and Voss (1998). Second, it emphasises disaggregation by states and territories as the preferred level of analysis. Because obtaining evidence on efficiency economy-wide does not necessarily mean efficiency is attained in each individual state, or that the support of inefficiency at the aggregate level of the economy does not inevitably imply that the provision of infrastructure in each state is sub-optimal, the study proposes to examine infrastructure allocation in each of the states separately.[2] In addition to regional disaggregation, we draw attention to the importance of disaggregation by infrastructure components. Our argument in this context is that attaining optimality in the provision of aggregate infrastructure investment does not guarantee that each class of infrastructure is optimally provided. Accordingly, the analysis is extended to examine the allocation of each type of infrastructure investment individually.

Besides the advantage of answering the question of resource allocation, the approach followed in this study is appealing for several other reasons. First, it provides estimates on the elasticity and implied rate of return of the economic infrastructure. In contrast to much of the previous literature, which focuses on partial equilibrium models (such as production or cost function approaches) to estimate the effect of infrastructure, our estimates are produced from an analysis of efficient provision which is tied to optimisation processes for producers and consumers.

Second, the model addresses the problem of endogeneity of infrastructure by treating it as an endogenous variable. A great deal of earlier literature has been challenged for neglecting to handle the possibility of reverse causality which exists as a result of treating infrastructure investment as an exogenous variable. Further, by considering two functional forms for the production function, our approach allows a variation in the assumption underlying the specification

[2] Whenever 'state' is used in the text, it reflects one of the six states or two territories.

of the model. This serves as a sensitivity test for the results.

Although the focus of the paper is on examining efficiency in the *provision* of infrastructure, it is worth mentioning that in the literature researchers also use the term 'efficiency' to refer to another distinct, but relevant, concept which reflects the notion of offering better service quality at lower cost. This in particular is known as efficiency in *delivering* infrastructure services. In general, one would expect the level of efficiency of resource use to have implications for achieving the optimal allocation of these resources. For instance, if we observe infrastructure investment falling over time relative to total spending, this may not result in a shortage in the provision of services if the existing capital stock is operating more efficiently. The efficiency of the use of infrastructure resources is an important issue that merits generous attention from researchers and policy makers because it affects the flow of services. In Section 2, we will offer a brief discussion in relation to this theme; however, a definitive treatment of the topic is, though important, beyond the scope of the current analysis.

To pursue the objective of the study, we identify conditions of efficient resource allocation for an economy (which may represent the total Australian economy or the economy of one of the states) for two classes of capital sectors. These are economic infrastructure capital and other (non-economic infrastructure) capital. As we will argue in this paper, interest is focused on the total supply of services delivered in the economy; thus, we construct a measure that combines both private and public sector ownership. The efficiency conditions produce a set of moments which are estimated using the Generalised Method of Moments (GMM) and tested by the Hansen's test of over-identifying restrictions. The empirical results suggest that dealing with individual types of infrastructure investment at state level (rather than a collective measure of infrastructure at the whole economy level) when examining resource allocation leads to more accurate conclusions. In particular, our evidence shows that while the aggregate level of economic infrastructure is optimally allocated at country and state levels, disaggregate analysis by infrastructure class yields evidence of inefficient resource allocation.

The remainder of the paper is structured as follows. Section 2 reviews some of the arguments surrounding the private sector provision of infrastructure and how some views hold that the public sector's delivery to infrastructure is less efficient than that of private enterprise. Section 3 describes the setup of the efficiency conditions under the two alternative production functions. The empirical method and results are presented in Section 4. Section 5 concludes.

2 Privatisation

Investment in public infrastructure in Australia has recently declined considerably because of financial constraints. Federal, state and local governments have sought private funding for this sector as a means to meet the financing problem. Over the past two decades, the country has witnessed a great flurry of privatisation as many government agencies were subjected to increased commercialisation and a large number of infrastructure projects were privatised, with their operations subjected to government regulation. Besides the imposition of financial constraints, these changes were also induced by the ongoing microeconomic reform regime through which governments have encouraged private sector provision of infrastructure.[3] Whether the method of providing infrastructure by the private sector has led to a greater net benefit remains a controversial issue. Whilst one view sees many advantages in the private sector provision of public infrastructure, the other view emphasises the disadvantages. The reasons often cited in support of government intervention relate to the risk of market failure in producing economically efficient results. A potential source of this failure is the provision of a public good, which is characterised by non-excludability and non-rivalry (Neutze 1995). With these properties, it is infeasible or too costly to exclude those who do not pay from some or all of the benefits delivered by these goods. Another source is the monopolistic nature of infrastructure. Due to the high-priced initial capital stock required to establish these projects and the economies of scale, competition is difficult to establish in practice (Aulich et al. 2001). These peculiar properties of infrastructure have led to the belief that private sector provision will result in the abuse of monopoly power and hence a loss of public interest.

Other arguments against the private sector provision of infrastructure are the externalities which occur when the benefits or costs of producing (or consuming) a good or a service affect agents other than those engaged in the process, and the inability of the private sector to manage the large risk involved in large-scale infrastructure projects (Shleifer 1998). A last argument to mention here is the deterioration which is expected to exist in the standard of services, because profit is the core driving force for private projects.

On the other hand, there is some advocacy for private sector provision of infrastructure. The proponents of this view rely on reasons such as a belief that the involvement of the private sector will increase competition in the economy which will lead to reduced costs, reduced prices and the increased quality of services (for example see Kay and Thompson 1986 and Yarrow 1986). A second reason is the efficiency gain which is expected due to the lower unit cost of private enterprises relative to the public sector counterpart. Improvement in efficiency is a normal consequence of competition which is necessary to provide powerful incentives to produce and price efficiently. Although empirical research does not provide clear cut evidence that public sector management is innately inferior to the private sector, broadly speaking, considerable efficiency gains have been observed in enterprises that were previously publicly owned (Borcherding et al. 1982). Other factors in support of privatisation are the reduction in public deficit and the protection of funding for community services and welfare needs, because the involvement of the private sector in providing infrastructure can mitigate severe budgetary constraints (Quiggin 1995). Moreover, there is a claim that the private sector offers an advanced means for organising productive activity because of the greater incentives that exist within these organisations for lower cost. Finally, there is the improvement in work practices, as private firms with their target of maximising profit may offer methods of cost saving by introducing technology plus access to skills and training (Dixit 1997).

Although there is no clear cut evidence in the above discussion as to which sector is efficiently

[3] Readers may refer to the Economic Planning Advisory Commission (1995) for details on how the provision of private infrastructure has evolved in Australia, and to Lim and Dwyer (1999) for a review on microeconomic reform and National Competition Policy.

superior in delivering infrastructure services, this ambiguity does not represent a barrier to performing the analysis intended in this study. The major concern of the study is the pivotal role played by the aggregate supply of infrastructure services in the Australian economy, and whether such services are provided at an optimal level. Put differently, from the point of view of its users, it may be argued that the important question is not whether infrastructure is publicly or privately provided, but whether it is adequately provided.

The majority of previous Australian research has generally focused on publicly owned infrastructure systems. However, from the viewpoint of this analysis, perhaps the most important issue is to evaluate the contributions and provisions of all types of infrastructure capital to the growth of output and productivity, irrespective of whether they are publicly or privately owned. This seems a legitimate approach given that at the present time a significant portion of the infrastructure system in Australia is, in fact, privately owned.

A complementary though brief discussion provided in this section depicts the channels through which private sector investment in infrastructure can affect productivity and economic growth. Since privately provided infrastructure is recognised as being subject to user charges, one would not expect to receive the so called 'free input effect' which hinges on the notion of being an unaccounted-for direct input into the production process. However, there are still two channels via which privately owned infrastructure can benefit the economy: (i) through the production spillover effect, it can enable or facilitate product or process innovations and therefore lead to benefits that indirectly affect private sector output and productivity, for example 'network' effects from transport or communications infrastructure that enable producers to extend their markets and better coordinate their activities; (ii) it can affect the productivity of other inputs; for example, it can be a complement to or substitute for public capital or labour (see Shanks and Barnes 2008 for more discussion on these channels).

An additional justification for the study's focus on a total measure for infrastructure (i.e. a combination of publicly- and privately-owned infrastructure) is linked to measurement difficulties. Due to the increase in privatisation since the 1980s, it has become infeasible to collect accurate data that separate the ownership of infrastructure. The problem of how to deal with these statistical difficulties was easier to handle in previous studies, such as that of Otto and Voss (1998), in which researchers chose to exclude corporation enterprises from the definition of public capital because they were mostly affected by privatisation. However, over time the transfer of ownership to the private sector has turned to affect other categories of public investment.

3 Efficiency conditions in the provision of infrastructure

To construct the model, let us consider an economy which consists of a representative firm and a representative consumer. The firm produces a single output with two inputs, labour and capital. The aggregate production function of this economy is given as :

$$Y = F(K, L), \tag{1}$$

where Y, K, and L represent total output, total capital stock, and labour input respectively. The capital stock, K, is divided into two types: K_1, represents the total economic infrastructure capital stock, and K_2, represents all other types of capital stock employed in the production of Y but not included in K_1.[4] Thus, (1) is rewritten as:

$$Y = F(K_1, K_2, L). \tag{2}$$

With the two types of capital goods, there exist two types of gross investment returns, $R_{i,t+1}$, where $i = 1, 2$. If such an economy faces a stochastic discount factor, m_{t+1}, which is common to both the firm and the consumer, then the intertemporal efficiency conditions (i.e. the Euler equations) are given as:

$$E_t(m_{t+1}R_{i,t+1}) = 1, \qquad i = 1, 2, \tag{3}$$

where E_t is the expectations operator conditional on information available at time t.

These conditions can be utilised to examine whether investment in infrastructure capital is optimally allocated, although the estimation and testing of these conditions first requires the specification of functional forms for m_{t+1} and R_{it+1}. The specification of the stochastic discount factor, m_{t+1}, comes from modelling individual preferences, whereas the specification of returns, R_{it+1}, originates from the modelling of the aggregate production function.

3.1 Preferences

The representative consumer maximises expected lifetime utility:

$$U_t = E_t \sum_{s=t}^{\infty} \beta^{s-t} u(c_s), \tag{4}$$

where c_s represents private per-capita real consumption in period s; β is the subjective discount factor; $u(.)$ is assumed to be an increasing and concave function in c_s. The maximisation problem is subject to a budget constraint defined as:

$$\sum_{i=1}^{n} P_{it}A_{it} + c_t \leq \sum_{i=1}^{n} R_{it}A_{it-1} + W_t, \tag{5}$$

where P_{it} and A_{it} are the price and quantity respectively of asset i held at time t. W_t is real labour income at time t.[5] Following standard intertemporal theories of consumption and asset pricing, the marginal rate of substitution for this consumer with a time separable utility function

[4] K_2 includes all other types of non-dwelling construction; machinery and equipment; R&D; computer software etc., in addition to social infrastructure such as education and health services. We use the term 'other capital' and 'non-infrastructure capital' interchangeably to reflect K_2.

[5] In this model, the preference between labour and leisure is not taken into the account. This is equivalent to the assumption that labour is supplied inelastically.

is:

$$m_{t+1} \equiv \beta \frac{u'(c_{t+1})}{u'(c_t)}, \tag{6}$$

where u' is marginal utility. To accommodate the estimation task, further assume a constant relative risk aversion (CRRA) utility function specified as:

$$u(c_t) = \frac{c_t^\sigma}{\sigma}, \tag{7}$$

with $\sigma \leq 1$. The term $\frac{1}{1-\sigma}$ is the intertemporal elasticity of substitution and $1 - \sigma$ is the coefficient of relative risk aversion.

3.2 Production

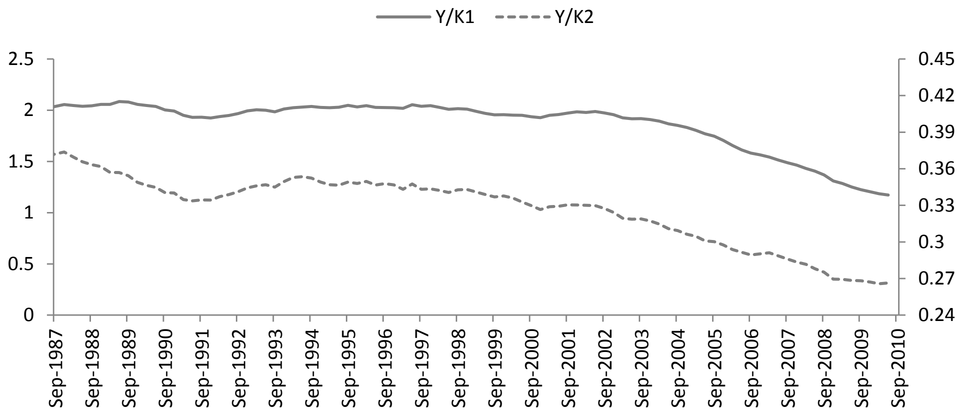
To specify a functional form for R_{it+1}, we employ a framework of production-based asset pricing by Cochrane (1991, 1992) which links the producer's stock returns to investment returns by using information about producers and production functions. We apply his framework at a sectoral level, and in this context, the returns to investment are typically derived from a producer value-maximisation problem which explicitly allows for investment adjustment cost as a function of investment expenditure and capital stock. In the Appendix, we provide a mathematical derivation for the return to investment following the standard literature of production-based asset pricing. To avoid modelling the unknown functional form of the adjustment costs, this study will adopt the method suggested by Otto and Voss (1998) and utilise the prices of each type of investment good to represent the adjustment costs. Accordingly, the gross investment return can be described by the following formula:

$$R_{it+1} \equiv \frac{1}{p_{it}}[F_{K_{i,t+1}} + (1 - \delta_i)p_{it+1}], \tag{8}$$

where p_{it} is the relative price of investment good i in terms of aggregate output; $F_{K_{i,t+1}} \equiv \partial Y_{t+1}/\partial K_{i,t+1}$ and δ_i are the marginal productivity of and deprecation rate for capital i respectively. The economic intuition of this formula is that one unit of forgone consumption at time t invested in sector i provides $1/p_{it}$ units of investment good. This increases future output by $F_{K_{i,t+1}}$ and future capital stock by $(1 - \delta_i)$ valued at p_{it+1}.

