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Measuring the concentration of information and communication technology infrastructure in Australia: Do affordability and remoteness matter?

Mohammad Afshar Ali[a,c,*], Khorshed Alam[a], Brad Taylor[b]

[a] School of Commerce, Faculty of Business, Education, Law & Arts, University of Southern Queensland, Toowoomba, Queensland, 4350, Australia
[b] School of Commerce, Faculty of Business, Education, Law & Arts, University of Southern Queensland, Springfield, Queensland, 4300, Australia
[c] Department of Economics, Jagannath University, Dhaka-1100, Bangladesh

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ABSTRACT

This study measures the concentration of information and communication technology (ICT) infrastructure and expenditure inequality in the disaggregated spatial unit of various locations in Australia. Using survey data from the Household, Income and Labour Dynamics in Australia, a composite concentration index for ICT infrastructure is constructed for urban and rural households. In addition, the Gini coefficient of ICT expenditure is computed to measure the concentration of affordability of ICT services. Findings demonstrate that the concentrations of ICT infrastructure and affosrdability are profound in the Greater Sydney and Greater Melbourne areas. Nevertheless, results indicate that the remoteness of spatial units has a noteworthy impact on the concentration of ICT infrastructure. In addition, canonical correlation analysis reveals that the association between the concentration of ICT infrastructure and inequality in the affordability of ICT services is statistically significant. These findings imply that policy makers should employ a holistic approach that will not only include technological and economic considerations but also examine place-based context in designing an all-inclusive ICT policy.

1. Introduction

Access to information and communication technology (ICT) greatly differs among and within countries [1]. For example, approximately 49% of the world population still lacks Internet connection [1]. Several studies confirm the existence of a multi-layered divide in Australia involving the three interconnected dimensions of infrastructure, connectivity and digital engagement [2–4]. Specifically, the rural and remote parts of Australia remain at risk of digital disadvantage compared with major cities [4]. Such a difference contributes to the persistent underdevelopment of regional Australia. Following the mining investment boom, which witnessed strong economic growth in remote parts of the country, transitioning to a broad economic base is necessary [5]. A major obstacle to this transition, however, is the lack of sufficient ICT infrastructure.

Although the existence of a geographic digital divide is widely acknowledged, understanding of its precise nature is limited. Studies on the concentration of ICT at the disaggregated spatial unit of locations are scarce, especially those that take the Greater Capital City Area (GCCSA) as the spatial reference unit. In addition, existing studies insufficiently investigated the links among digital exclusion, affordability and remoteness. Given these limitations, an empirical study can assist in devising ICT infrastructure-related public policies not only for Australia but also for countries with similar economic, social and political contexts.

This study constructs a concentration index (CI) for ICT infrastructure in Australia and examines its connections to socio-demographic inequality, affordability and remoteness. This work provides further empirical traction on the digital divide in Australia. To achieve this research objective, we aim to answer three questions:

(i) Do ICT CIs vary among different spatial units?
(ii) Is the concentration of ICT infrastructure associated with remoteness?
(iii) Do concentration of ICT access and affordability of ICT services have any correlation at the household level?

Existing research has yet to capture the potential impacts of socio-spatial heterogeneity and affordability of information and communication technology (ICT) services in measuring the concentration of ICT infrastructure. To the best of our knowledge, this study is the first attempt to measure the concentration of ICT infrastructure at the GCCA.

* Corresponding author.
E-mail addresses: MohammadAfshar.Ali@usq.edu.au (M.A. Ali), Khorshed.Alam@usq.edu.au (K. Alam), Brad.Taylor@usq.edu.au (B. Taylor).

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This work makes several contributions to the literature. Firstly, this study uses three household ICT variables, namely, telephone and mobile phone access, Internet access and no ICT access, to comprehensively measure the concentration of ICT infrastructure. Using these variables, the study constructs a composite CI for ICT infrastructure, which is composed of the following: (i) location quotient (LQ), (ii) the Herfindahl–Hirschman modified (HHm) index and (iii) relative participation (RP). Secondly, this study examines whether the concentration of ICT infrastructure varies with remoteness. Thirdly, employing the canonical correlation analysis, the study explores the association between ICT access concentration and expenditure inequality, which has received limited attention in the empirical literature.

The remainder of the paper is structured as follows. Section 2 provides a critical review of the existing literature. Section 3 describes the data and methods used. Section 4 presents the results in detail. Section 5 discusses these results. Finally, Section 6 considers the policy implications, study limitations and future research directions.

2. Review of literature

A considerable amount of literature investigates the associations among digital concentration, socio-economic factors and socio-spatial locations. Many studies identify location as one of the major factors of digital inequality. For example, in China, citizens residing in urban areas (62.8%) are more than twice as likely to have Internet access than those who live in rural areas (28.8%) [6]. In another report, 82% of urban households in India have telephone access compared with 54% of rural households [7]. [8] argued that the disparity in Internet access widens across rural–urban countryside–city and highly accessible–remotely located areas.

As digital technologies are reported to yield substantial impacts on economies and societies, ICT statistics are receiving paramount attention from researchers [7]. These ICT statistics not only measure the digital divide within a given country or region [6,9–12] but also reflect international disparity in digital technology adoption and use by reporting the gap between countries [7,13,14]. For instance, ITU's ICT Development Index [7] measures the global digital divide across countries around the world, whereas [11] proposed an index to evaluate the development of ICT at the regional level in Spain.

[15] found that socio-economic status and socio-spatial location are two major determinants of computer ownership and Internet access. According to the authors, the likelihood of having access to the Internet is positively associated with the ownership of material and the presence of intangible resources. Other studies find a similar positive association between digital inclusion and personal income level [7,9,15–17]. Another strand of empirical work investigated the association between digital inclusion and education level [7–9,12,15–17]. These studies report that the level of an individual's digital inclusion varies with the education level attained by such an individual [16]. carried out the most detailed study on measuring ICT access concentration to date. Using four types of classes, namely, computers and Internet access, mobile phones access, fixed phones access and no access, the authors found a substantial spatial disparity between the municipalities of the Amazon and other regions in terms of ICT infrastructure concentration at the household level. In addition, the results demonstrate that rural households are more likely to lack any kind of ICT service than urban households. Although this study meticulously uses the theoretical tools of spatial economics, it overlooks the affordability dimension in measuring the concentration of ICT services. However, affordability is reported to have a crucial impact on access to ICT services [7,18].

A number of studies investigate digital concentration with special reference to Australia. Several of these works report that digital divide in Australia is aggravated by a set of socio-economic and demographic factors, including income, education and employment status, to name a few [2,4,19,20]. [21] provided evidence of spatial inequalities across and among local government areas of Sydney by using geo-cartographical maps. Recently [20], have developed a digital inclusion index for eight states in Australia. They found that the rate of digital exclusion is high for socio-economic groups with low levels of income, education and employment. However, composite measures of the socio-economic divide are required to comprehensively consider the link between digital inclusion and socio-economic status (see Section 3.1 for details). The study also reveals a significant disparity between rural and urban areas in terms of ICT access.

The study, however, has several methodological shortcomings. Firstly, the study vaguely establishes the theoretical basis for selecting the corresponding components for the three sub-indices, namely, access, affordability and digital ability. Secondly, 'headline variables' are computed by applying simple averages which can potentially yield biased and flawed index scores. Thirdly, whether any type of weighting has been applied to estimate the weight of sub-indices and headline variables remains unclear. Fourthly, although existing empirical works provide evidence that remoteness has a huge impact on ICT inclusion or concentration, the study fails to capture any variation in the digital inclusion pattern with regard to remoteness. Finally, many studies reveal that access to ICT goods and services is significantly associated with the affordability of corresponding ICT services [7,18]. However, the current study remains unsuccessful in uncovering whether a significant association exists between digital inclusion and affordability in the context of Australia.

Evidently, a large and growing body of literature has investigated the association among digital concentration, socio-economic factors and socio-spatial locations. However, the extant studies fail to capture the potential impact of socio-spatial differences in the affordability of ICT services on measuring the ICT infrastructure concentration. One of the major concern is that affordability plays a pivotal role in ICT adoption; thus, it constitutes a central part in ICT development [7,18,20]. Previous studies also fail to demonstrate the link between the concentration of ICT and remoteness of spatial units. In addition, the constructed indexes to measure digital inclusion are based on a flawed methodological framework. The current study fills the research gap by incorporating the affordability dimension in constructing the CI for ICT infrastructure and investigating the association among ICT infrastructure concentration, affordability and remoteness.

3. Materials and methods

3.1. Study area and population

The broadest spatial unit used by the Australian Bureau of Statistics is the state/territory. Nine of these spatial units represent six states (New South Wales or NSW, Victoria, Queensland, South Australia, Western Australia and Tasmania), two major territories (Northern Territory and Australian Capital Territory) and an 'other territories' category, which consists of one small administrative territory and external territories [22]. The current study is based on the six states and two major territories, excluding the 'other territories' unit. In 2016, the proportion of populations residing on the eight states/territories were as follows: NSW - 32.0%, Victoria - 25.5%, Queensland - 20.0, South Australia - 7.1%, Western Australia - 10.6%, Tasmania - 2.1%, Northern Territory - 1.0% and Australian Capital Territory - 1.7% [23]. Each state and territory is divided into a 'greater capital city' and a 'rest of state region'. In total, 16 Greater Capital City Statistical Areas (GCCSA) encompass and demarcate the country, specifically, eight Greater Capital City Areas, seven 'rest of state' areas and 'other territories' area (for details, see Fig. 2). The Australian Capital Territory consists of only one statistical area because the greater capital city encompasses the entire territory. Statistical Area Level 4 (SA4s) is the building block of GCCSAs. In total, Australia comprises 87 SA4s [22]. According to recent statistics, 67.1% of the total population of Australia resides in GCCSAs, whilst the remaining 32.9% live in the remaining states/territories [24]. This study uses data from the Household, Income and Labour

Dynamics in Australia (HILDA) Survey Restricted Release 16 [25], which is a survey conducted on 10,837 households. ICT infrastructure (telephone and mobile phone access and Internet access) and expenditure (household expenditure, such as telephone rent, call and Internet charge) in urban and rural households are analysed in conjunction with the socio-economic status and demographic divide. In Australia, 89.8% of the total population of Australia lives in urban areas, whilst the remaining 10.2% reside in rural areas [23]. Unlike the study of [20]; the current research uses Socio-economic Indexes for Areas (SEIFA) to measure the socio-economic advantage and disadvantage (SAD), economic resources (ER), education and occupation (E&O), remoteness and population size (POP) of the regions.

These composite indexes include a number of domains, e.g. household income, education, occupation, employment, housing and other indicators of SAD. These indexes can better measure the spatial socio-economic divide compared with one of the domains in isolation [26].

3.2. Sources of data

The HILDA Survey Restricted Release 16 is used as the source of ICT access and expenditure data at the household level in Australia. This restricted dataset is available upon request from the Department of Social Services. Data accumulation is conducted with respect to (i) the rural–urban decomposition of households, (ii) the existence of telephone and mobile access, (iii) the existence of the Internet, (iv) no ICT access[1] and (v) ICT expenditure. This study uses GCCSA as spatial reference units. The rationale behind selecting GCCSA as the reference unit is that it is the most appropriate disaggregated geographical unit available. According to the terms and conditions of the HILDA Restricted Release, reporting of study findings below this level is not permitted. The data on SAD, ER, E&O and POP are collected from the Census of Population and Housing on SEIFA [26]. Details on the candidate variables used to construct SEIFA can be found in a Technical Paper on SEIFA (2011) [26]. The data on the Accessibility/Remoteness Index of Australia (ARIA) are collected from the Australian Statistical Geography Standard Remoteness Structure [27]. These indicators are then classified into several categories using the ranges of values listed in Table 1.

In each SEIFA index (i.e. SAD, ER and E&O), Australia as a whole is classified into 10 deciles. Deciles 1 and 10 indicate areas with the lowest and highest proportions of corresponding index scores, respectively. In this study, each of the two consecutive deciles is grouped as quintiles for the corresponding indexes. For example, SAD deciles 1 and 2 are grouped as SAD quintile 1. This procedure is reiterated for the remaining deciles and across all SEIFA indexes (i.e. ER and E&O). This study uses ARIA to classify entire Australia into five categories on the basis of the average ARIA index score (Table 1). Finally, to classify the regions on the basis of size/populations, the benchmark range values for each class are computed using the statistical software package 'Stata 14', which applies three equal cut points for three groups, namely, small, medium and low. Table 1 reports the range of values for each group.

3.3. Methods

3.3.1. Conceptual framework

Fig. 1 elaborates the approach undertaken in the study to analyse the concentration of ICT access and expenditure. This process comprises five steps as follows: (i) analysing the ICT infrastructure concentration in urban and rural households at the GCCSA and state levels; (ii) exploring the associations between ICT access status in urban and rural households with indicators for SAD, ER, E&O, remoteness and POP; (iii) analysing the ICT expenditure inequality in urban and rural households at the GCCSA and state levels[2]; (iv) exploring the associations between ICT expenditure inequality in urban and rural households with indicators for SAD, ER, E&O and remoteness; and (v) assessing the association between ICT infrastructure concentration and expenditure inequality. In the first step, the CIs are computed and analysed according to the types of access (telephone and mobile phone, Internet, no ICT) and types of households (rural or urban) in order to identify the ICT infrastructure concentration. In the second step, the association between ICT infrastructure concentration and SAD, ER, E&O, remoteness and POP is investigated by cross-tabulating the ICT infrastructure index score with the SEIFA indexes, remoteness level and size of the spatial unit in terms of population.

3.3.2. Estimation strategy

Measuring the ICT infrastructure CI. In the analysis of ICT infrastructure concentration, six classes are defined for the type of access (Table 2). These classes determine the characteristics of households with respect to the type of household (urban or rural) and access type based on the three kinds of ICT access. Each access type is represented by separate indicators, namely, telephone and mobile phone, Internet and no ICT.

In sequence, a normalised CI is constructed to measure the concentration of ICT infrastructure in each class (telephone & mobile phone, Internet and no ICT) in each spatial unit analysed, i.e. GCCSAs and states. The CI is a composite index that is used to quantify local productive agglomerations. In this study, the methodology developed by [28] is used to calculate ICT infrastructure CI. Moreover, the concept of productive agglomeration is extended with reference to the spatial concentration of households according to the ownership of ICT assets (telephone & mobile phone and Internet). The ICT infrastructure CI comprises three sub-indexes as listed below.

i. LQ is an index that aims to determine whether a GCCSA has a particular specialisation in a specific class. The mathematical expression of LQ is outlined in Equation (1) as follows:

$$LQ_{ij} = \frac{E_{ij}/E_i}{E_j/E} \tag{1}$$

ii. HHm is a modification of the Herfindahl–Hirschman index developed by [28] to capture the weight of a class in GCCSA. This index is defined by Equation (2) as follows:

$$HHm_{ij} = \frac{E_{ij}}{E_i} - \frac{E_j}{E} \tag{2}$$

iii. RP measures the relative participation of the class in the GCCSA in relation to a region. Equation (3) mathematically expresses RP as follows:

$$RP_{ij} = \frac{E_{ij}}{E_i}, \tag{3}$$

where

E_{ij} is the occurrence of class i in GCCSA j,
E_j is the total occurrence in GCCSA j,
E_i is the occurrence of class i considering the entire region under study and
E is the total occurrence considering all classes and entire region under study.

[1] Households without access to any type of ICT services, i.e. telephone, mobile phone or Internet.

[2] This study follows the ABS Section of State (SOS) Structure of the ASGS to define urban and rural areas. Two SOS identifier categories, namely, 'major urban' and 'other urban', are defined as urban areas. The remaining two SOS identifier categories, namely, 'bounded locality' and 'rural balance', are referred to as rural areas [22].

Table 1
Classification of regions based on socio-economic, demographic and spatial indexes.