As noted, the current study adopts the general framework of Otto and Voss (1998) in which they set up the intertemporal conditions and use them to examine the optimality of resource allocation. In contrast to their paper, however, our classification of capital is made according to the nature and extent of certain characteristics of the investment goods. In other words, we classify infrastructure projects as a group of capital goods that have distinct properties - such as the large size and longevity of the projects, the monopolistic nature and the sunk investment in these assets - which make them differentiable from other types of capital goods. Further, we focus more on the economic infrastructure (as opposed to the social infrastructure) as a set of projects that have a more direct and immediate effect on the production process. Consequently,

Figure 1 Output to capital ratios: Australia, 1987q1 - 2010q2



The left vertical axis measures Y/K_1 while the right axis measures Y/K_2.

and as indicated earlier in (2), the division of the capital stock to K_1 and K_2 indicates economic infrastructure capital and other capital respectively.[6]

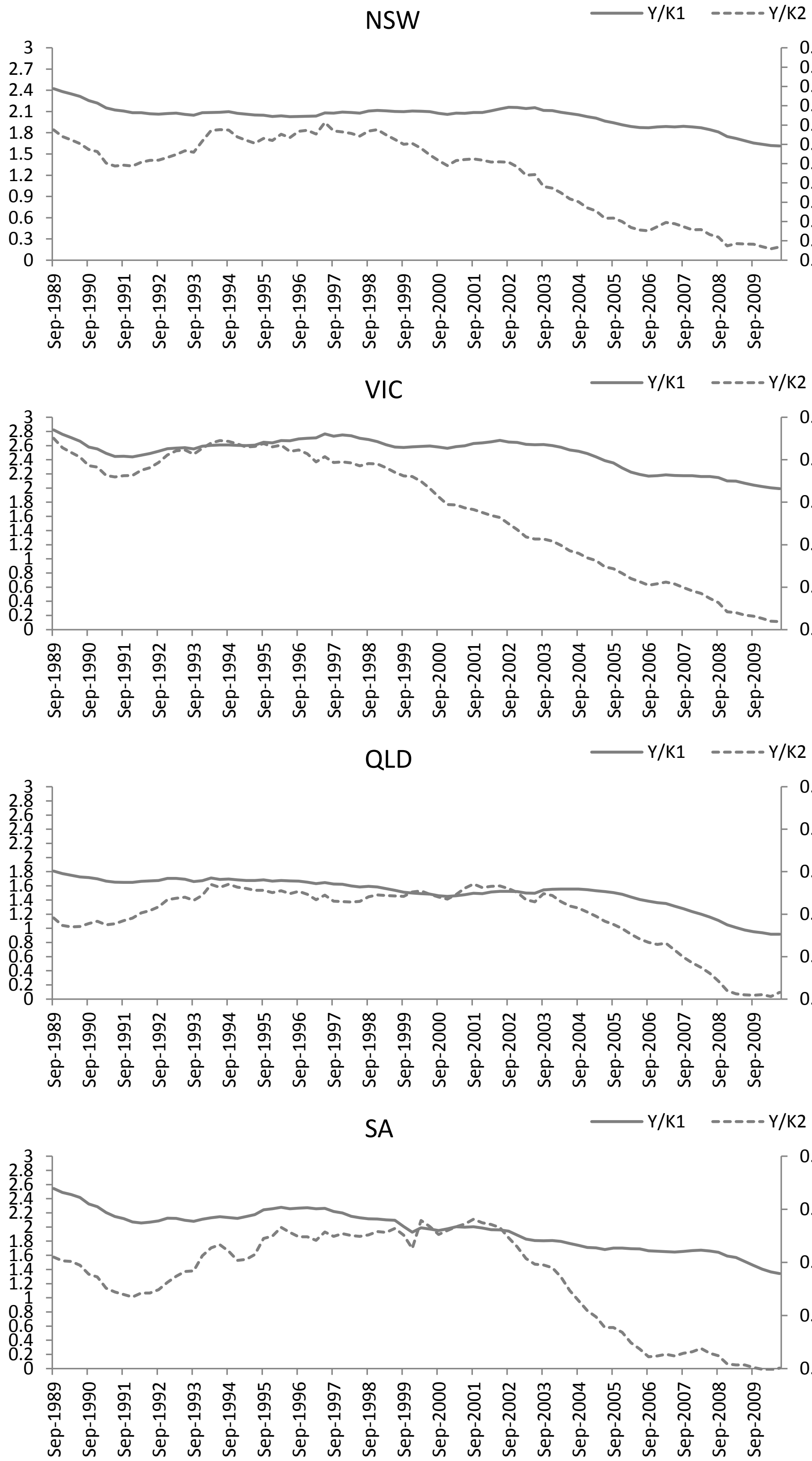
Another aspect of comparison with the earlier paper is the nature of the relationship between the two types of capital goods. While the trends of the output to capital ratios presented in Otto and Voss's study suggest a substitutability between private and public capital, there is no clear a priori expectation on how K_1 correlates to K_2 in the present study. To investigate a possible relationship, we plot the output-capital ratios in Figure 1 to represent the case of Australia and Figure 2 to represent the case of each of the states. As can be seen in these figures, the two ratios are likely to move together in several episodes across the sample period. Although a formal statistical test is required to determine the relationship between the two goods, observing these particular trends portrays K_1 and K_2 as perhaps being complements rather than substitutes.

The decline in the output-capital ratios presented in Figures 1 and 2 reflect a fall in productivity of the two types of capital during the 1990s and 2000s. The economic theory points towards two forces that affect capital productivity. These are capital deepening (large increases in capital relative to labour) and technological change. Using official published measures of inputs, output, and multifactor productivity (MFP) we observed a large increase in capital deepening during that period which means, on average, that a unit of capital increasingly has less labour to work with and so less output can be produced per unit of capital input. This observation is the mirror image of an increase in labour productivity. With an increasing capital-labour ratio, each unit of labour has, on average, more capital to work with and so more output can be produced per unit of labour input. The second reason behind the decline in capital productivity is the negative growth in the technological change (measured as MFP) during that period. For more discussion on the decomposition of changes in capital productivity into growth in capital deepening and growth in MFP, see Parham (1999).

To proceed, we need to parameterise $F_{K_{i,t+1}}$ by giving the production function a specific

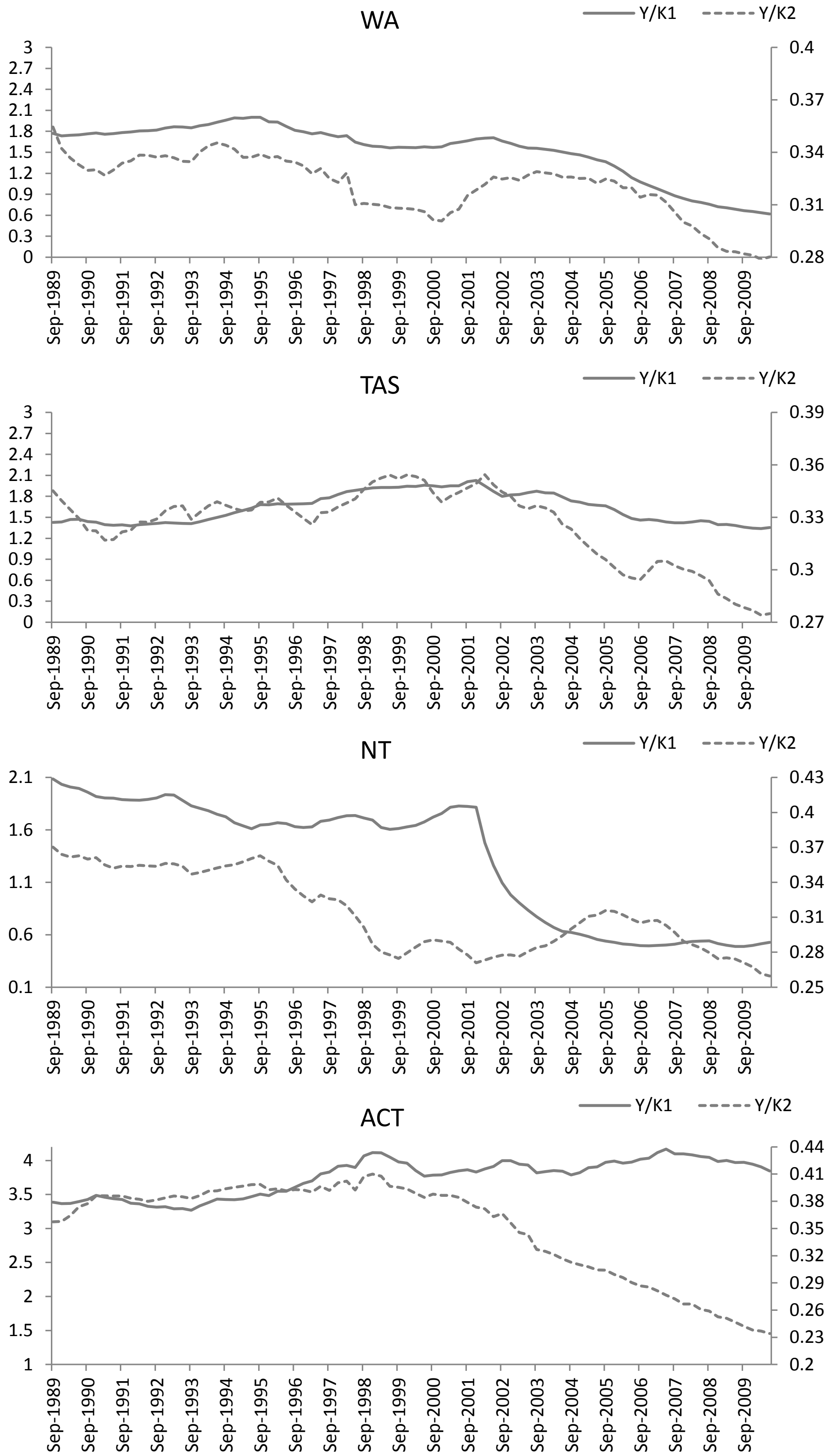
[6]Note that, K_1 and K_2 represent public and private capital goods in the Otto and Voss (1998) paper.

Figure 2 Output to capital ratios: States, 1989q2 - 2010q2



The left vertical axis measures Y/K_1 while the right axis measures Y/K_2.

Figure 2 continued: Output to capital ratios: states, 1989q2 - 2010q2



The left vertical axis measures Y/K_1 while the right axis measures Y/K_2.

form. A standard Cobb-Douglas representation with constant returns to scale (CRS) in all inputs is proposed and given as:

$$Y = K_1^{\rho_1} K_2^{\rho_2} L^{1-\rho_1-\rho_2}, \tag{9}$$

where the exponential coefficient of each input represents the elasticity of output with respect to that input.[7] The assumption of CRS is generally viewed as being a 'safe' assumption when working with highly aggregated data (as opposed to a single project). However, one can argue that even though it is reasonable to assume CRS over non-infrastructure capital and labour inputs, with infrastructure we usually expect economies with alternative sources of increasing and decreasing returns to scale. Therefore, the CRS imposed on the production function seems to be a somewhat strong assumption. To account for violation of the CRS, we have also considered a Cobb-Douglas function with variable returns to scale, but, we find that relaxing this assumption does not change the formulation of return to investment (see the Appendix for proof).[8]

Although the simple structure of the Cobb-Douglas function has the advantage of easy estimation, it is somewhat restrictive. To avoid potential problems as a result of using incorrect representation of production, Otto and Voss suggested considering a more flexible representation for the production function which allows for a high degree of substitutability between private and public capital; that is, the constant elasticity of substitution (CES) production function.

Since the present framework defines two different categories of capital, we will argue in this paper that the Cobb-Douglas function is a sensible representation for the data. Nevertheless, being a generalised functional form of the Cobb-Douglas function, the CES function is also considered to provide robustness against possible 'restrictive' functional representation. Following Otto and Voss, we adopt the following version of the CES function:

$$Y = \left[\alpha K_1^{\phi} + (1-\alpha) K_2^{\phi}\right]^{\gamma/\phi} L^{1-\gamma}. \tag{10}$$

Having put forward the foundations required to build up the model, we next turn to constructing the efficiency conditions. As outlined earlier, the approach presented in this paper considers two levels of aggregation. Thus, two frameworks are sketched below to specify the conditions employed at each level.

3.3 Framework 1: Efficiency of aggregate infrastructure capital stock

Considering the two specifications of the production function, the estimation strategy involves two efficiency conditions. With the Cobb-Douglas representation, the first pair is shown in (11) below:

[7] Following the argument of Otto and Voss (1998), we do not include a measure of technology which traditionally appears in the Cobb-Douglas function. This is because the focus of the analysis is on the sectoral returns which are usually expressed independently of the technological specification.

[8] With the assumption of CRS ($\rho_1 + \rho_2 + \rho_3 = 1$), the per-capita production function is given as $y = k_1^{\rho_1} k_2^{\rho_2}$, where $y = \frac{Y}{L}$ is the per-capita output, and $k_i = \frac{K_i}{L}$ is the per-capita-capital stock for sector i.

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1}+(1-\delta_i)p_{it+1}]\right]=1, \qquad i=1,2, \tag{11}$$

where y_{t+1} is per-capita output, and k_{it+1} is the per-capita capital stock for sector i. Another pair is constructed with the CES representation, which is given by (12) and (13) :

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_1t}\right)\right.$$
$$\left.\left(\gamma\alpha\frac{y_{t+1}k_{1t+1}^{\phi-1}}{\alpha k_{1t+1}^{\phi}+(1-\alpha)k_{2t+1}^{\phi}}+(1-\delta_1)p_{1t+1}\right)\right]=1, \tag{12}$$

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_2t}\right)\right.$$
$$\left.\left(\gamma(1-\alpha)\frac{y_{t+1}k_{2t+1}^{\phi-1}}{\alpha k_{1t+1}^{\phi}+(1-\alpha)k_{2t+1}^{\phi}}+(1-\delta_2)p_{2t+1}\right)\right]=1, \tag{13}$$

where all notation remains unchanged.

3.4 Framework 2: Efficiency of disaggregated infrastructure capital stock

The approach described under Framework 1 is only useful for providing information on whether economic infrastructure is efficiently provided at the aggregate level of the whole country or a state. To examine whether each type of infrastructure capital such as roads, telecommunications, electricity is adequately provided, we modify the model by disaggregating infrastructure capital stock K_1 into N components. This means we can rewrite the general form of the production function presented earlier in (2) as:

$$Y=F(K_{11},K_{12},...,K_{1N},K_2,L), \tag{14}$$

where $K_{1n}\in K_1$ reflects one type of infrastructure capital good. For convenience, let us denote K_{1n} by simply K_n. In the second step, for each K_n we construct a counterpart measure which aggregates all the other types of infrastructure capital goods, i.e. the aggregate of all types in the vector $K_{-n}\in K_1$. This procedure results in two vectors of K_n and K_{-n} with a dimension of $(N\times 1)$. Consequently, (14) is rewritten as:

$$Y=F(K_n,K_{-n},K_2,L). \tag{15}$$

To construct efficiency conditions that are suitable for examining a provision of K_n, the original functional forms of the production functions and the corresponding Euler equations developed earlier have to be rewritten. For the sake of simplicity, the focus with our disaggregate analysis will be on the Cobb-Douglas production function which, in contrast to the CES function, directly provides estimates for the output elasticities.[9] Hence, (9) is modified to be:

$$Y = K_n^{\rho_1} K_{-n}^{\rho_2} K_2^{\rho_3} L^{1-\rho_1-\rho_2-\rho_3}, \tag{16}$$

with the corresponding efficiency conditions given by:

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_i t}\right)\left[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}\right]\right] = 1, \qquad i = n, -n, and\ 2. \tag{17}$$

In these two frameworks, we aim to estimate the vector of production function parameters while the other parameters have been set at specific values. The subjective discount factor β is set at 0.99 which implies an annual discount rate of 4%, the intertemporal rate of substitution σ is set at a value of -1.0, and the depreciation rate $\delta_i = 0.011$ for K_1, and 0.017 for K_n, K_{-n} and K_2.[10]

4 Empirical method

4.1 Generalised Method of Moments estimation

For each version of the model, the optimality conditions define an error term vector ($\mu_{t+1} = m_{t+1}R_{i,t+1} - 1$) with a dimension $q \times 1$ that, given information at time t, should have a zero conditional mean if the model is correct.[11] Assuming an $h \times 1$ vector of instrumental variables that are known at time t and denoted by z_t implies that $E(\mu_{t+1}|z_t) = 0$, and therefore $E(\mu_{t+1}z_t) = 0$.

Now, given q types of returns on capital and h instruments, there are $L = qh$ orthogonality conditions, $E_t(\mu_{t+1} \otimes z_t) = 0$, that map naturally into Hansen's (1982) Generalised Method of Moments (GMM) framework for estimation and testing.
Rewrite the L moments as:

$$g_t(\theta) = E(\mu_{t+1}z_t), \tag{18}$$

where θ is a $M \times 1$ vector of parameters (θ equals $[\rho_1, \rho_2]$ in the Cobb-Douglas model, or $[\gamma, \phi, \alpha]$

[9]In contrast to the scope of estimation of Framework 1 which considers efficiency conditions under two representations of the production function, we restrict the estimation of the disaggregate analysis to the Cobb-Douglas function only. This is mainly due to the fact that with N types of capital goods ($N = 7$), an exercise which allows for two functional representations will generate a very large number of results corresponding to the case of the whole country and eight individual states. More importantly, as we will argue later in the results section, the findings from the aggregate analysis with the Cobb-Douglas function representation are very consistent with the findings from the CES function; furthermore, the Cobb-Douglas function has generally proved to fit better than the CES function. Readers interested in the structure of efficiency conditions with a multi-input representation of the CES production function can find it provided in the Appendix.

[10]There is no a priori assumption regarding suitable depreciation rates to apply for these two types of capital; thus, the choice of these rates is somewhat arbitrary. For the purpose of sensitivity checks, differing rates have been implemented; however, the change in results is very slight.

[11]The dimension of the error term vector q reflects the number of asset types which is set to equal 2 for the case of aggregate infrastructure and 3 for the case of disaggregate infrastructure.

in the CES model). The L moment equations correspond to a vector of sample orthogonality conditions $\overline{g}_t$ given by:

$$\overline{g}_t(\hat{\theta}) = \frac{1}{T}\sum_{t=1}^{T} g_t(\hat{\theta}) = \frac{1}{T}\sum_{t=1}^{T} \mu_{t+1} \otimes z_t. \tag{19}$$

The GMM chooses the parameters , $\hat{\theta}$, that solve $\overline{g}_T(\hat{\theta}) = 0$.

If the equations to be estimated are exactly identified, so that $L = M$, it is possible to find $\hat{\theta}$ that solves $\overline{g}(\theta) = 0$, and this GMM estimator is in fact the Instrumental Variable (IV) estimator. However, if the equations are over-identified, so that $L > M$, it will not be possible to find the $\hat{\theta}$ which will set all the sample moment conditions to exactly zero. Thus, we need to use an $L \times L$ symmetric and positive semi-definite weighting matrix W that determines the relative importance of the various moment conditions to construct a quadratic form in the moment conditions. This gives us the GMM objective function:

$$J(\hat{\theta}) = \overline{g}_T(\theta)' W_T \overline{g}_T(\theta). \tag{20}$$

Therefore, the GMM estimator for θ is the $\hat{\theta}$ that minimises $J(\hat{\theta})$. Note that, depending on the choice of W, there are many GMM estimators. An important contribution of Hansen (1982) is to point out that an efficient GMM estimator is the one with an optimal weighting matrix which minimises the asymptotic variance of the estimator. This latter can be achieved by setting $W = S^{-1}$, where S^{-1} is the inverse of an asymptotic covariance matrix.

Hansen (1982) provides sufficient conditions under which the GMM estimates are consistent and asymptotically normal and the minimised value of the quadratic form is asymptotically distributed as a chi-square. Empirical evidence shows that with multiple assets returns the iterated GMM approach provides more accurate test statistics than the two-stage GMM approach which, as described in Hansen and Singleton (1982), tends too often to reject the models in larger systems. Therefore, we use an iterated GMM approach in this study.[12]

4.2 Quality of instruments

The reliability of the results from the GMM estimation is greatly influenced by the quality of the instruments. The presence of weak instruments may cause serious distortions in the estimates, hypothesis tests and confidence intervals (see Stock, Wright and Yogo 2002 for an overview of problems caused by weak instruments and some recommendations on how to deal with them). Briefly speaking, the poor quality of the instruments can lead to two concerns. One is the inability of GMM estimators to approach normal distributions even with large samples. This behaviour is associated with the weak instrument asymptotic developed in Stock and Wright (2000). In their studies, the authors derive a new large sample theory that is non-normal and

[12]More precisely, employing the software RATS, the method implemented constructs the weighting matrix W by using the parameter estimates from the jth stage, then uses this matrix to find parameters for stage $j + 1$ which minimises the quadratic form, and then uses the new parameters to update the weighting matrix. The iterations continue until the objective function converges.

non-standard in the case of weak instruments with which they find that the GMM estimators are inconsistent.

The other concern with weak instruments is that in the finite sample, GMM estimators are biased and the test statistics have size problems; for example see Hansen, Heaton and Yaron (1996), and Stock, Wright and Yogo (2002).

A good instrument should satisfy two requirements: relevance, which means the instrument must correlate with the included endogenous variable(s); and validity, which means it should be orthogonal to the error process. While the relevance condition can be tested statistically, it is impractical to test for the validity requirement because the moment condition involves the unobservable residual term. Usually the assumption that the instrument is valid is taken on faith, where one has to believe in the theoretical arguments underlying the exclusion restriction.[13] To test the relevance condition, we follow Shea (1997) and consider a sample partial correlation statistic which measures instrument quality in multivariate models. This procedure involves calculating the sample-squared correlation coefficient from regressing the derivatives of the Euler equations with respect to the estimated parameters against the instruments set.

4.3 Data

The estimation analysis employs quarterly data which cover the period 1987q1 - 2010q2 for Australia's regressions and the period 1990q4 - 2010q2 for the states' regressions. In this section, we briefly outline the sources and methods used to construct these data. Estimates of economic infrastructure (aggregated and disaggregated by asset type) are constructed at the country and state levels by using value-of-work-done data on engineering construction activity which have been compiled from the Engineering Construction Survey (ECS) and collected from the ABS (cat. no. 8762.0).[14] We sum the value-of-work-done by both public and private sectors to construct a combined measure that reflects the total supply of economic infrastructure. A standard perpetual inventory method (PIM) is applied to convert the flow of these investments into stocks.[15] To estimate a measure for non-economic infrastructure or other capital stock, we first calculate non-economic infrastructure investment as a sum of private and public gross fixed capital formation less economic infrastructure investment, then apply the PIM to estimate the

[13]To overcome the validity problem of instruments, some studies adopt methods that are immune to the presence of weak instruments, such as the procedure of Anderson and Rubin (1949).

[14]The ECS estimates cover the value-of-work-done on seven types of construction (see the results section for details of these types). Our preference for using the ECS data comes from the fact that it is very close in nature to the spending on core/economic infrastructure. In addition, availability at state and sector levels and construction type is another advantage.

[15]The PIM is represented by the following formula:

$$K_t = K_{t-1}(1 - \delta_t) + I_t, \tag{21}$$

where K_t is the value of capital stock in the current period; K_{t-1} is the value of capital stock in the previous period; I_t is the value of investment in the current period; and δ_t is a constant rate of depreciation with annual value of 5%. The benchmark, or starting period, capital stock, K_{t^*}, is computed based on the depreciation rate, δ; the value of investment in the initial period, I_t^*; and on the assumption that the average growth rate of the observed total investment, κ, adequately describes the annual growth rate for the indefinitely long preceding unobserved series. Accordingly, $K_{t^*} = \frac{I_t^*}{(\kappa+\delta)}$.

capital stock.

Consumption is defined as the total private final household consumption expenditure which is a seasonally adjusted chain volume measure. Output for Australia is the seasonally adjusted chain volume measure of gross domestic product which, like the data on consumption, is sourced from the Australian National Accounts (ABS, cat. no. 5206.0). At the state level, the quarterly estimates are interpolated by applying the Chow and Lin (1971) best linear unbiased interpolation procedure on annual gross state product data published in the State Accounts of the ABS (cat. no. 5220.0).[16] Output and consumption are measured in per-capita terms using population data from Australian demographic statistics (cat. no. 3101.0). The price deflators of output and the two types of investment are used as measures for output and investment prices.

It is well recognised that using larger instrument sets will produce asymptotically efficient estimates; however, the use of smaller instrument sets is recommended with small samples to avoid finite sample bias. Thus, we follow Otto and Voss (1998) in choosing three relatively small instrument sets which are dated $t-1$ or earlier. Instrument Set 1 contains a constant and a measure of the real interest rate which was estimated by Otto and Voss (1998) following a method put forward by Mishkin (1981).[17] Instrument Set 2 contains a constant, the real interest rate, and output-capital ratios for the corresponding types of capital included in each regression. Finally, Instrument Set 3 includes price-weighted output-capital ratios plus the gross growth rates of the investment prices.

Summary statistics of all variables are presented in Table 1.[18]

4.4 Estimation Results

This section presents the estimation results and their robustness to several empirical considerations. We check for instrument quality via two techniques: by checking the sensitivity of results with three different instrument sets, and also by computing the quality diagnostic tests with these three sets.

4.4.1 Aggregate analysis

We begin by presenting the estimation results obtained from the efficiency conditions specified under the subheading 'Framework 1'. As those conditions describe the provision of aggregate infrastructure capital, we label this part of the results section as aggregate analysis. However, since

[16] To avoid the finite sample bias of the GMM we preferred using quarterly data which offer many degrees of freedom over annual data which go back only to 1990.

[17] The real interest rate is computed as the predicted value of the ex-post real interest rate, r_t^e, from a linear regression of r_t^e on $\{constant, t, \pi_{t-1}^e, ..., \pi_{t-4}^e, i_{t-1}, ..., i_{t-4}, \hat{y}_{t-1}, ..., \hat{y}_{t-4}\}$, where $r_t^e \equiv i_t - \pi_t^e$; i_t is nominal interest rate on Commonwealth government two-year bond; $\pi_t^e \equiv \frac{P_{t+1}-P_t}{P_t}$ is the inflation rate, where P_t is consumer price index; t is a time trend; $\hat{y}_t$ is output growth; and $t-i, i = 1, ..., t-4$ denotes four lags. Data on i_t and P_t are obtained from the Reserve Bank of Australia and ABS (cat. no. 6401.0) respectively.