Indicator/index	Description	Classification of regions	Ranges
SAD	Used to define the relative SAD in terms of people's access to material and social resources and their capability to participate in society.	Quintile 1: highly disadvantaged area	SEIFA SAD deciles 1 & 2
		Quintile 2: disadvantaged area	SEIFA SAD deciles 3 & 4
		Quintile 3: balanced area	SEIFA SAD deciles 5 & 6
		Quintile 4: advantaged area	SEIFA SAD deciles 7 & 8
		Quintile 5: highly advantaged area	SEIFA SAD deciles 9 & 10
ER	Comprised of variables in relation to the financial aspects of relative SAD. It indicates accessibility to ER.	Quintile 1: very low accessible area	SEIFA SAD deciles 1 & 2
		Quintile 2: low accessible area	SEIFA SAD deciles 3 & 4
		Quintile 3: moderate accessible area	SEIFA SAD deciles 5 & 6
		Quintile 4: high accessible area	SEIFA SAD deciles 7 & 8
		Quintile 5: very high accessible area	SEIFA SAD deciles 9 & 10
E&O	This index encompasses variables in relation to the educational and occupational aspects of relative SAD. It emphasises the skills of people in an area in terms of formal qualifications and occupational skills.	Quintile 1: majority are very less skilled and qualified	SEIFA SAD deciles 1 & 2
		Quintile 2: majority are less skilled and qualified	SEIFA SAD deciles 3 & 4
		Quintile 3: majority are moderately skilled and qualified	SEIFA SAD deciles 5 & 6
		Quintile 4: majority are highly skilled and qualified	SEIFA SAD deciles 7 & 8
		Quintile 5: majority are extremely skilled and qualified	SEIFA SAD deciles 9 & 10
ARIA	This index classifies the geographical units of Australia on the basis of remoteness or distance from services.	Extremely remote: very low or no accessible area	Average ARIA index score > 10.53
		Remote: low accessible area	Average ARIA index score 5.92–10.53
		Outer region: moderately accessible area	Average ARIA index score 2.4–5.92
		Inner regional: accessible area	Average ARIA index score 0.2–2.4
		Major cities: highly accessible area	Average ARIA index score < 0.2
POP	Size of regions based on total populations.	Small	Less than 167,080 inhabitants
		Medium	From 167,080 to 273,340 inhabitants
		Low	More than 273,340 inhabitants

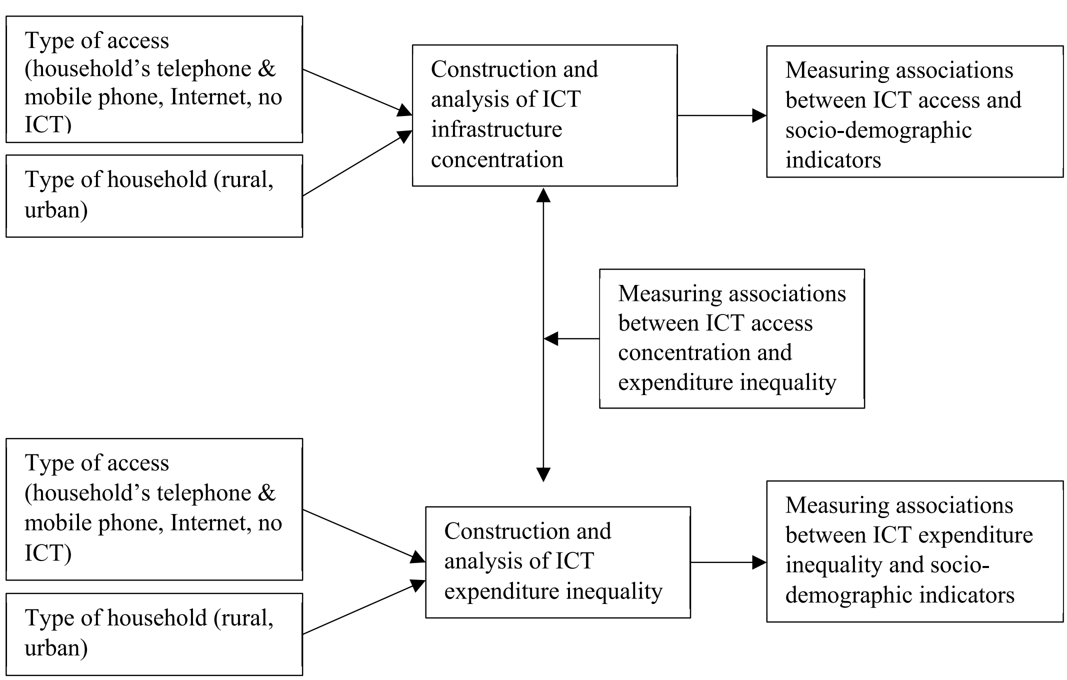

Fig. 1. Approach to analyse the concentration of ICT infrastructure and expenditure.

The three indexes can capture three aspects. LQ demonstrates the concentration of a particular class *i* in a GCCSA compared with that at the national level. HHm measures the weight of a particular class *i* in a GCCSA *j* at the national level compared with the weight of all classes of the GCCSA as the sum of all classes in the nation. RP indicates the importance of class *i* in a GCCSA in relation to the total of a corresponding class in the nation.

Based on these indexes, the ICT infrastructure CI can be expressed as

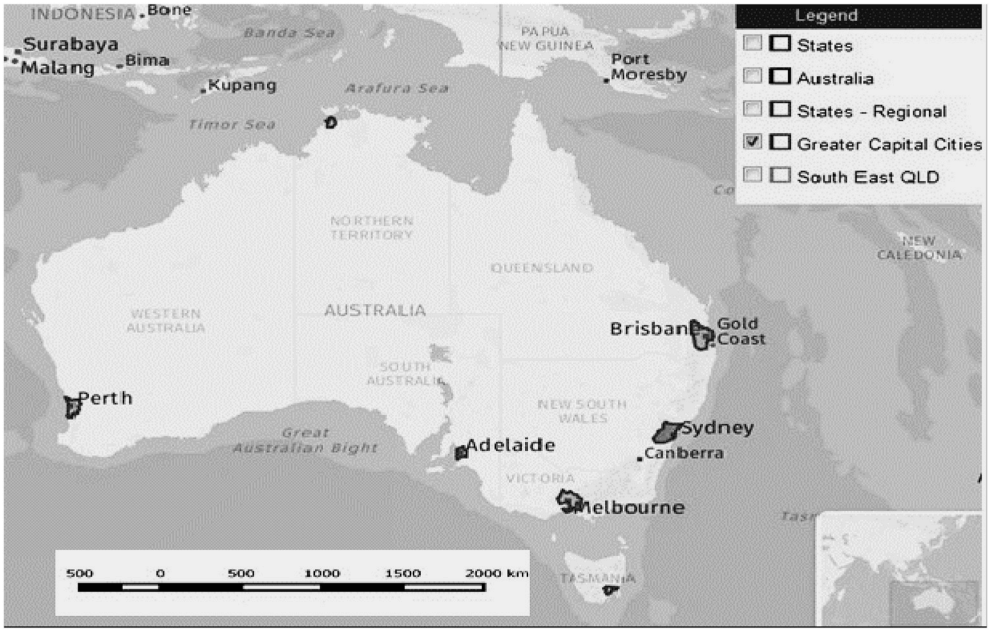

Fig. 2. Greater Capital City and remainder of state areas in Australia.

Table 2
Variable descriptions.

Class	Type of household	Variable for type of access	Description	Possible values
1	Urban	Telephone & mobile phone	Urban households with a telephone (landline or mobile phone)	1 = Yes; 2 = No
2	Urban	Internet	Urban households with Internet	1 = Yes; 2 = No
3	Urban	No ICT	Urban households with no telephone, mobile phone, and Internet	1 = Yes; 2 = No
4	Rural	Telephone & mobile phone	Rural households with a telephone (landline or mobile phone)	1 = Yes; 2 = No
5	Rural	Internet	Rural households with Internet	1 = Yes; 2 = No
6	Rural	No ICT	Rural households with no telephone, mobile phone and Internet	1 = Yes; 2 = No
7	National	Telephone & mobile phone access	Total households with a telephone (landline or mobile phone)	1 = Yes; 2 = No
8	National	Internet	Total households with Internet	1 = Yes; 2 = No
9	National	No ICT	Total households with no telephone, mobile phone, and Internet	1 = Yes; 2 = No

follows:

$$CI_{ij} = \theta_1 LQ_{ij} + \theta_2 HHm_{ij} + \theta_3 RP_{ij}, \tag{4}$$

where θ_1, θ_2 and θ_3 denote the respective weights of each index for each class.

Principal component analysis (PCA) is used to compute the weights. For details on PCA, see [29]. The ICT infrastructure CI is calculated for each class *i* and each GCCSA *j* of Australia. The index scores of telephone and mobile phone, Internet and no ICT access of urban and rural households are then compared between each GCCSA and state. The index contains no maximum or minimum ranges. Therefore, GCCSAs and states with the highest CI scores are regarded as a highly concentrated region in terms of ICT access.