[18] In Table 1, NT appears to have relatively large mean and standard deviation values for capital in comparison to Australia and other states. The explanation for this lies in the nature of the investment series employed to construct capital stock. In particular, we observed a marked and relatively sudden increase in the recorded value-of-work-done by the private sector since 2002.

Table 1 Summary statistics

	Australia	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
y									
Mean	11.949	12.144	11.512	12.121	10.066	16.783	9.208	15.301	15.799
Std. Dev	1.761	1.477	1.539	1.775	1.301	2.475	1.185	2.013	1.846
c									
Mean	6.283	6.793	6.630	6.175	6.069	6.316	5.591	6.234	7.603
Std. Dev	0.982	0.898	0.939	0.851	0.916	0.903	0.818	1.257	1.242
k_1									
Mean	6.657	6.095	4.709	8.475	5.381	13.019	5.697	17.466	4.177
Std. Dev	2.069	1.108	0.992	2.678	1.432	7.308	1.131	12.678	0.282
k_2									
Mean	37.201	36.717	36.894	41.128	31.981	52.994	28.632	81.325	47.362
Std. Dev	8.865	6.514	9.766	8.972	6.696	10.255	5.415	27.990	14.036
p_1									
Mean	0.687	0.730	0.740	0.707	0.713	0.719	0.683	0.720	0.754
Std. Dev	0.148	0.136	0.132	0.140	0.139	0.136	0.160	0.133	0.123
p_2									
Mean	0.861	0.918	0.920	0.833	0.877	0.869	0.869	0.846	0.701
Std. Dev	0.074	0.053	0.048	0.085	0.065	0.070	0.070	0.117	0.053
p									
Mean	0.729	0.785	0.826	0.728	0.803	0.651	0.788	0.697	0.743
Std. Dev	0.138	0.122	0.105	0.123	0.121	0.164	0.139	0.165	0.149
r									
Mean	0.009	0.009	0.009	0.008	0.008	0.008	0.009	0.009	0.008
Std. Dev	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004
No. of Obs.	94	79	79	79	79	79	79	79	79

y : output per capita; c : consumption per capita; k_1 : economic infrastructure capital per capita; k_2 : other capital per capita; p_1 : price of k_1; p_2 : price of k_2; p : output price; r : interest rate.

the estimation task is pursued at two geographical levels (the whole economy versus individual states) the analysis has a somewhat geographical disaggregation dimension as well.

The upper part of Table 2 shows the results for the whole economy using the Cobb-Douglas model, while the lower part shows the results from the CES model. The most striking feature observed from a first glance at this table is the similarity of the results. In all cases the orthogonality conditions imposed by the Euler equations are not rejected by the data. These are documented by the results of the Hansen's test of over-identifying restrictions which unambiguously states that the aggregate infrastructure in the Australian economy is efficiently provided over the study period. The estimated parameters of the Cobb-Douglas function reflect elasticities of output with respect to each type of capital good. The estimated elasticity on economic infrastructure variable (denoted by $\hat{\rho}_1$) is strongly significant and ranges from 0.015 to 0.016. The corresponding average of the implied rate of return is found to be 1.020 or 8 percent per annum. Indeed, these magnitudes seem credible and remarkably lower than the estimates of previous Australian studies.[19] Our explanation for such a quantitative improvement in the estimated effect of infrastructure is the assumption of efficient resource allocation maintained by the model which imposes a restriction on the parameters' estimation. Furthermore, the table includes results of the estimated parameter $\hat{\rho}_2$ which reflects the effect of K_2, the other capital stock. The average size of this coefficient is 0.15 and it is always significant. To ascertain whether the above findings are legitimate, we compute the sample partial correlation statistic suggested by Shea (1997). The upper part of Table 3 shows these numbers relating to the Cobb-Douglas model. It is clear that Instrument Set 2 performs far better than Sets 1 and 3.

Similar to the Cobb-Douglas case, Hansen's test does not reject any of the efficiency conditions with the CES production specification. This conclusion is endorsed by the quality of Instrument Set 2 and Set 3 which both show high correlation coefficients, as can be seen in the lower part of Table 3. In regards to the estimated parameters, Instrument Set 2 is the only case where all estimates are simultaneously significant. Using these parameters, the calculated rate of return to economic infrastructure is found to be 8.4 percent per annum which is very close to the average rate suggested by the Cobb-Douglas specification. Thus, findings from the CES model are quite informative for eradicating the risk one might encounter from using a hypothetically incorrect representation of production. On the other hand, while the results of the Hansen's test and the implied rate of returns validate our conclusion thus far, the positive sign of the substitution parameter indicates that K_1 and K_2 are substitutes. This finding, surprisingly, does not support the picture perceived from observing figures 1 and 2, nor our expectation about a complementarity relationship. For instance, thinking of the nature of assets included in K_1 such as roads, electricity and water supply, and telecommunications, and those included in K_2 such as machinery and equipment, R&D, education, and health services, it seems less likely for K_2 to serve as a substitute for K_1. In any case, because this finding appears at odds with the theory, it becomes hard to draw a confident conclusion about the relationship between the two types of capital. Also, in other regressions - the results of which are not reported here - the coefficient of ϕ appears with a negative, though insignificant, sign.

An interesting point to highlight here is the consistency between the results of the present study and those of Otto and Voss. Despite our different classification of the two capital stocks and the different time horizon we consider, the results discussed above are very close to the results obtained earlier. Both studies suggest optimality in resource allocation at the national level. Also, the efficiency approach adopted by the two analyses produces plausible estimated returns to all classes of capital.

[19] Using the same data set, our own findings from a panel cointegration model which controls for several econometric shortcomings, based on a partial equilibrium production function approach, suggests an estimated elasticity of 0.12.

Table 2 Aggregate infrastructure, Australia

Instruments

Set 1: $[c, r_{t-1}]$,
Set 2: $[c, r_{t-1}, \tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}]$,
Set 3: $[c, \tilde{y}_{1,t-1}/p_{1,t-2}, \tilde{y}_{2,t-1}/p_{2,t-2}, p_{1,t-1}/p_{1,t-2}, p_{2,t-1}/p_{2,t-2}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

Cobb-Douglas Model

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)\left[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}\right]\right] = 1 \qquad i = 1, 2.$$

	ρ_1	ρ_2	J	Rate of Return to K_1	Rate of Return to K_2
Instrument Set 1	0.016***	0.158***	3.464	1.021	-
	(0.001)	(0.007)	(0.177)	-	1.022
Instrument Set 2	0.016***	0.156***	4.540	1.021	-
	(0.001)	(0.006)	(0.603)	-	1.021
Instrument Set 3	0.015***	0.156***	5.846	1.019	-
	(0.001)	(0.005)	(0.665)	-	1.021

CES Model

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_1t}\right)\left(\gamma\alpha\frac{y_{t+1}k_{1t+1}^{\phi-1}}{\alpha k_{1t+1}^{\phi}+(1-\alpha)k_{2t+1}^{\phi}} + (1-\delta_1)p_{1t+1}\right)\right] = 1.$$

$$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_2t}\right)\left(\gamma(1-\alpha)\frac{y_{t+1}k_{2t+1}^{\phi-1}}{\alpha k_{1t+1}^{\phi}+(1-\alpha)k_{2t+1}^{\phi}} + (1-\delta_2)p_{2t+1}\right)\right] = 1.$$

	γ	ϕ	α	J	Rate of Return to K_1	Rate of Return to K_2
Instrument Set1[a]	0.170***	4.519**	0.996	0.316		
	(0.007)	(2.234)	(0.014)	(0.573)		
Instrument Set 2	0.171***	1.334**	0.517*	3.897	1.021	-
	(0.005)	(0.674)	(0.295)	(0.564)	-	1.021
Instrument Set 3	0.170***	-2.010	0.003	4.779		
	(0.006)	(1.341)	(0.007)	(0.686)		

Sample is 1987q1 - 2010q2. J is Hansen's J-statistic obeys $\chi^2(L-M)$ distribution, where L is the total number of moments conditions estimated and M is the number of estimated parameters, under the null hypothesis that the capital goods included in the estimation are optimally provided. Numbers in parentheses are standard errors except for the J test, where these numbers are the marginal significance levels. The first rate of return number corresponds to K_1 and the second to K_2. The covariance matrix is estimated with Newey-West/Bartlett Window using a lag truncation parameter of four. **a** The objective function converges only when r_{t-1} is replaced by r_{t-2}.

Looking at the state level, two separate tables are constructed to represent the results from the Cobb-Douglas and the CES models; these are tables 4 and 6 respectively. The estimated elasticity of infrastructure as indicated from the Cobb-Douglas model is always significant and

Table 3 Aggregate infrastructure, Australia: instrument quality tests

Instruments

Set 1: $[c, r_{t-1}]$,

Set 2: $[c, r_{t-1}, \tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}]$,
Set 3: $[c, \tilde{y}_{1,t-1}/p_{1,t-2}, \tilde{y}_{2,t-1}/p_{2,t-2}, p_{1,t-1}/p_{1,t-2}, p_{2,t-1}/p_{2,t-2}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	
Cobb-Douglas Model				
Instrument Set 1	i=1	0.276	-	
	i=2	-	0.367	
Instrument Set 2	i=1	0.988	-	
	i=2	-	0.503	
Instrument Set 3	i=1	0.982	-	
	i=2	-	0.354	
		$\partial\mu_{i,t+1}/\partial\gamma$	$\partial\mu_{i,t+1}/\partial\alpha$	$\partial\mu_{i,t+1}/\partial\phi$
CES Model				
Instrument Set 1	i=1	0.003	0.052	0.236
	i=2	0.030	0.118	0.126
Instrument Set 2	i=1	0.973	0.977	0.986
	i=2	0.578	0.868	0.629
Instrument Set 3	i=1	0.984	0.984	0.985
	i=2	0.379	0.910	0.884

Figures reflect the sample-squared correlation coefficients from regressions suggested in Shea (1997).

consistent across the states with a magnitude which is somewhat near to the estimated coefficient of the whole country.[20] Specifically, it is equal to 0.01 in each of New South Wales (NSW), Victoria (VIC), South Australia (SA), Australian Capital Territory (ACT). In Queensland (QLD), Western Australia (WA), and in Tasmania (TAS) it is 0.02, while in Northern Territory (NT) it is equal to 0.03. Similarly, the elasticity of K_2 is significant and varies in a reasonable range across the states. In sum, one can argue that all results are robust across the three sets of instruments; in addition, with the exception of one case in NT, the results of the Hansen's test suggest optimality in resource allocation in all the states. To check the quality of the instruments, we perform the Shea (1997) test and present the results in Table 5. From the recorded values of R-squared, it is observed that either or both Instrument Set 2 and Instrument Set 3 show good

[20] Consistent with our previous findings, we do not observe a significant difference in infrastructure coefficient between the country and state level regressions. This result is not very supportive to the argument of regional studies which find a considerable reduction in infrastructure coefficient from using U.S. regional data (see Munnell 1990; and Garcia-Mila and T.McGuire 1992 for examples). However; as we argued in another work, using Australian state data has produced reasonable estimates only after we control for the states' individual characteristics.

Table 4: Aggregate infrastructure, individual states: Cobb-Douglas model

Instruments

Set 1: $[c, r_{t-1}]$,

Set 2: $[c, r_{t-1}, \tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}]$,

Set 3: $[c, \tilde{y}_{1,t-1}/p_{1,t-2}, \tilde{y}_{2,t-1}/p_{2,t-2}, p_{1,t-1}/p_{1,t-2}, p_{2,t-1}/p_{2,t-2}]$,

where $\tilde{y}_{it} = y_{it}/k_{it}$.

$$E_t \left[\beta \left(\frac{c_{t+1}}{c_t} \right)^{\sigma - 1} \left(\frac{1}{p_it} \right) [\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}] \right] = 1 \qquad i = 1, 2.$$

	Instrument set 1				Instrument set 2				Instrument set 3			
State	ρ_1	ρ_2	J	Rate of return	ρ_1	ρ_2	J	Rate of return	ρ_1	ρ_2	J	Rate of return
NSW	0.014***	0.147***	1.143	1.020	0.014***	0.150***	5.33	1.020	0.014***	0.149***	4.561	1.020
	(0.001)	(0.009)	(0.565)	1.020	(0.001)	(0.008)	(0.254)	1.021	(0.001)	(0.008)	(0.803)	1.020
VIC	0.011***	0.146***	0.090	1.021	0.011***	0.147***	0.325	1.021	0.011***	0.149***	2.100	1.021
	(0.000)	(0.007)	(0.956)	1.021	(0.000)	(0.007)	(0.988)	1.021	(0.001)	(0.007)	(0.978)	1.022
QLD	0.018***	0.149***	2.570	1.018	0.018***	0.149***	4.614	1.018	0.018***	0.149***	4.763	1.018
	(0.001)	(0.007)	(0.277)	1.019	(0.001)	(0.006)	(0.329)	1.019	(0.001)	(0.007)	(0.783)	1.019
SA	0.013***	0.139***	2.889	1.019	0.013***	0.138***	6.295	1.019	0.014***	0.148***	7.617	1.021
	(0.001)	(0.010)	(0.236)	1.020	(0.001)	(0.009)	(0.178)	1.019	(0.001)	(0.008)	(0.472)	1.022
WA	0.023***	0.182***	4.542	1.018	0.022***	0.191***	4.881	1.016	0.023***	0.187***	7.168	1.018
	(0.002)	(0.015)	(0.103)	1.020	(0.002)	(0.012)	(0.299)	1.022	(0.002)	(0.012)	(0.519)	1.022
TAS	0.016***	0.140***	2.244	1.021	0.016***	0.146***	1.706	1.021	0.015***	0.144***	3.013	1.019
	(0.001)	(0.010)	(0.325)	1.020	(0.001)	(0.010)	(0.789)	1.022	(0.001)	(0.010)	(0.933)	1.021
NT	0.027**	0.203***	7.356	1.021	0.026***	0.195***	8.237	1.020	0.022***	0.168***	8.416	1.015
	(0.004)	(0.020)	(0.025)	1.030	(0.003)	(0.147)	(0.221)	1.028	(0.003)	(0.017)	(0.393)	1.021
ACT	0.010***	0.130***	1.826	1.023	0.010***	0.0.127***	2.562	1.023	0.010***	0.136***	6.298	1.023
	(0.001)	(0.015)	(0.401)	1.024	(0.001)	(0.015)	(0.633)	1.023	(0.001)	(0.014)	(0.614)	1.026

Sample is 1990q4 - 2010q2. J is Hansen's J-statistic obeys $\chi^2(L-M)$ distribution, where L is the total number of moments conditions estimated and M is the number of estimated parameters, under the null hypothesis that the capital goods included in the estimation are optimally provided. Numbers in parentheses are standard errors except for the J test, where these numbers are the marginal significance levels. The first rate of return number corresponds to K_1 and the second to K_2. The covariance matrix is estimated with Newey-West/Bartlett Window using a lag truncation parameter of four.

Table 5 Aggregate infrastructure, individual states: instrument quality tests (Cobb-Douglas model)

Instruments ,
Set 1: $[c, r_{t-1}]$,
Set 2: $[c, r_{t-1}, \tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}]$,
Set 3: $[c, \tilde{y}_{1,t-1}/p_{1,t-2}, \tilde{y}_{2,t-1}/p_{2,t-2}, p_{1,t-1}/p_{1,t-2}, p_{2,t-1}/p_{2,t-2}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$
		NSW		**VIC**	
Instrument Set 1	i=1	0.137	-	0.196	-
	i=2	-	0.388	-	0.154
Instrument Set 2	i=1	0.939	-	0.954	-
	i=2	-	0.326	-	0.760
Instrument Set 3	i=1	0.876	-	0.958	-
	i=2	-	0.556	-	0.694
		QLD		**SA**	
Instrument Set 1	i=1	0.409	-	0.321	-
	i=2	-	0.097	-	0.125
Instrument Set 2	i=1	0.973	-	0.955	-
	i=2	-	0.619	-	0.569
Instrument Set 3	i=1	0.943	-	0.949	-
	i=2	-	0.492	-	0.414
		WA		**TAS**	
Instrument Set 1	i=1	0.305	-	0.007	-
	i=2	-	0.380	-	0.385
Instrument Set 2	i=1	0.976	-	0.939	-
	i=2	-	0.799	-	0.602
Instrument Set 3	i=1	0.953	-	0.950	-
	i=2	-	0.825	-	0.676
		NT		**ACT**	
Instrument Set 1	i=1	0.443	-	0.589	-
	i=2	-	0.056	-	0.062
Instrument Set 2	i=1	0.962	-	0.855	-
	i=2	-	0.574	-	0.363
Instrument Set 3	i=1	0.964	-	0.884	-
	i=2	-	0.368	-	0.368

Figures reflect the sample-squared correlation coefficients from regressions suggested in Shea (1997).

Table 6: Aggregate infrastructure, individual states: CES model

Instruments

Set 1: $[c, r_{t-1}]$,

Set 2: $[c, r_{t-1}, \tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}]$,

Set 3: $[c, \tilde{y}_{1,t-1}/p_{1,t-2}, \tilde{y}_{2,t-1}/p_{2,t-2}, p_{1,t-1}/p_{1,t-2}, p_{2,t-1}/p_{2,t-2}]$,

where $\tilde{y}_{it} = y_{it}/k_{it}$.

$$E_t \left[\beta \left(\frac{c_{t+1}}{c_t} \right)^{\sigma-1} \left(\frac{1}{p_1 t} \right) \left(\gamma\alpha \frac{y_{t+1} k_{1t+1}^{\phi-1}}{\alpha k_{1t+1}^{\phi} + (1-\alpha) k_{2t+1}^{\phi}} + (1-\delta_1) p_{1t+1} \right) \right] = 1.$$

$$E_t \left[\beta \left(\frac{c_{t+1}}{c_t} \right)^{\sigma-1} \left(\frac{1}{p_2 t} \right) \left(\gamma(1-\alpha) \frac{y_{t+1} k_{2t+1}^{\phi-1}}{\alpha k_{1t+1}^{\phi} + (1-\alpha) k_{2t+1}^{\phi}} + (1-\delta_2) p_{2t+1} \right) \right] = 1.$$

	Instrument set 1				Instrument set 2				Instrument set 3			
State	γ	ϕ	α	J	γ	ϕ	α	J	γ	ϕ	α	J
NSW^a	-	-	-	-	0.165***	3.333***	0.973***	0.914	0.161***	2.574**	0.905***	2.729
					(0.009)	(1.176)	(0.053)	(0.821)	(0.009)	(1.175)	(0.179)	(0.908)
VIC	0.157***	0.051	0.076	0.087	0.158***	-0.046	0.063	0.318	0.161***	-0.166	0.050	1.953
	(0.008)	(0.893)	(0.128)	(0.768)	(0.008)	(0.470)	(0.057)	(0.956)	(0.007)	(0.465)	(0.045)	(0.962)
QLD	0.171***	1.389**	0.540**	0.001	0.171***	1.400***	0.541***	1.566	0.173***	1.495***	0.579***	2.178
	(0.008)	(0.632)	(0.252)	(0.981)	(0.008)	(0.385)	(0.154)	(0.667)	(0.008)	(0.350)	(0.136)	(0.949)
SA	0.158***	1.810**	0.716**	0.403	0.169***	1.876***	0.736***	3.639	0.174***	1.915***	0.746***	4.303
	(0.011)	(0.823)	(0.300)	(0.525)	(0.010)	(0.449)	(0.157)	(0.303)	(0.009)	(0.471)	(0.160)	(0.744)
WA	0.209***	1.309***	0.510***	1.308	0.223***	1.340***	0.519***	1.235	0.215***	1.346***	0.525***	3.564
	(0.015)	(0.305)	(0.115)	(0.252)	(0.014)	(0.156)	(0.060)	(0.744)	(0.013)	(0.151)	(0.057)	(0.828)
TAS	0.157***	0.965	0.351	1.526	0.162***	0.386	0.170	1.195	0.159***	0.250	0.137	2.872
	(0.010)	(1.033)	(0.378)	(0.216)	(0.009)	(0.484)	(0.110)	(0.754)	(0.009)	(0.538)	(0.104)	(0.896)
NT	0.124	1.169	0.752	1.242	0.407***	0.941***	0.320**	4.319	0.328***	0.902***	0.362***	4.454
	(0.164)	(0.783)	(0.640)	(0.265)	(0.143)	(0.161)	(0.135)	(0.229)	(0.049)	(0.131)	(0.055)	(0.726)
ACT	0.136***	0.531	0.221	0.802	0.136***	0.350	0.151	1.193	0.144***	0.368	0.147	6.135
	(0.015)	(0.465)	(0.193)	(0.370)	(0.016)	(0.296)	(0.092)	(0.754)	(0.014)	(0.296)	(0.091)	(0.524)

Notes: see Table 4.

Sample is 1990q4 - 2010q2. *a* The objective function has a difficulty to converge. See Table 4 for other notes.

Table 7 Aggregate infrastructure, individual states: instrument quality tests - CES model

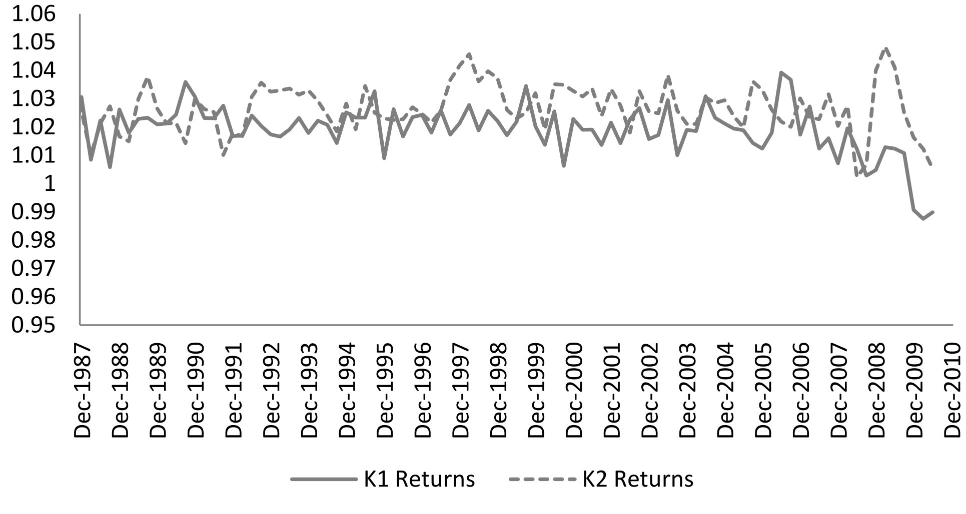
		$\partial\mu_{i,t+1}/\partial\gamma$	$\partial\mu_{i,t+1}/\partial\alpha$	$\partial\mu_{i,t+1}/\partial\phi$	$\partial\mu_{i,t+1}/\partial\gamma$	$\partial\mu_{i,t+1}/\partial\alpha$	$\partial\mu_{i,t+1}/\partial\phi$
			NSW			VIC	
Instrument Set 1	i=1	-	-	-	0.210	0.209	0.074
	i=2				0.152	0.171	0.010
Instrument Set 2	i=1	0.935	0.934	0.929	0.954	0.953	0.943
	i=2	0.248	0.915	0.887	0.761	0.749	0.629
Instrument Set 3	i=1	0.944	0.939	0.922	0.956	0.957	0.945
	i=2	0.499	0.908	0.883	0.710	0.656	0.556
			QLD			SA	
Instrument Set 1	i=1	0.129	0.181	0.333	0.003	0.010	0.114
	i=2	0.010	0.577	0.490	0.056	0.452	0.416
Instrument Set 2	i=1	0.900	0.924	0.966	0.941	0.940	0.941
	i=2	0.656	0.935	0.783	0.510	0.921	0.872
Instrument Set 3	i=1	0.884	0.893	0.922	0.942	0.941	0.938
	i=2	0.522	0.923	0.788	0.340	0.887	0.831
			WA			TAS	
Instrument Set 1	i=1	0.106	0.052	0.263	0.053	0.032	0.003
	i=2	0.350	0.284	0.385	0.391	0.060	0.381
Instrument Set 2	i=1	0.665	0.471	0.954	0.923	0.925	0.949
	i=2	0.384	0.960	0.850	0.627	0.331	0.756
Instrument Set 3	i=1	0.491	0.173	0.898	0.943	0.944	0.959
	i=2	0.483	0.920	0.872	0.689	0.542	0.830
			NT			ACT	
Instrument Set 1	i=1	0.518	0.001	0.243	0.026	0.064	0.574
	i=2	0.092	0.449	0.089	0.093	0.065	0.035
Instrument Set 2	i=1	0.943	0.870	0.874	0.593	0.612	0.895
	i=2	0.471	0.855	0.434	0.356	0.851	0.363
Instrument Set 3	i=1	0.875	0.767	0.887	0.624	0.641	0.915
	i=2	0.416	0.868	0.358	0.363	0.582	0.378

Figures reflect the sample-squared correlation coefficients from regressions suggested in Shea (1997).

performance. A last point to mention here is the findings from the CES model. As in the case of the whole country, the CES model strongly supports optimal infrastructure provision in all the states. Results from quality tests of instruments with this model are presented in Table 7 and they confirm the good performance of Sets 2 and 3.[21]

To finalise this subsection, it is interesting to explore the behaviour of the rate of return implied from our estimated elasticities over the period of the study. Using results obtained with Instrument Set 2, figures 3 and 4 depict the returns to both capital types for the whole country and the individual states respectively. In both figures, the returns appear to be stationary around a mean. This observation mitigates our concern about the nonstationarity trend observed in the output-capital ratios (see figures 1 and 2 above). Analogous to the paper of Otto and Voss (1998), we have initially estimated a benchmark model with the assumption of constant unit relative prices of investment using a Cobb-Douglas production. The resultant rate of returns implied from the benchmark model are observed to show some form of trend behaviour. This observation is identical to what Otto and Voss noticed with their benchmark model. However, following their suggestion, the inclusion of investment prices greatly changes the nature of these returns. This is not the case with CES model, however, because even after the inclusion of investment prices, the return component in the moments remains a non-linear function of output to capital ratios plus ratios of both types of capital stocks. This adds one more advantage to the performance of the Cobb-Douglas model over the CES model. Another point which is consistent with the