Furthermore, the RP scores of each GCCSA and state are represented in a systematic order to explore the associations among ICT infrastructure concentration, SAD, ER, E&O, remoteness and POP. RP is used to analyse the classes according to socio-economic, spatial and demographic indicators. The rationale for selecting RP is that it shows the percentage of participation, that is, it measures the contribution of a particular GCCSA *j* to class *i*.

Measuring inequality in ICT expenditure. In order to measure inequality in ICT expenditure in each GCCSA, the Gini coefficient for ICT expenditure at the household level for each GCCSA is computed. The Gini coefficient is the standard method in the field of economics research to measure inequality in income and wealth [30]. The Gini coefficient, formulated in 1912 by the Italian statistician and sociologist Corrado Gini [31], is defined as the average of absolute differences between all pairs of individuals. The value of a Gini coefficient ranges between 0 (distribution of a particular variable is most even, i.e. no inequality) to 1 (distribution of that variable is most uneven, i.e. perfect inequality) [32]. In the present study, the Gini coefficient is used to measure inequality in ICT expenditure at the household level with the Jasso–Deaton formula [33,34] as expressed in Equation (5):

$$G = \frac{n+1}{n-1} - \frac{2}{n(n-1)\mu} \sum_{i=1}^{n} P_i X_i, \tag{5}$$

where

μ = mean ICT expenditure of the inhabitants of GCCSA *j*,
P_i = rank of person *i* in GCCSA *j* in terms of ICT expenditure,
X_i = annual ICT expenditure of person *i* and
n = total number of persons living in GCCSA *j*.

To explore the associations among ICT expenditure inequality, SAD, ER, E&O and remoteness, the Gini coefficient scores of ICT expenditure for each GCCSA and state are organised using different tabulations. At the last stage, three maps (one each for telephone and mobile phone access CI, Internet access CI and ICT expenditure inequality) are produced to demonstrate the spatial distribution of ICT infrastructure CI and ICT expenditure Gini. The maps depict the concentrations of ICT

Table 3
Urban and rural households by type of ICT access.

State/Territory	Variable for type of access	Urban households (%)	Rural households (%)	All households (%)
New South Wales	Telephone and mobile phone	99.7	100.0	99.7
	Internet	90.9	88.2	90.6
	No ICT	0.1	0.0	0.1
Victoria	Telephone and mobile phone	99.8	100.0	99.8
	Internet	93.0	86.9	92.3
	No ICT	0.2	0.0	0.2
Queensland	Telephone and mobile phone	99.6	99.7	99.7
	Internet	91.3	92.0	91.4
	No ICT	0.1	0.3	0.2
South Australia	Telephone and mobile phone	99.3	100.0	99.4
	Internet	89.8	84.7	89.2
	No ICT	0.7	0.0	0.7
Western Australia	Telephone and mobile phone	100.0	100.0	100.0
	Internet	93.9	84.9	92.9
	No ICT	0.0	0.0	0.0
Tasmania	Telephone and mobile phone	100.0	100.0	100.0
	Internet	89.6	95.3	91.1
	No ICT	0.0	0.0	0.0
Northern Territory	Telephone and mobile phone	100.0	100.0	100.0
	Internet	97.5	76.9	92.5
	No ICT	0.0	0.0	0.0
Australian Capital Territory	Telephone and mobile phone	100.0	100.0	100.0
	Internet	98.3	100.0	98.3
	No ICT	0.0	0.0	0.0

access and extensity of inequality in ICT expenditure for all households (urban and rural) at the state level.[3]

Measuring the association between ICT infrastructure CI and ICT expenditure inequality. Finally, the canonical correlation analysis (CCA) is applied to explore the potential association between ICT infrastructure CI and ICT expenditure inequality. This analysis enables the investigation of the relationship between two sets of variables (vectors), which are all measured on the same identity [35]. The null hypothesis states that the two sets of variables are not linearly associated. If the test-static (F statistic) is statistically significant (approximately at the 10% level), then the null hypothesis can be rejected. The measures for ICT infrastructure concentration and expenditure inequality are associated with each other. Conversely, the null hypothesis cannot be rejected if test-static (F statistic) is statistically insignificant.

4. Results

4.1. ICT infrastructure concentration

4.1.1. Analysis of ICT infrastructure concentration

With regards telephone and mobile phones in urban households, the state of South Australia has the lowest percentage (99.3%) compared with the eight states and territories studied. For rural households, Queensland has the lowest percentage of households with telephones and mobile phones (99.7%) (see Table 3). Considering all households (urban and rural), South Australia stands last in terms of the percentage of households with telephone and mobile phone access (99.4%). For Internet access, Tasmania (89.6%) and Northern Territory (76.9%) rank last for urban and rural households, respectively. Considering all households (urban and rural), South Australia has the lowest percentage among all households with Internet access (89.2%). South Australia has the highest prevalence of households without any type of ICT access (0.7% for both urban and all households). These results primarily indicate that the probability of no ICT concentration is highest for households in South Australia compared with those in other parts of Australia. As evident from Table 3, there exists an urban–rural divide between households in terms of Internet access. For example, in four states and territories, the proportion of households with Internet access is much higher in urban areas than that in rural areas (greater than 5%). The difference between urban and rural households in terms of Internet access is highest in the Northern Territory (10.6%).

Next, PCA is applied to calculate the weights of LQ, HHm and RP. Table 4 reports the weights for the three sub-indexes, namely, θ_1, θ_2 and θ_3. The table shows that for each type of household, HHm and RP account for approximately 35% of variations in CI for telephone and mobile phone access and Internet access, whilst LQ explains the remaining 30% of variation for these two types of ICT access. Conversely, for no ICT access, LQ, HHm and RP carry nearly equal weights (approximately 33% each) irrespective of household type (i.e. urban or rural).

The weights are used to calculate the CI for each GCCSA for each class analysed. Table 5 reports the CI scores for urban households. Panel A in Table 5 shows that Greater Melbourne has the highest CI scores for telephone and mobile phone (0.3661) and Internet (0.3702) access. Northern Territory has the lowest CI score (0.2906) for telephone and mobile phone access. For Internet access, the Rest of South Australia

Table 4
Weights for LQ, HHm and RP.

Class	Type of household	Variable for type of access	θ_1	θ_2	θ_3
1	Urban	Telephone and mobile phone	0.2963	0.3529	0.3507
2	Urban	Internet	0.2968	0.3527	0.3505
3	Urban	No ICT	0.3261	0.3373	0.3366
4	Rural	Telephone and mobile phone	0.3118	0.3460	0.3421
5	Rural	Internet	0.3125	0.3456	0.3417
6	Rural	No ICT	0.3334	0.3331	0.3334
7	All	Telephone and mobile phone	0.3018	0.3499	0.3481
8	All	Internet	0.3020	0.3498	0.3480
9	All	No ICT	0.3273	0.3364	0.3361

3 The maps at the GCCSA level cannot be produced as the shapefile format is unavailable at that disaggregated geographical level. However, the georeferenced cartographic database of the Australian states and regions is freely available online in shapefile format. These datasets are compiled from the ASGS dataset on the Main Structure and Greater Capital City Statistical Areas published by [43]. QGIS (version 2.12.1- Lyon), a free and open-source geographic information system software (available at http://www.qgis.org), is used to plot all maps in this study.

Table 5
Average CI for urban household classes and GCCSA with highest CI in each class.