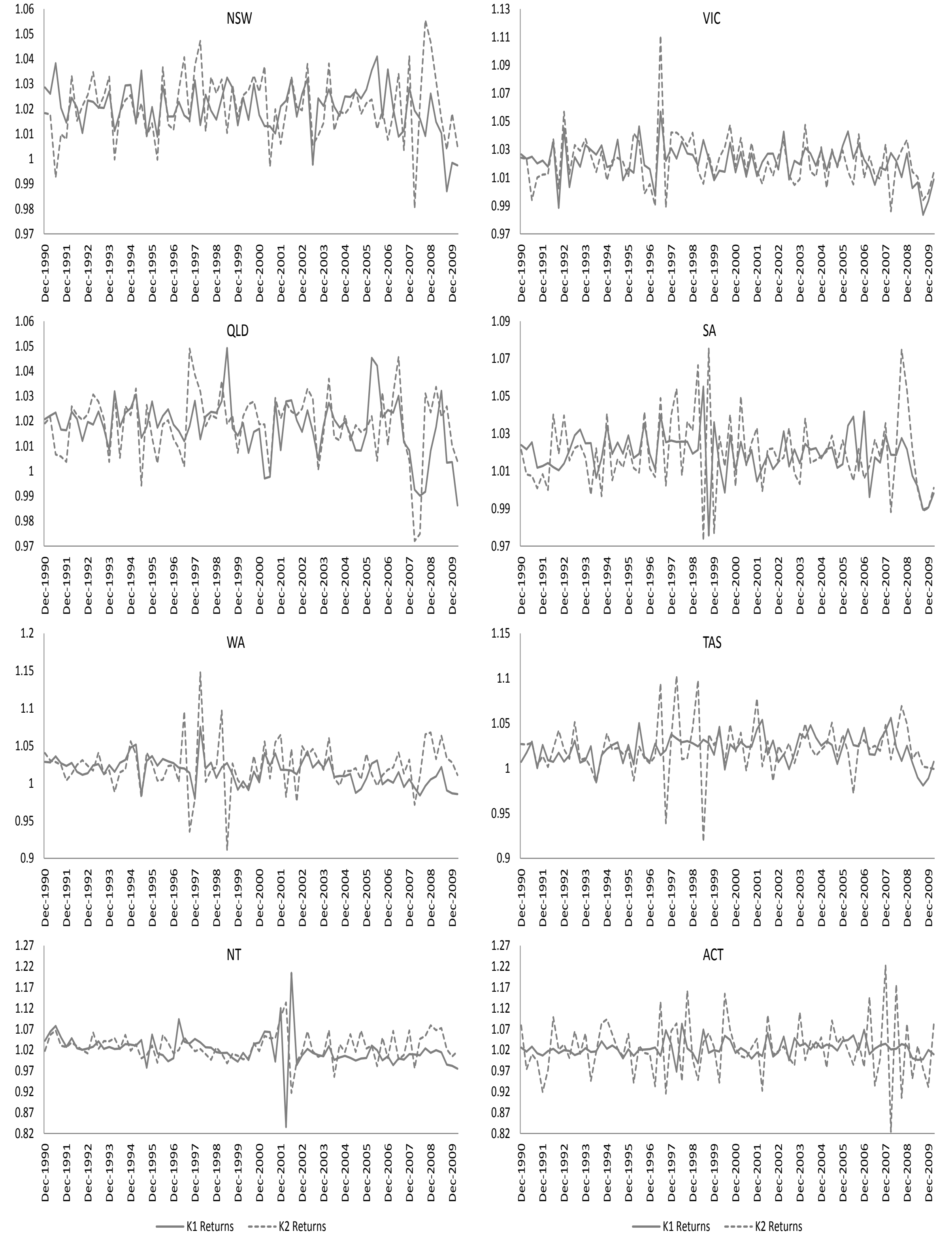
Figure 3 Rate of return: Australia, 1987q2 - 2010q4



previous paper, and worth mentioning here, is that the returns to both classes of capital appear

[21] Again, we have noticed a positive coefficient of the substitution parameter, though not statistically significant in all cases, which leaves the puzzle regarding the relationship between K_1 and K_2 unresolved.

Figure 4 Rate of return: states, 1990:$q4$-2010:$q4$



to be highly correlated as they move together throughout the sample period. Otto and Voss asserted that this observation is quite sensible, bearing in mind that the estimation procedure implemented yields average returns in each capital sector as close as possible to one another over the sample period. The over-identifying restrictions test then examines whether there has been a statistically significant divergence from these average returns.

The results so far indicate that the provision of aggregate stock of infrastructure is optimal; in addition, applying regional disaggregate investigations has not changed the picture. Nevertheless, we have argued earlier that aggregate analysis does not necessarily indicate the efficient allocation of individual types of infrastructure. This is what the next subsection will explore.

4.4.2 Disaggregate analysis

To examine the provision of disaggregated infrastructure, we employ the sets of Euler equations described under Framework 2. The estimation procedure involves seven types of investments, namely: roads, highways and subdivisions (K_{11}); bridges, railways and harbours (K_{12}); electricity generation, transmission etc. and pipelines (K_{13}); water storage and supply, sewerage and drainage (K_{14}); telecommunications (K_{15}); heavy industry (K_{16}); and recreation and others (K_{17}). As Instrument Set 2 has proven good performance in the above regressions, the results from the other instrument sets are not reported. Table 8 displays the estimation results for the whole country. All estimated parameters recorded in this table are strongly significant. The coefficient of an individual infrastructure type, denoted by $\hat{\rho}_1$, represents the elasticity of output with respect to that type of infrastructure. It is noteworthy that the size of this coefficient is considerably smaller in comparison to the estimate of the aggregate measure of infrastructure and it varies from 0.001 to 0.003 across different components. This reduction in the size of the coefficient sounds reasonable, as one expects each individual component of infrastructure to produce a smaller effect relative to the effect of total infrastructure. The table shows the estimates of two other coefficients. First, $\hat{\rho}_2$, which represents the effect of the other types of infrastructure collectively, has an average size of 0.012 which is slightly below the counterpart coefficient obtained from the aggregate analysis. The explanation for such a difference in size is that with the disaggregate framework, one component of infrastructure (K_n) is extracted from the collective measure (K_1) and entered as a separate variable (K_{-n}) in the regression. Hence, we expect K_{-n} to produce a smaller effect relative to K_1. In addition, the table displays the results on the estimated parameter $\hat{\rho}_3$ which denotes the effect of the other capital stock. Again, the magnitude of this latter parameter is very consistent with the one presented in the aggregate analysis. The last three columns of the table show the results from the instrument quality test. The performance level of Instrument Set 2, although not as good as before, looks acceptable.[22]

While everything seems to be in harmony with the story received from the aggregate analysis, there is a major difference with respect to the results of the Hansen's test. More explicitly, the efficiency conditions are rejected in four out of seven cases. Thus, based on this result one

[22]There is a slight change in the elements of Instrument Set 2 from the one presented earlier. We find that the exclusion of the real interest rate from the set has improved the performance of the diagnostic test, and in addition, enables some of the objective functions to converge.

Table 8 Disaggregated infrastructure - Australia

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model: $E_t \left[\beta \left(\frac{c_{t+1}}{c_t} \right)^{\sigma-1} \left(\frac{1}{p_i t} \right) [\rho_i y_{t+1}/k_{it+1} + (1-\delta_i) p_{it+1}] \right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.003***	0.008***	0.136***	114.879	1.010	i=1	0.975	-	-
	(0.000)	(0.000)	(0.004)	(0.021)		i=2	-	0.987	-
						i=3	-	-	0.530
K_{12}									
	0.001***	0.015***	0.161***	9.010	1.013	i=1	0.983	-	-
	(0.000)	(0.001)	(0.005)	(0.172)		i=2	-	0.986	-
						i=3	-	-	0.481
K_{13}									
	0.002***	0.011***	0.145***	10.396	1.016	i=1	0.989	-	-
	(0.000)	(0.000)	(0.004)	(0.109)		i=2	-	0.987	-
						i=3	-	-	0.467
K_{14}									
	0.001***	0.015	0.154***	11.440	1.010	i=1	0.982	-	-
	(0.000)	(0.001)	(0.005)	(0.076)		i=2	-	0.991	-
						i=3	-	-	0.267
K_{15}									
	0.003***	0.012***	0.155***	6.372	1.013	i=1	0.893	-	-
	(0.000)	(0.000)	(0.006)	(0.383)		i=2	-	0.991	-
						i=3	-	-	0.107
K_{16}									
	0.002***	0.012***	0.142***	11.736	1.017	i=1	0.995	-	-
	(0.000)	(0.001)	(0.005)	(0.068)		i=2	-	0.974	-
						i=3	-	-	0.514
K_{17}									
	0.001***	0.013***	0.144***	12.018	1.035	i=1	0.995	-	-
	(0.000)	(0.000)	(0.005)	(0.062)		i=2	-	0.987	-
						i=3	-	-	0.244

Sample is 1987q1 - 2010q2. J is Hansen's J-statistic obeys $\chi^2(L-M)$ distribution, where L is the total of moments conditions estimated and M is the number of estimated parameters, under the null hypothesis that the capital goods included in the estimation are optimally provided. Numbers in parentheses are standard errors except for the J test, where these numbers are the marginal significance levels. The rate of return number corresponds to K_1n. Figures in the last three columns are the sample-squared correlation coefficients from regressions suggested in Shea (1997).

can argue that Australia has experienced economy-wide distortions in the allocation of K_{11}, K_{14},K_{16}, and K_{17} over the period of the study. This finding is quite interesting because it suggests that relying on aggregate analysis to assess the provision of infrastructure may lead to flawed conclusions.

Although the above exercise has revealed for us a different view of resource allocation, we argue that this is not the final conclusion on the subject. Other than the four categories mentioned above, more distortions to resource allocation may exist within individual states, but looking to the provision of those types at country-level may perhaps conceal such inefficiencies.[23] To elaborate on this, we perform a disaggregate infrastructure analysis for each state and display the results in appendix tables A.1 - A.7. This provides a comparison between those results and the results obtained for Australia as a whole (displayed in Table 8). Endorsed by the outcomes from the instruments quality test, reported in the last three columns of each of the seven tables, these results seem justifiable.[24]

There is consistency in the findings regarding the first type of infrastructure which includes bridges, railways and harbours. As suggested in Table 8, investment in those projects is inefficiently provided at the country level. This result is supported by the sub-optimal level of investment achieved in SA (presented in appendix table A.4). The second type of investment which is classified to include bridges, railways and harbours is suggested to be optimally provided across the whole country. However, QLD (presented in appendix table A.3) shows evidence of inefficiency in the provision of those assets. This inconsistency in results challenges the reliability of the outcomes obtained from a higher level of geographical aggregation, specifically, when we deal with the disaggregated infrastructure. The third category of projects represented by electricity generation, transmission, and pipelines appears to be optimally provided at the country level. Similar to the case mentioned above, however, when we look at the performance of individual states we find that each of QLD, SA, WA (presented in appendix A.5), and TAS (presented in appendix table A.6) have a sub-optimal investment level. In regards to water storage and supply, sewerage, and drainage which together represent the fourth type of infrastructure examined in this study, we notice a consistency between what is proposed by regressing a model for Australia as a whole and for its states and territories. In particular, the regression results reveal that the inefficiency in the provision of this type of infrastructure is particularly evident in the performance of VIC and ACT (as depicted in appendix table A.2 and A.8 respectively). Looking at telecommunications, interestingly, we find that this fifth type of infrastructure is the only type which is efficiently provided at all geographical levels. A likely explanation for this optimal attainment may be due to the large involvement of the private sector in this industry during recent years, which in turn suggests adequacy in the provision of services. Heavy industry, however, which represents our sixth component, is found to be inefficient in NSW (depicted at appendix table A.1), QLD, and ACT which in turn validates the result from Australia's regression. Finally, the seventh type that we consider is labeled recreation and others, and this

[23] For instance, there may exist a situation in which one type of infrastructure experiences over-investing while at the same time another type may experience under-investing. When one looks to the total of these investments, however, such sub-optimal levels do not appear as the excess and shortage in investments are balanced out.

[24] There are a few exceptions in which the quality test does not show convincing results, mainly in the NT.

reveals consistency in the findings between the country and states' results. In particular, the sub-optimality in investment achieved in each of NSW, SA and ACT justifies the results of the Hansen's test which reject the hypothesis of efficient allocation in Australia as a whole.

To end the discussion on this part of disaggregate analysis, we briefly offer a few final comments on the results from the states' regressions. The same pattern observed with the whole economy regressions regarding the reduction of the size of infrastructure parameter, $\hat{\rho}_1$, when we moved from aggregate to disaggregate analysis, is also noticed with state-level regressions. Moreover, the coefficient $\hat{\rho}_2$, which represents the effect of the other types of infrastructure collectively, in all the states is found to be below the corresponding coefficient obtained from the aggregate analysis. This again is justified as the effect of K_{-n} is assumed to be less than that of K_1. Concerning the results on the estimated parameter $\hat{\rho}_3$ which denotes the effect of the other capitals, as found with the case of whole economy, the size of this estimate is very consistent with the one presented in the aggregate analysis.