Region/GCCSA	State	Urban households		
		Telephone and mobile phone access	Internet access	No ICT access
Panel A				
Greater Sydney	New South Wales	0.3597	0.3632	0.4673
Rest of NSW	New South Wales	0.3422	0.3282	−0.0372
Greater Melbourne	Victoria	**0.3661**	**0.3702**	0.3266
Rest of Victoria	Victoria	0.3217	0.3057	0.6024
Greater Brisbane	Queensland	0.3322	0.3368	0.2853
Rest of Queensland	Queensland	0.3361	0.3281	0.3028
Greater Adelaide	South Australia	0.3234	0.3214	**1.4744**
Rest of South Australia	South Australia	0.3124	0.2891	0.9749
Greater Perth	Western Australia	0.3197	0.3317	−0.0275
Rest of Western Australia	Western Australia	0.3119	0.2892	−0.0041
Tasmania	Tasmania	0.3106	0.3025	−0.0095
Northern Territory	Northern Territory	0.2906	0.3082	−0.0021
Australian Capital Territory	Australian Capital Territory	0.2949	0.3158	−0.0078
Panel B				
New South Wales	Average	**0.3509**	**0.3457**	0.2151
Victoria	Average	0.3439	0.3380	0.4645
Queensland	Average	0.3342	0.3324	0.2941
South Australia	Average	0.3179	0.3053	**1.2246**
Western Australia	Average	0.3158	0.3105	−0.0158
Tasmania	Average	0.3106	0.3025	−0.0095
Northern Territory	Average	0.2906	0.3082	−0.0021
Australian Capital Territory	Average	0.2949	0.3158	−0.0078

Note: Highest values are printed in bold. Figures for Greater Hobart, Rest of Tasmania, Great Darwin and Rest of Northern Territory are unavailable as the relevant indicators are not reported at corresponding GCCSA level in the HILDA data.

region possesses the least concentration (0.2891). Furthermore, the CI scores are comparatively higher in the 'greater capital city' areas compared with the corresponding 'rest of regions' within each state for telephone and mobile phone access and Internet access. Among the eight states (see Panel B), CI scores are highest in NSW for telephone and mobile phone access (0.3509) and Internet access (0.3457). Among all GCCSAs, no ICT access concentration is most prevalent in Greater Adelaide (1.2246) for urban households. At the state level, South Australia has the highest concentration of no ICT access (1.2246). Evidently, as shown in Table 5, the average CI score for no ICT access is highly positive in one case (Greater Adelaide) and negative in a number of other cases. This phenomenon can be explained using the mathematical expression outlined in Equation (2). As for a number of GCSSAs, the number of households with no ICT access is zero ($E_{ij} = 0$), the quotient of the first part of the right-hand side of Equation (2) equals zero. Therefore, the entire output of HHm for those GCCSAs are negative and eventually yield negative CI scores. Following this line of reasoning, the average CI score is highly positive for one GCCSA.

Panels A and B in Table 6 summarise the CI scores for rural households at the GCCSA and state levels, respectively. The Rest of NSW obtained the highest CI scores for telephone and mobile phone access (0.3973). The highest score for Internet access was obtained for Greater Melbourne (0.3702). Northern Territory has the lowest CI score (0.2906) for telephone and mobile phone access, whilst Greater Melbourne has the highest CI (0.3884) for Internet access. Among the eight states, the CI score for telephone and mobile phone access is highest in NSW (0.3570), whilst that for Internet access is highest in Victoria (0.3821). Among all GCCSAs, no ICT access concentration is most prevalent in rural households in the Rest of Queensland (2.3574). Exhibiting a similar trend at the state level, Queensland topped all states in terms of concentration of no ICT access (1.2246) after considering the sample of rural households. As shown in Table 5, the average CI score for no ICT access is highly positive for one GCSSA (Rest of Queensland) and negative for a number of GCSSAs. Similar to the cases described in the preceding paragraph, this phenomenon can be explained through the mathematical properties of Equation (2).

Table 7 provides the CI scores for all households (urban and rural). As can be seen, the results are similar to the corresponding CI scores for urban households. Evidently, the following table shows that for telephone and mobile phone access, the Rest of Victoria has the highest CI score (0.3661), and Greater Melbourne has the highest CI scores for Internet access (0.3819). Among the eight states, CI scores are highest in Victoria (0.4117) for telephone and mobile phone access and in NSW (0.3603) for Internet access. Among all GCCSAs, no ICT access concentration is most prevalent in Greater Adelaide (1.5639) for all households. At the state and territory levels, South Australia ranks first in terms of concentration of no ICT access (1.0349). In a nutshell, Victoria and NSW have the highest concentrations for telephone and Internet access and Internet access, respectively, regardless of the household location (urban or rural) at the state level. The relative participation statistics imply a similar indication. For example, the relative participation for telephone and mobile phone access is highest (30.7%) in Victoria relative to other states. Similarly, for the case of Internet access, households in NSW have the highest relative participation of 29.3% (for mapping, see Figs. 3 and 4). Moreover, South Australia exhibits the highest concentration regardless of household type for no ICT access. The relative participation of South Australia for no ICT access is highest (33.3%) compared with the other states.

4.1.2. Associations among ICT infrastructure concentration, socio-economic divide and remoteness

Table 8 presents the RP scores for telephone and mobile phone, Internet and no ICT access for urban and rural households. To better demonstrate the associations between socio-demographic indicators and ICT infrastructure concentration, the RP scores are represented systematically on the basis of four indicators, namely, (i) SEIFA index on SAD, (ii) SEIFA index on ER, (iii) SEIFA index on E&O and (iv) POP of the region. For the SAD index, the relative participation is highest in quintile 4 for telephone and mobile phone (27.6%) and Internet (30.0%) access. For no ICT access class, the prevalence is persistent in the lower quintiles, namely, quintiles 3 (32.1%) and 2 (24.3%). The results are almost identical when the RP scores are categorised along the quintiles that are arranged on the basis of the indexes of ER and E&O. Taking these results together, the concentration of ICT can be

Table 6
Average CI for rural household classes and GCCSA with highest CI in each class.

Region/GCCSA	State	Rural households		
		Telephone and mobile phone access	Internet access	No ICT access
Panel A				
Greater Sydney	New South Wales	0.3167	0.3441	−0.0171
Rest of NSW	New South Wales	**0.3973**	0.3878	−0.0795
Greater Melbourne	Victoria	0.2721	**0.3884**	−0.0142
Rest of Victoria	Victoria	0.3899	0.3757	−0.0700
Greater Brisbane	Queensland	0.3121	0.3354	−0.0107
Rest of Queensland	Queensland	0.3677	0.3842	**2.3574**
Greater Adelaide	South Australia	0.3155	0.3151	−0.0031
Rest of South Australia	South Australia	0.3467	0.3292	−0.0259
Greater Perth	Western Australia	0.3122	0.3303	−0.0084
Rest of Western Australia	Western Australia	0.3439	0.3144	−0.0176
Tasmania	Tasmania	0.3239	0.3514	−0.0242
Northern Territory	Northern Territory	0.3375	0.2932	−0.0044
Australian Capital Territory	Australian Capital Territory	0.2951	0.3341	−0.0012
Panel B				
New South Wales	Average	**0.3570**	0.3660	−0.0483
Victoria	Average	0.3310	**0.3821**	−0.0421
Queensland	Average	0.3399	0.3598	**1.1734**
South Australia	Average	0.3311	0.3221	−0.0145
Western Australia	Average	0.3281	0.3224	−0.0130
Tasmania	Average	0.3239	0.3514	−0.0242
Northern Territory	Average	0.3375	0.2932	−0.0044
Australian Capital Territory	Average	0.2951	0.3341	−0.0012

Note: Highest values are printed in bold. Figures for Greater Hobart, Rest of Tasmania, Great Darwin and Rest of Northern Territory are unavailable because the relevant indictors are not reported at corresponding GCCSA level in the HILDA data.

concluded to vary depending on socio-economic status, concentration of wealth and levels of education and skills. Specifically, the higher the levels of socio-economic status, wealth and education, the higher the prevalence of ICT infrastructure concentration. The larger-sized regions in terms of population have the highest relative participation rates for telephone and mobile phone (45.1%) and Internet (45.8%) access. Moreover, small and medium-sized GCCSAs comprise the majority of the proportion of households with no ICT access.

Table 9 presents the RP scores in telephone and mobile, Internet and no ICT access according to remoteness structure. The results show that for each type of class (i.e. telephone and mobile phone, Internet and no ICT access), the RP is highest among the households located in major cities, whereas these scores appear to be lower for remote and very remote areas. These findings indicate that spatial distance from the civic service centres crucially affects households' RP in ICT, such that the higher the accessibility of households to the centres, the higher the RP in ICT services and vice versa.

Table 7
Average CI for all household classes and GCCSA with highest CI in each class.