Finally, there is one issue that warrants attention as it could potentially threaten the validity of the empirical findings of this study. It particularly relates to the statistical properties of some of our series. It is well known that failure of stationarity assumption of the data means that the GMM estimator may not have its standard asymptotic properties (Hansen 1982). Bearing in mind that the behaviour of the output-capital ratios, presented in figures 1 and 2, reveals certain trends, this could cause a problem, mainly with the estimation of the benchmark models (which assume unit constant investment prices) as the moment conditions may include nonstationary series. Nevertheless, the inclusion of the relative prices of investment in the moments has lessened the problem because these prices act as a weight for the output-capital ratio series and hence result in compound series with less trend behaviour. We have shown in Figures 3 and 4 that the returns R_{it+1} are stationary around a mean. In fact, the estimated residuals $\hat{u}_{it+1}$ (which are dominated by the return component) are more likely to be stationary as well. It is relevant to this that Otto and Voss (1998), to support this model, raised an interesting argument in which they describe an informal extension of the principles of cointegration to method of moments estimation. They outline that the estimated parameters of this model combine a set of nonstationary and stationary series into a stationary residual in a fashion that resembles a linear cointegration model. Otto and Voss (1998) assert that, although having some nonstationary series in the model can weaken the confidence on the formal inference, there are many reasons to have considerable confidence in the parameter estimates and overall performance of the model. For instance, the sensible magnitude of the estimated effects of infrastructure when it is compared to the findings from the previous studies; in addition, the automatic adjustment which occurs to the magnitude of this estimate (to reflect a smaller effect from infrastructure) when we moved from aggregate to disaggregate analysis is strongly supported by economic theory. Moreover, the consistency of results across different instruments sets and production functional forms reinforces this view.

5 Conclusion

This paper examines the efficiency in the provision of economic infrastructure in Australia and its states and territories by identifying and estimating conditions of efficient resource allocation. Given the important and growing role played by the private sector in delivering infrastructure services, the analysis has considered an aggregate measure for economic infrastructure that combines both public and private sector ownership. The central question raised by the study is whether the disaggregation of infrastructure into components, and the geographical disaggregation, are important when assessing the provision of infrastructure. To answer this question, the analysis adopts two strategies to estimate the efficiency conditions. First, it investigates the provision of aggregate economic infrastructure in Australia as a whole and in each of the states individually. Next, it separately examines the provision of seven types of infrastructure at the two geographical levels. To estimate the models and test their validity, the GMM estimator was applied, together with the application of certain measures to check the robustness of the results.

The empirical evidence of the study suggests that while the states' investments in some types of infrastructure have been achieved at sub-optimal levels, these inefficiencies are not observed with the aggregate analysis. Our approach of applying aggregate and disaggregate levels of investigation makes a strong case for working with disaggregate data. The analysis emphasises that a very high level of disaggregate data with respect to geographical regions and infrastructure investments will show more realistic results when assessing the efficiency of infrastructure provision. Although the study is limited by the availability of data at state level and only seven broad types of infrastructure, which may mean some information available at finer levels of data are not yet revealed, it has drawn attention to potential inefficiencies in particular areas.

In addition to answering the question of resource allocation, our efficiency approach has produced credible estimates for the effect of infrastructure on the economy. These findings contradict the results of previous studies which find an implausible excessive return to infrastructure from the application of partial equilibrium models. Furthermore, our disaggregated analysis is useful in providing the rates of return to each individual type of infrastructure.

Because the quality of the instruments can considerably affect the validity of the results, this issue has received keen attention. Our analysis has adopted a diagnostic test to examine the performance of the instruments. Further work may use a method which is immune to the presence of weak instruments, such as the identification robust method of Anderson and Rubin (1949).

In view of the empirical findings of the study, which indicate some inefficiency in the investment decisions of particular types of infrastructure within particular states, a potential policy implication is to encourage federal, state and local governments to improve the composition of their infrastructure architecture via a better allocation of existing spending. To identify areas that require improvement, emphasis should be placed on a disaggregate analysis, such as the one presented here, which examines each infrastructure component individually. While important issues remain to be addressed in future work, such as how to determine whether an observed inefficiency is due to over- or under-investment, the current study has made progress in understanding the efficient provision of infrastructure at different levels of aggregation.

Appendix

A mathematical derivation of returns to investment

The representative producer is assumed to choose a production plan for investment, output, capital stocks and labour input to maximise the present value of all firm future dividend, $V_t(.)$. The maximisation problem is described as:

$$V_t = \max_{(I_{t+j}, L_{t+j})} E_t \sum_{j=0}^{\infty} (m_{t,t+j} D_{t+j}), \tag{A.1}$$

subject to :

$$D_{t+j} = Q_{t+j} - I_{t+j}, \tag{A.2}$$

$$Q_{t+j} = F(K_{t+j}, L_{t+j}) - \varphi(I_{t+j}, K_{t+j-1}) - w_{t+j} L_{t+j}, \tag{A.3}$$

$$K_{t+1} = (1-\delta)K_t + I_{t+1}, \tag{A.4}$$

$$K_t = \bar{K}, \tag{A.5}$$

where D_{t+j} is dividend at time $t+j$ which is equal to the net cash flow; Q_{t+j} is the firm cash flow; $F(.)$ is the production function; K_{t+j} and L_{t+j} are capital stocks and labour input respectively. $\varphi(.)$ is a convex adjustment costs function ; I is the investment; w is the wage rate; and δ is the capital depreciation rate.[25] (A.4) represents capital accumulation process.

The stochastic discount factor can be decomposed as: $m_{t,t+j} = m_{t,t+1}.m_{t1,t+j}$ with $m_{t,t} = 1$; accordingly, the firm value maximisation problem is rewritten as :

$$V_t = \max_{(I_t, L_t)} \Big\{ D_t + E_t \Big[m_{t,t+j} V(K_{t+j}) \Big] \Big\}, \tag{A.6}$$

subject to the constraints (A.2)-(A.5). The first term of (A.6), denoted by D_t, is the firm's dividend during period t. The second part of the equation contains the expected discounted value of dividends of the period $t+1-t+j$.

The optimal investment plan is derived from the first order condition of the optimisation problem with respect to investment:

$$1 + \varphi_I(I_t, K_{t-1}) = E_t \Big[m_{t,t+1}(1-\delta)V'(K_{t+1}) \Big]. \tag{A.7}$$

(A.7) states that the marginal cost of investment at time t, the term on the left, equals the

[25] The adjustment costs $\varphi(I_{t+j}, K_{t+j-1})$ reflect the expenses of installing and transforming output into physical capital stock and the function obeys the following properties: $\partial\varphi(I_{t+1}, K_t)/\partial I_{t+1} \equiv \varphi_I(t) \geq 0$; $\partial\varphi_I(t)/\partial I_{t+1} \geq 0$;$\partial\varphi(I_{t+1}, K_t)/\partial K_t \equiv \varphi_K(t) \leq 0$

marginal benefit of the firm value, the term on the right hand. Now rewrite (A.7) as:

$$
\begin{aligned}
1+\varphi_I(I_t, K_{t-1}) \qquad &= E_t\Bigg\{m_{t,t+1}\Bigg[F_{K,t+1}+(1-\delta)(1+\varphi_I(I_{t+1}, K_t)) \\
&-\varphi_K(I_{t+1}, K_t)\Bigg]\Bigg\},
\end{aligned} \tag{A.8}
$$

or,

$$
1 = E_t\Bigg\{m_{t,t+1}\Bigg[\frac{F_{K,t+1}+(1-\delta)(1+\varphi_I(I_{t+1}, K_t))-\varphi_K(I_{t+1}, K_t)}{1+\varphi_I(I_t, K_{t-1})}\Bigg]\Bigg\}, \tag{A.9}
$$

with the investment return:

$$
R_{t+1} \equiv \frac{F_{K,t+1}+(1-\delta)(1+\varphi_I(I_{t+1}, K_t))-\varphi_K(I_{t+1}, K_t)}{1+\varphi_I(I_t, K_{t-1})}. \tag{A.10}
$$

Violation of the constant returns to scale assumption

Consider a Cobb-Douglas production function with non-constant returns to scale over the two types of capital and the labour input (K_1, K_2, and L) which is given by:

$$
Y = K_1^{\rho_1} K_2^{\rho_2} L^{\rho_3}, \tag{A.11}
$$

where the exponential coefficient of each input, ρ_i, represents the elasticity of output with respect to that input. With non-constant returns to scale, we define the following equation:

$$
\rho_1+\rho_2+\rho_3 = 1+\vartheta, \tag{A.12}
$$

where $\vartheta > 0$ and $\vartheta < 0$ indicate increasing and decreasing returns to scale respectively. Now, calculate the real output per-capita, y as follows:

$$
y \equiv \frac{Y}{L} = \frac{K_1^{\rho_1} K_2^{\rho_2}}{L^{1-\rho_3}}. \tag{A.13}
$$

Re-arrange (A.12) we get:

$$
1-\rho_3 = \rho_1+\rho_2-\vartheta, \tag{A.14}
$$

then substitute (A.14) into (A.13) to have:

$$
y = \frac{K_1^{\rho_1} K_2^{\rho_2}}{L^{\rho_1+\rho_2-\vartheta}}. \tag{A.15}
$$

(A.15) can be rewritten as:

$$
y = \left(\frac{K_1}{L}\right)^{\rho_1}\left(\frac{K_2}{L}\right)^{\rho_2} L^{\vartheta} \equiv k_1^{\rho_1} k_2^{\rho_2} L^{\vartheta}, \tag{A.16}
$$

where k_i , $i = 1, 2$ is the capital stock per-capita for sector i.
To derive the marginal productivity of k_1 and k_2 (i.e F_{k_1} and F_{k_2}), take the first derivative of (A.16) with respect to k_1 and k_2 respectively. This gives the following two equations:

$$F_{k_1} \equiv \partial y/\partial k_1 = \rho_1 \frac{k_1^{\rho_1} k_2^{\rho_2} L^{\vartheta}}{k_1} = \rho_1 \frac{y}{k_1}, \tag{A.17}$$

$$\begin{aligned} F_{k_2} \equiv \partial y/\partial k_2 \quad &= \rho_2 \frac{k_1^{\rho_1} k_2^{\rho_2} L^{\vartheta}}{k_1} \\ &= \rho_2 \frac{y}{k_2}. \end{aligned} \tag{A.18}$$

Note that, the formulations of the marginal productivity of capital stocks (in per-capita terms) given in the above two equations is identical to those derived from the CRS function.

Efficiency conditions with multi-inputs CES

With three capital goods, the CES production function is described as:

$$Y = \left[\alpha_1 K_n^{\phi} + \alpha_2 K_{-n}^{\phi} + (1 - \alpha_1 - \alpha_2) K_2^{\phi}\right]^{\gamma/\phi} L^{1-\gamma}. \tag{A.19}$$

Accordingly, the efficiency conditions which includes variable relative prices are given as follows:

$$\begin{aligned} E_t \Bigg[\beta \left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1} \left(\frac{1}{p_1 t}\right) \Bigg(\gamma \alpha_1 \frac{y_{t+1} k_{1t+1}^{\phi-1}}{\alpha_1 k_{n,t+1}^{\phi} + \alpha_2 k_{-n,t+1}^{\phi} + (1 - \alpha_1 - \alpha_2) k_{2,t+1}^{\phi}} \\ +(1 - \delta_1) p_{1t+1} \Bigg) \Bigg] = 1, \end{aligned} \tag{A.20}$$

$$\begin{aligned} E_t \Bigg[\beta \left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1} \left(\frac{1}{p_2 t}\right) \Bigg(\gamma \alpha_2 \frac{y_{t+1} k_{1t+1}^{\phi-1}}{\alpha_1 k_{n,t+1}^{\phi} + \alpha_2 k_{-n,t+1}^{\phi} + (1 - \alpha_1 - \alpha_2) k_{2,t+1}^{\phi}} \\ +(1 - \delta_2) p_{2t+1} \Bigg) \Bigg] = 1, \end{aligned} \tag{A.21}$$

$$\begin{aligned} E_t \Bigg[\beta \left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1} \left(\frac{1}{p_3 t}\right) \Bigg(\gamma (1 - \alpha_1 - \alpha_2) \\ \frac{y_{t+1} k_{1t+1}^{\phi-1}}{\alpha_1 k_{n,t+1}^{\phi} + \alpha_2 k_{-n,t+1}^{\phi} + (1 - \alpha_1 - \alpha_2) k_{2,t+1}^{\phi}} + (1 - \delta_3) p_{3t+1} \Bigg) \Bigg] = 1, \end{aligned} \tag{A.22}$$

where all notation is as previously mentioned in the text.

Table A.1 Disaggregated infrastructure - NSW

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model: $E_t \left[\beta \left(\frac{c_{t+1}}{c_t} \right)^{\sigma-1} \left(\frac{1}{p_i t} \right) [\rho_i y_{t+1}/k_{it+1} + (1-\delta_i) p_{it+1}] \right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.005***	0.010***	0.146***	10.397	1.023	i=1	0.885	-	-
	(0.000)	(0.001)	(0.008)	(0.108)		i=2	-	0.846	-
						i=3	-	-	0.272
K_{12}									
	0.002***	0.012***	0.148***	8.133	1.023	i=1	0.960	-	-
	(0.000)	(0.001)	(0.008)	(0.228)		i=2	-	0.851	-
						i=3	-	-	0.714
K_{13}									
	0.002***	0.010***	0.142***	7.082	1.023	i=1	0.979	-	-
	(0.000)	(0.000)	(0.006)	(0.313)		i=2	-	0.894	-
						i=3	-	-	0.424
K_{14}									
	0.001***	0.012***	0.145***	9.765	1.011	i=1	0.932	-	-
	(0.000)	(0.001)	(0.008)	(0.134)		i=2	-	0.857	-
						i=3	-	-	0.482
K_{15}									
	0.002***	0.009***	0.142***	9.462	1.014	i=1	0.763	-	-
	(0.000)	(0.001)	(0.007)	(0.149)		i=2	-	0.941	-
						i=3	-	-	0.261
K_{16}									
	0.001***	0.012***	0.12***	11.430	1.017	i=1	0.922	-	-
	(0.000)	(0.001)	(0.007)	(0.076)		i=2	-	0.845	-
						i=3	-	-	0.0.258
K_{17}^a									
	0.001***	0.014***	0.150***	6.785	1.035	i=1	0.429	-	-
	(0.000)	(0.000)	(0.009)	(0.079)		i=2	-	0.047	-
						i=3	-	-	0.388

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.
a The objective function converges only with the instrument set $[constant, r_{t-1}]$.