Region/GCCSA	State	Urban and rural households		
		Telephone and mobile phone access	Internet access	No ICT access
Panel A				
Greater Sydney	New South Wales	0.3667	0.3730	0.4864
Rest of NSW	New South Wales	0.3625	0.3476	−0.0423
Greater Melbourne	Victoria	0.3674	**0.3819**	0.3500
Rest of Victoria	Victoria	**0.4561**	0.2258	0.2968
Greater Brisbane	Queensland	0.3426	0.3495	0.2987
Rest of Queensland	Queensland	0.3528	0.3479	0.4099
Greater Adelaide	South Australia	0.3347	0.3344	**1.5639**
Rest of South Australia	South Australia	0.3314	0.3067	0.6260
Greater Perth	Western Australia	0.3313	0.3453	−0.0252
Rest of Western Australia	Western Australia	0.3318	0.3033	−0.0057
Tasmania	Tasmania	0.3246	0.3231	−0.0113
Northern Territory	Northern Territory	0.3132	0.3166	−0.0024
Australian Capital Territory	Australian Capital Territory	0.3082	0.3318	−0.0070
Panel B				
New South Wales	Average	0.3646	**0.3603**	0.2220
Victoria	Average	**0.4117**	0.3039	0.3234
Queensland	Average	0.3477	0.3487	0.3543
South Australia	Average	0.3330	0.3205	**1.0949**
Western Australia	Average	0.3315	0.3243	−0.0154
Tasmania	Average	0.3246	0.3231	−0.0113
Northern Territory	Average	0.3132	0.3166	−0.0024
Australian Capital Territory	Average	0.3082	0.3318	−0.0070

Note: Highest values are in bold. Figures for Greater Hobart, Rest of Tasmania, Great Darwin and Rest of Northern Territory are unavailable because the relevant indictors are not reported at corresponding GCCSA level in the HILDA data.

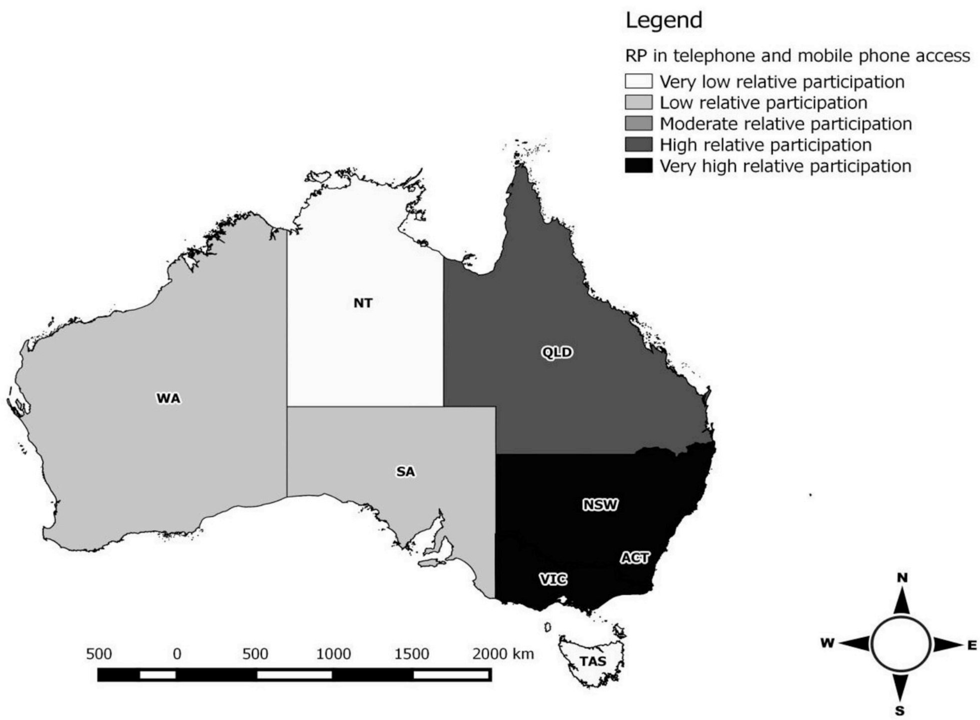

Fig. 3. Relative participation in telephone and mobile phone access in urban and rural households.

4.2. ICT expenditure concentration

4.2.1. Analysis of ICT expenditure concentration

To measure the ICT expenditure concentration, the Gini coefficient is estimated using the household ICT expenditure data. Table 10 reports the results of the Gini coefficient in ICT expenditure for urban and rural households. At the GCCSA level, the incidence of inequality is highest in the Rest of NSW (0.5345) for urban households; the Gini coefficient of ICT expenditure for this GCSSA is much higher than the nationwide value of 0.4404. This result indicates that ICT expenditure in the Rest of NSW areas and the whole of Australia are mostly concentrated within 53.5% and 44.0% of the respondents, respectively. For rural and all

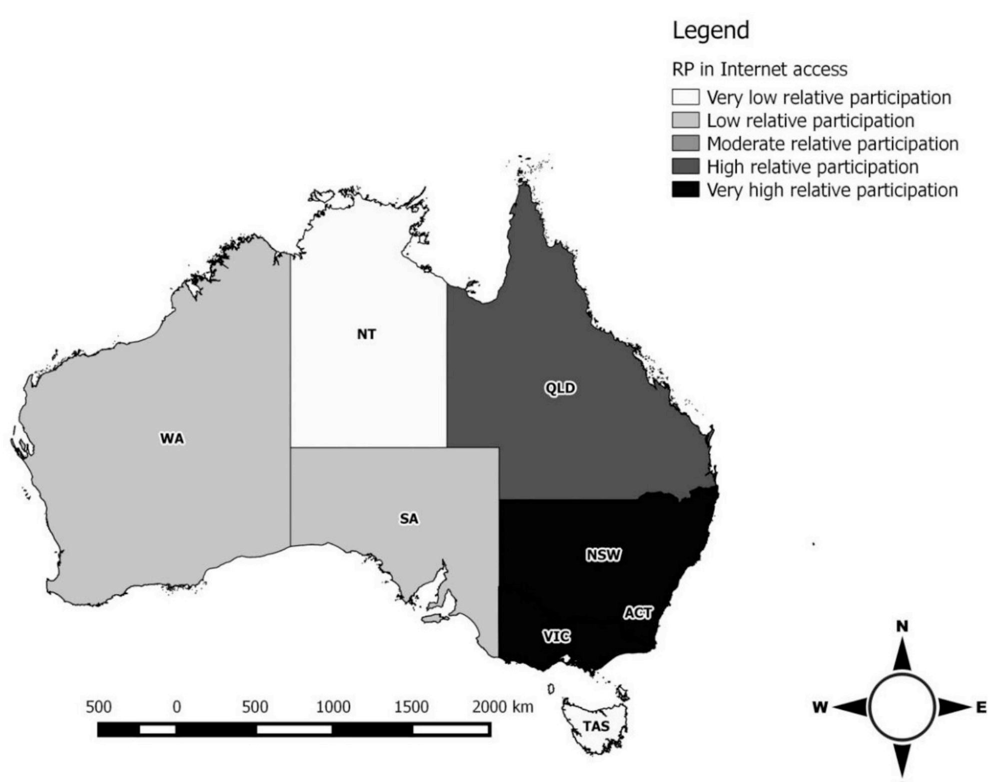

Fig. 4. Relative participation in Internet access in urban and rural households.

Table 8
RP in telephone and mobile, Internet, and no ICT access according to socio-economic and demographic indexes.

Classification of regions	All households (urban and rural)		
	Telephone and mobile phone access	Internet access	No ICT access
SAD			
Quintile 1	0.2321	0.2293	0.1265
Quintile 2	0.1423	0.1385	0.2426
Quintile 3	0.1034	0.1014	**0.3206**
Quintile 4	**0.2757**	**0.2796**	0.2024
Quintile 5	0.2465	0.2512	0.1080
ER			
Quintile 1	0.1883	0.1853	0.0000
Quintile 2	0.2170	0.2169	**0.3857**
Quintile 3	0.0936	0.0907	0.3500
Quintile 4	0.1580	0.1599	0.2644
Quintile 5	**0.3431**	**0.3472**	0.0000
E&O			
Quintile 1	0.1846	0.1816	0.0776
Quintile 2	0.0839	0.0816	0.1900
Quintile 3	0.1810	0.1776	**0.4467**
Quintile 4	**0.3260**	**0.3314**	0.1863
Quintile 5	0.2245	0.2278	0.0994
Size of region			
Small	0.3171	0.3126	0.2999
Medium	0.2316	0.2289	**0.3504**
Large	**0.4513**	**0.4585**	0.3497

Note: Highest values are in bold. Figures for Greater Hobart, Rest of Tasmania, Great Darwin and Rest of Northern Territory are unavailable because the relevant indictors are not reported at corresponding GCCSA level in the HILDA data.

Table 9
RP in telephone and mobile, Internet and no ICT access according to remoteness.