Table A.2 Disaggregated infrastructure - VIC

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model: $E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}]\right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$.
K_{11}									
	0.003***	0.008***	0.150***	7.318	1.020	i=1	0.971	-	-
	(0.000)	(0.000)	(0.007)	(0.292)		i=2	-	0.890	-
						i=3	-	-	0.615
K_{12}									
	0.001***	0.010***	0.135***	8.471	1.040	i=1	0.954	-	-
	(0.000)	(0.000)	(0.007)	(0.205)		i=2	-	0.916	-
						i=3	-	-	0.766
K_{13}									
	0.002***	0.008***	0.132***	9.112	1.020	i=1	0.958	-	-
	(0.000)	(0.000)	(0.006)	(0.167)		i=2	-	0.961	-
						i=3	-	-	0.764
K_{14}									
	0.001***	0.011***	0.141***	11.155	1.024	i=1	0.900	-	-
	(0.000)	(0.001)	(0.008)	(0.083)		i=2	-	0.922	-
						i=3	-	-	0.536
K_{15}									
	0.002***	0.008***	0.148***	6.715	1.018	i=1	0.573	-	-
	(0.000)	(0.000)	(0.007)	(0.348)		i=2	-	0.973	-
						i=3	-	-	0.780
K_{16}									
	0.001***	0.009***	0.150***	8.708	1.018	i=1	0.984	-	-
	(0.000)	(0.000)	(0.006)	(0.191)		i=2	-	0.920	-
						i=3	-	-	0.695
K_{17}									
	0.0004***	0.009***	0.106***	13.643	1.021	i=1	0.991	-	-
	(0.000)	(0.000)	(0.005)	(0.135)		i=2	-	0.945	-
						i=3	-	-	0.773

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.

Table A.3 Disaggregated infrastructure - QLD

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model: $E_t \left[\beta \left(\frac{c_{t+1}}{c_t} \right)^{\sigma-1} \left(\frac{1}{p_i t} \right) [\rho_i y_{t+1}/k_{it+1} + (1-\delta_i) p_{it+1}] \right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.005***	0.012***	0.147***	9.808	1.015	i=1	0.929	-	-
	(0.000)	(0.000)	(0.005)	(0.132)		i=2	-	0.980	-
						i=3	-	-	0.397
K_{12}									
	0.001***	0.014***	0.119***	12.228	1.010	i=1	0.935	-	-
	(0.000)	(0.001)	(0.006)	(0.057)		i=2	-	0.969	-
						i=3	-	-	0.355
K_{13}									
	0.003***	0.014***	0.137***	11.353	1.021	i=1	0.971	-	-
	(0.000)	(0.001)	(0.006)	(0.078)		i=2	-	0.963	-
						i=3	-	-	0.599
K_{14}									
	0.002***	0.017***	0.154***	8.356	1.022	i=1	0.955	-	-
	(0.000)	(0.001)	(0.006)	(0.213)		i=2	-	0.964	-
						i=3	-	-	0.227
K_{15}									
	0.003***	0.015***	0.148***	7.463	1.023	i=1	0.949	-	-
	(0.000)	(0.001)	(0.007)	(0.280)		i=2	-	0.975	-
						i=3	-	-	0.611
K_{16}									
	0.001***	0.014***	0.137***	12.586	1.001	i=1	0.995	-	-
	(0.000)	(0.001)	(0.005)	(0.050)		i=2	-	0.917	-
						i=3	-	-	0.180
K_{17}									
	0.001***	0.016***	0.137***	9.364	1.019	i=1	0.984	-	-
	(0.000)	(0.001)	(0.005)	(0.154)		i=2	-	0.960	-
						i=3	-	-	0.286

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.

Table A.4 Disaggregated infrastructure - SA

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model: $E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}]\right] = 1 \qquad i = 1,3$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.003***	0.008***	0.126***	10.885	1.013	i=1	0.829	-	-
	(0.000)	(0.001)	(0.009)	(0.092)		i=2	-	0.950	-
						i=3	-	-	0.372
K_{12}									
	0.0004***	0.012***	0.145***	10.295	1.015	i=1	0.966	-	-
	(0.000)	(0.001)	(0.007)	(0.112)		i=2	-	0.943	-
						i=3	-	-	0.534
K_{13}									
	0.001***	0.009***	0.118***	11.500	1.004	i=1	0.978	-	-
	(0.000)	(0.001)	(0.007)	(0.074)		i=2	-	0.916	-
						i=3	-	-	0.749
K_{14}									
	0.001***	0.010***	0.128***	9.754	1.013	i=1	0.765	-	-
	(0.000)	(0.001)	(0.008)	(0.135)		i=2	-	0.948	-
						i=3	-	-	0.398
K_{15}									
	0.002***	0.012***	0.148***	10.490	1.018	i=1	0.922	-	-
	(0.000)	(0.001)	(0.006)	(0.105)		i=2	-	0.979	-
						i=3	-	-	0.470
K_{16}									
	0.001***	0.010***	0.129***	10.179	1.005	i=1	0.977	-	-
	(0.000)	(0.001)	(0.008)	(0.117)		i=2	-	0.885	-
						i=3	-	-	0.656
K_{17}									
	0.0004***	0.009***	0.101***	10.929	1.005	i=1	0.978	-	-
	(0.000)	(0.001)	(0.007)	(0.091)		i=2	-	0.914	-
						i=3	-	-	0.075

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.

Table A.5 Disaggregated infrastructure - WA

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model:$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}]\right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.005***	0.017***	0.189***	9.171	1.020	i=1	0.882	-	-
	(0.000)	(0.001)	(0.013)	(0.164)		i=2	-	0.982	-
						i=3	-	-	0.841
K_{12}									
	0.001***	0.018***	0.172***	10.314	1.005	i=1	0.977	-	-
	(0.000)	(0.001)	(0.011)	(0.112)		i=2	-	0.974	-
						i=3	-	-	0.823
K_{13}									
	0.002***	0.018***	0.156***	12.442	1.013	i=1	0.976	-	-
	(0.000)	(0.000)	(0.011)	(0.052)		i=2	-	0.979	-
						i=3	-	-	0.830
K_{14}									
	0.002***	0.021***	0.184***	10.028	1.026	i=1	0.796	-	-
	(0.000)	(0.002)	(0.011)	(0.123)		i=2	-	0.978	-
						i=3	-	-	0.810
K_{15}									
	0.002***	0.019***	0.189***	6.962	1.019	i=1	0.901	-	-
	(0.000)	(0.001)	(0.011)	(0.324)		i=2	-	0.979	-
						i=3	-	-	0.810
K_{16}									
	0.007***	0.013***	0.192***	9.836	1.012	i=1	0.985	-	-
	(0.001)	(0.001)	(0.010)	(0.131)		i=2	-	0.944	-
						i=3	-	-	0.809
K_{17}									
	0.001***	0.020***	0.193***	8.566	1.034	i=1	0.990	-	-
	(0.000)	(0.001)	(0.010)	(0.199)		i=2	-	0.976	-
						i=3	-	-	0.810

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.

Table A.6 Disaggregated infrastructure - TAS

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model:$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1}+(1-\delta_i)p_{it+1}]\right]=1 \qquad i=1,3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}	0.005***	0.010***	0.153***	10.508	1.021	i=1	0.728	-	-
	(0.000)	(0.000)	(0.008)	(0.104)		i=2	-	0.972	-
						i=3	-	-	0.575
K_{12}									
	0.001***	0.015***	0.147***	8.991	1.039	i=1	0.914	-	-
	(0.000)	(0.001)	(0.008)	(0.174)		i=2	-	0.940	-
						i=3	-	-	0.514
K_{13}									
	0.002***	0.012***	0.141***	10.715	1.013	i=1	0.982	-	-
	(0.000)	(0.001)	(0.008)	(0.097)		i=2	-	0.895	-
						i=3	-	-	0.669
K_{14}									
	0.001***	0.013***	0.127***	10.280	0.010	i=1	0.968	-	-
	(0.000)	(0.001)	(0.008)	(0.113)		i=2	-	0.938	-
						i=3	-	-	0.463
K_{15}									
	0.002***	0.013***	0.144***	8.575	1.021	i=1	0.942	-	-
	(0.000)	(0.001)	(0.009)	(0.199)		i=2	-	0.925	-
						i=3	-	-	0.579
K_{16}									
	0.001***	0.013***	0.127***	8.636	1.025	i=1	0.980	-	-
	(0.000)	(0.001)	(0.008)	(0.195)		i=2	-	0.915	-
						i=3	-	-	0.069
K_{17}									
	0.001***	0.015***	0.145***	6.939	1.052	i=1	0.984	-	-
	(0.000)	(0.001)	(0.010)	(0.326)		i=2	-	0.945	-
						i=3	-	-	0.572

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.

Table A.7 Disaggregated infrastructure - NT

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model:$E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}]\right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.006***	0.010***	0.148***	9.853	1.019	i=1	0.937	-	-
	(0.001)	(0.002)	(0.016)	(0.131)		i=2	-	0.962	-
						i=3	-	-	0.588
K_{12}^a									
	0.002***	0.023***	0.201***	7.671	1.037	i=1	0.519	-	-
	(0.000)	(0.000)	(0.018)	(0.263)		i=2	-	0.427	-
						i=3	-	-	0.081
K_{13}									
	0.003***	0.017***	0.154***	9.398	1.022	i=1	0.879	-	-
	(0.000)	(0.003)	(0.018)	(0.152)		i=2	-	0.959	-
						i=3	-	-	0.582
K_{14}									
	0.001***	0.020***	0.156***	9.535	1.016	i=1	0.216	-	-
	(0.000)	(0.003)	(0.018)	(0.145)		i=2	-	0.472	-
						i=3	-	-	0.080
K_{15}^b									
	0.003***	0.022***	0.178***	1.704	1.018	i=1	0.880	-	-
	(0.000)	(0.003)	(0.021)	(0.636)		i=2	-	0.954	-
						i=3	-	-	0.435
K_{16}^c									
	0.004***	0.021***	0.178***	1.787	1.016	i=1	0.636	-	-
	(0.001)	(0.003)	(0.021)	(0.617)		i=2	-	0.070	-
						i=3	-	-	0.080
K_{17}^d									
	0.0004***	0.001***	0.193***	7.554	1.410	i=1	0.275	-	-
	(0.000)	(0.000)	(0.017)	(0.272)		i=2	-	0.241	-
						i=3	-	-	0.081

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.
a and d The objective function converges only with the instrument set $[constant, r_{t-1}, r_{t-2}]$.
b and c The objective function converges only with the instrument set $[r_{t-1}, r_{t-2}]$.

Table A.8 Disaggregated infrastructure - ACT

Set 2: $[\tilde{y}_{1,t-1}, \tilde{y}_{2,t-1}, \tilde{y}_{3,t-1}]$,
where $\tilde{y}_{it} = y_{it}/k_{it}$.

model: $E_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{\sigma-1}\left(\frac{1}{p_it}\right)[\rho_i y_{t+1}/k_{it+1} + (1-\delta_i)p_{it+1}]\right] = 1 \qquad i = 1, 3.$

K_{11}: Roads, highways and subdivisions.

K_{12}: Bridges, railways and harbours.

K_{13}: Electricity generation, transmission and pipelines.

K_{14}: Water storage and supply, sewerage and drainage.

K_{15}: Telecommunications.

K_{16}: Heavy industry.

K_{17}: Recreation and other.

	ρ_1	ρ_2	ρ_3	J	Rate of return		$\partial\mu_{i,t+1}/\partial\rho_1$	$\partial\mu_{i,t+1}/\partial\rho_2$	$\partial\mu_{i,t+1}/\partial\rho_3$
K_{11}									
	0.004***	0.003***	0.108***	9.763	1.020	i=1	0.978	-	-
	(0.000)	(0.000)	(0.013)	(0.135)		i=2	-	0.944	-
						i=3	-	-	0.382
K_{12}									
	0.00004***	0.008***	0.125***	10.588	1.010	i=1	0.947	-	-
	(0.000)	(0.001)	(0.014)	(0.102)		i=2	-	0.969	-
						i=3	-	-	0.199
K_{13}									
	0.001***	0.009***	0.127***	7.407	1.045	i=1	0.986	-	-
	(0.000)	(0.001)	(0.014)	(0.285)		i=2	-	0.974	-
						i=3	-	-	0.242
K_{14}									
	0.001***	0.005***	0.092***	11.126	1.017	i=1	0.877	-	-
	(0.000)	(0.000)	(0.012)	(0.084)		i=2	-	0.987	-
						i=3	-	-	0.406
K_{15}									
	0.001***	0.009***	0.124***	7.369	1.062	i=1	0.989	-	-
	(0.000)	(0.001)	(0.015)	(0.288)		i=2	-	0.967	-
						i=3	-	-	0.247
K_{16}									
	0.00001***	0.008***	0.090***	11.745	1.020	i=1	0.913	-	-
	(0.000)	(0.001)	(0.013)	(0.067)		i=2	-	0.965	-
						i=3	-	-	0.345
K_{17}									
	0.0002***	0.002***	0.050***	12.753	1.000	i=1	0.966	-	-
	(0.000)	(0.000)	(0.011)	(0.047)		i=2	-	0.971	-
						i=3	-	-	0.147

Sample is 1990q4 - 2010q2. See Table 8 for the other notes.

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