Classification of regions	All households (urban and rural)		
	Telephone and mobile phone access	Internet access	No ICT access
Major city	**0.6711**	**0.6842**	**0.7500**
Inner regional area	0.2159	0.2096	0.2083
Outer regional area	0.1008	0.0950	0.0417
Remote area	0.0101	0.0092	0.0000
Very remote area	0.0021	0.0020	0.0000

Note: Highest values are in bold.

households, the index score is highest for Greater Melbourne (0.5691 and 0.4987, respectively). At the state level, inequality in ICT is highest in NSW (0.5036) for urban household, whereas for rural and all households, Victoria has the highest prevalence of ICT expenditure inequality (see Fig. 5).

4.2.2. Association between ICT expenditure inequality, socio-economic divide and remoteness

Table 11 represents the associations between socio-demographic indicators and ICT expenditure inequality. The Gini coefficient for ICT expenditure is categorically represented based on two indicators, namely, SEIFA indexes on SAD and ER. The results show that ICT expenditure inequality is predominant in quintiles 3 and 4 for both indexes of SAD and ER.

Table 12 lists the Gini coefficient for ICT expenditure according to remoteness structure. The results show that ICT expenditure inequality is most prevalent among households that are located in major cities (0.4783), indicating that ICT expenditure in major city areas is mostly concentrated among 47.8% of respondents. In other words, this high Gini index value indicates higher concentrations in ICT affordability,

Table 10
Average Gini coefficient in ICT expenditure for urban and rural households.

Region/GCCSA	State	Households		
		Urban	Rural	All
Panel A				
Greater Sydney	New South Wales	0.4768	0.3309	0.4578
Rest of NSW	New South Wales	**0.5345**	0.4591	0.4968
Greater Melbourne	Victoria	0.4690	**0.5691**	**0.4987**
Rest of Victoria	Victoria	0.4625	0.4613	0.4619
Greater Brisbane	Queensland	0.4718	0.4922	0.4724
Rest of Queensland	Queensland	0.4777	0.3609	0.4172
Greater Adelaide	South Australia	0.4359	0.2995	0.4072
Rest of South Australia	South Australia	0.4255	0.5200	0.4479
Greater Perth	Western Australia	0.4502	0.3466	0.4140
Rest of Western Australia	Western Australia	0.4201	0.4696	0.4448
Tasmania	Tasmania	0.4681	0.3433	0.3898
Northern Territory	Northern Territory	0.4393	0.3888	0.4140
Australian Capital Territory	Australian Capital Territory	0.4433	0.2538	0.3486
Panel B				
New South Wales	Average	**0.5036**	0.4289	0.4759
Victoria	Average	0.4660	**0.5075**	**0.4814**
Queensland	Average	0.4749	0.4078	0.4434
South Australia	Average	0.4314	0.4097	0.4247
Western Australia	Average	0.4401	0.3993	0.4243
Tasmania	Average	0.4563	0.3562	0.3795
Northern Territory	Average	0.4393	0.3888	0.4140
Australian Capital Territory	Average	0.4433	0.2538	0.3486

Note: Highest values are in bold. Figures for Greater Hobart, Rest of Tasmania, Great Darwin and Rest of Northern Territory are unavailable because the relevant indictors are not reported at corresponding GCCSA level in the HILDA data.

which eventually translate into higher inequality in terms of ICT expenditure. For very remote areas, the coefficient appears to be lower (0.3782), and such a lower level of concentration means lower inequality in ICT expenditure. These findings indicate the link between ICT expenditure inequality and state of the remoteness of households, such that the higher the accessibility of households to city centres, the higher the RP in ICT services and vice versa.

4.3. Association between ICT infrastructure concentration and expenditure inequality

CCA is used to explore the association between ICT infrastructure concentration and expenditure inequality (Table 13). In this analysis, two sets of variables are used. Set 1 comprises ICT infrastructure concentration measures, i.e. CIs for telephone and mobile phone, Internet and no ICT access. Set 2 encompasses ICT expenditure inequality. For variable combination A, the canonical correlation coefficient and Wilks' statistic are 0.7028 and 0.0560, respectively. The corresponding F statistic is 2.9288, which is statistically significant at 10% level. For combination B, the canonical correlation coefficient is statistically significant at 5% level. Therefore, we can reject the null hypothesis that our two sets of variables are not linearly related. This finding indicates that ICT infrastructure concentration and expenditure inequality are statistically associated with each other.

5. Discussion

This study finds that the concentration of telephone and mobile and Internet access is higher in Greater Sydney and Greater Melbourne at the GCCSA level. Following this trend, Victoria and NSW secure the top spots in terms of ICT infrastructure concentration at the state level. These findings are consistent with those of [20]; who reported that the two aforementioned states have the highest relevance of digital concentration in Australia. In turn, these results indicate that ICT

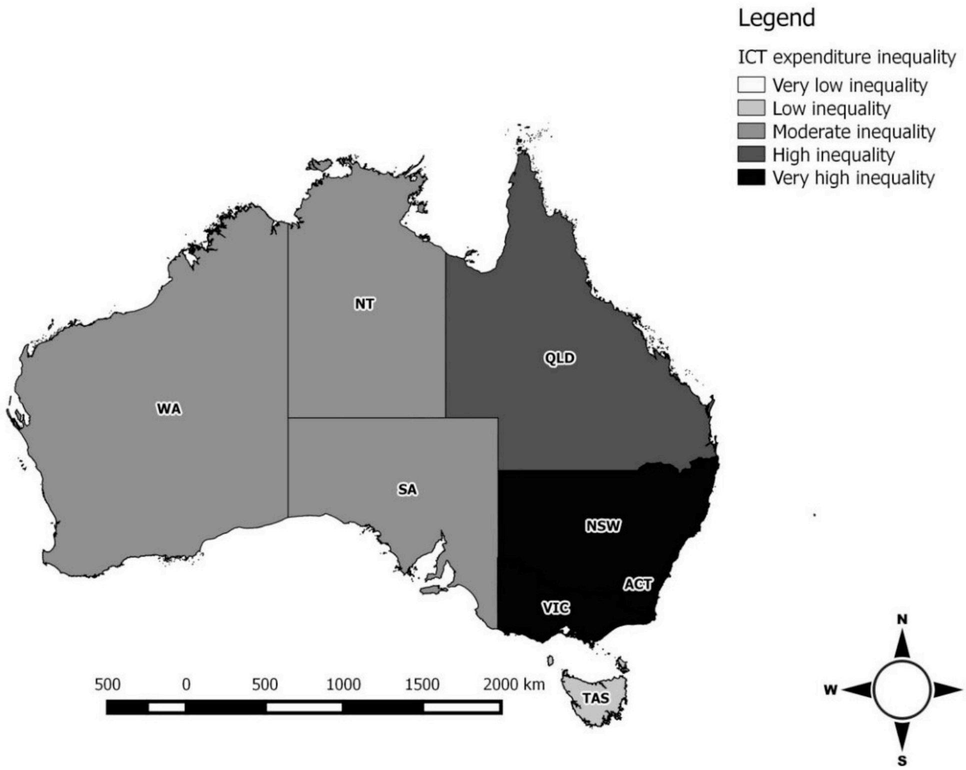

Fig. 5. Inequality in ICT expenditure in urban and rural households.

Table 11
Average Gini coefficient for ICT expenditure according to socio-economic classification of regions.

Classification of regions	All households (urban and rural)
SAD quintile	
Quintile 1	0.4507
Quintile 2	0.4636
Quintile 3	**0.4744**
Quintile 4	0.4624
Quintile 5	0.4146
ER quintile	
Quintile 1	0.4754
Quintile 2	0.4464
Quintile 3	**0.4783**
Quintile 4	0.4575
Quintile 5	0.3782

Note: Highest values are printed in bold.

Table 12
Average Gini coefficient for ICT expenditure according to remoteness.

Classification of regions	All households (urban and rural)
Major city	**0.4783**
Inner regional area	0.4464
Outer regional area	0.4754
Remote area	0.4575
Very remote area	0.3782

Note: Highest values are printed in bold.

infrastructure is highly concentrated in the largest economic hubs of Australia, namely, the urban centres in Sydney and Melbourne. The reason behind this phenomenon is that economic activity in Australia is concentrated most heavily in the cities [36]. The concentration of highly productive business enterprises and proximity to suppliers, customers and partners are the main reasons behind the consolidation of major economic activities in Sydney and Melbourne [36].

Aligning these numerical results with the entire population of Australia might aid in articulating the discussion of the results from a policy perspective. This comparative discussion can help identify those groups reaping benefits from the current distribution of ICT infrastructure. For all household classes, telephone and mobile phone access are highly concentrated in Rest of Victoria, which constitutes 6.0% of the total population (approximately 1.4 million people) [24]. The CI score for Internet access is highest in the Greater Melbourne region representing 19.5% of the total population (around 4.7 million people) [24]. No ICT access is most extensively concentrated in 5.5% of the population who are largely residing in the Greater Adelaide region [24]. In comparison, the CI scores for telephone and mobile phone access is lowest among 1.7% of people (0.4 million) living in the Australian Capital Territory [24]. For Internet access, 2.1% of the total population (0.5 million people belonging from Rest of Western Australia) have the lowest CI scores [24]. These figures indicate that digital exclusion is less prominent in Australian Capital Territory and the Rest of Western Australia region compared to that of the Rest of Victoria and Greater Melbourne regions.

Another important finding is that the degree of ICT infrastructure concentration varies with the level of income, educational qualification and employment status. This finding is in accordance with those of existing empirical studies [2,12,15–17]. Consistent with the literature, the current research finds that the digital divide broadens across rural–urban and regional–capital city households [6,8,20]. The findings of the current study extend those of [20] by representing ICT concentration with remoteness. Furthermore, the results of the current study indicate that ICT infrastructure concentration is predominant in households that are located in major cities compared with those in remote and very remote areas. Precisely, this study finds that about two-thirds of the respondents who reported having access to telephone and mobile phone as well as the Internet are located in major city areas. In turn, this implies that nearly about 17.3 million people (71.6% of the total population) reported demonstrating high concentration in terms of ICT access. These results are also consistent with existing empirical

Table 13
Canonical correlation between ICT infrastructure concentration and expenditure inequality.

Variable combination	Set 1 (ICT infrastructure concentration)	Set 2 (ICT expenditure inequality)	Canonical correlation	Wilks' statistic	F statistic
A	CIs for telephone and mobile phone, Internet, and no ICT access	ICT expenditure inequality	0.7028	0.5060	2.9288**
B	CIs for telephone and mobile phone and Internet access	ICT expenditure inequality	0.6977	0.5132	7.7437*

Note: * and ** denote statistical significance at the 5 and 10% levels, respectively.

studies [8], reinforcing the challenges faced by regional Australia during its transition to a broad-based economy as well as the geographic dimension of the digital divide [4,5].

The current study also extends the empirical contribution of [20] by investigating the association between digital inclusion and affordability in the Australian context. The concentration patterns of ICT infrastructure and expenditure inequality are comparatively high in Victoria and NSW. Inequality in ICT expenditure is found to be prevalent in households that are located in major cities. Nonetheless, a significant association exists between ICT infrastructure concentration and expenditure inequality. Specifically, the concentration of ICT expenditure is predominant in areas where the concentration of ICT infrastructure is high, indicating that ICT expenditure is a notable catalyst in ICT development because it plays a substantial role in explaining the pattern of ICT infrastructure concentration. These results corroborate the claim of previous seminal studies [7,18].

6. Conclusion

This study measures the concentration of ICT infrastructure and examines its association with various indicators, including socio-demographic inequality, affordability and remoteness in Australia. Constructing a composite CI for ICT infrastructure, the study finds that ICT infrastructure is highly concentrated in large economic hubs in Australia, i.e. Sydney and Melbourne. The results for ICT expenditure inequality demonstrate a similar trend. Employing CCA, the study also finds that the association between ICT infrastructure concentration and ICT expenditure inequality are statistically significant.

This research offers several practical implications. Most importantly, the research provides a comprehensive picture of the digital divide in Australia. A crucial first step towards narrowing the digital divide is accurately mapping the geographic patterns of disadvantage and this study extends the existing knowledge in this area. For example, according to the findings of this study, ICT infrastructure concentration is predominant in major cities compared to those in remote and very remote areas. This knowledge can be used by policy makers to inform the prioritisation of spatial and regional development strategies for digital infrastructure as it provides a compact guideline regarding the location of people without access. Furthermore, all dimensions of the digital divide should be taken together in devising ICT policies. The interplay between the first layer of the digital divide (i.e. access) should be holistically analysed with the second layer of the digital divide (i.e. affordability and digital literacy). In this regard, the nationwide National Broadband Network (NBN) rollout plan has been playing a major role in delivering quality broadband service to all Australians. This study provides support for this initiative and, in particular, for the provision of reliable high-speed Internet to regional and remote areas. Following different scenarios of cost-benefit analysis of broadband provision projected by the independent panel of experts and NBN Co, the total costs of continued NBN roll-out using fibre to the premises across Australia is estimated at AU$32.7 billion for the period of 2019–2024 (Department of Communication and the Arts, 2014; NBN Co, 2013). According to these projections, by 2024 about 13.06 million premises across Australia would potentially benefit from this nationwide NBN roll-out (Department of Communication and the Arts, 2014). Moreover, to deal with the divide in ICT infrastructure in socio-economically disadvantaged areas, regional and remote areas should be provided with increased reliable high-speed Internet connections. If the demand and willingness among a particular regional or remote community are sufficient, then the federal government can contribute towards the establishment of fibreoptic network connections. In this regard, the government-owned NBN Co and major telecommunications providers, such as Telstra and Optus, should work with local governments to identify critical infrastructure priorities and challenges. Consulting with the Ministry of Communication and Arts and the Ministry of Finance to allocate budget to encourage technological as well as service, institutional and market innovations in the telecommunication sector to facilitate last-mile connectivity would also further the goal of regional ICT development.

Digital literacy is another important aspect of the digital divide. Improved ICT infrastructure will mean little to disadvantaged individuals in remote communities without the appropriate skills and knowledge. In some ways, this is a catch-22 situation. Without ICT access individuals have no reason to develop ICT skills, and without ICT skills the practical impact of ICT access will be weak. Therefore, digital literacy must be considered alongside efforts to increase access, such as the NBN. For example, the Department of Local Government and Communities and the Department of Training and Workforce Development can provide assistance to communities in targeting ICT training programmes for vulnerable and disadvantaged groups in regional Australia. In both rural and urban areas, the digital divide is intertwined with other dimensions of social exclusion. For this reason, digital inclusion policy makers should take the systemic approach of looking beyond technological and narrowly economic factors to consider place-based context. In this regard, NBN Co can gather local community input and advice on the network roll-out by considering local communities as reference groups.

In the development and delivery of ICT infrastructure, the private sector can contribute significantly by bringing new technologies, innovation, experience and efficiency as well as better management. The development of public–private partnerships (PPPs) is a key avenue for mobilising resources from the private sector in the delivery of digital infrastructure. In particular, in addition to measures taken by the government, private telecommunication service providers can also play a major role in enhancing and expanding connectivity in regional and rural area through the network infrastructure. In this regard, Optus–the second largest telecommunication service provider in Australia–has invested AU$6 billion in infrastructure development. In addition, they have built a number of towers across 1000 + regional towns and upgraded existing ones [37]. They have also committed to investing AU$1 billion to improve and expand mobile coverage in regional and remote sites across Western Australia, South Australia and the Northern Territory [37]. Coordination among different departments of government and private telecommunication service provider play a substantial role in ensuring equitable access to ICT infrastructure and services. For example, Telstra–the largest telecommunication service provider of Australia–has a Universal Service Obligation (USO) to warrant standard telephone services and payphones are reasonably accessible to all people in Australia on an equitable basis regardless of where they work or live. On behalf of the Australian Government, the Department of Communications and Arts administers Telstra's USO Performance Agreement [38].

The current study also finds that a significant association exists between the digital divide and ICT expenditure inequality. As affordability is an important dimension of the digital divide, NBN co and the Department of Communications and Arts should work with various telecommunications companies in order to ensure that a range of technologies and services can be profitably provided in a way that is appropriate for all Australians. For example, issues of affordability are relevant to the choice between competing technologies in the NBN roll-out, as the technologically superior solution of using fibreoptic technology in these premises may not be the best choice once the effect on the government budget and retail prices are taken into account [39,40]. Competition policy is also highly relevant here, and the Australian Competition and Consumer Commission must look at competition not only at the national level, but also in specific regional communities that are more vulnerable to monopoly, and often less able to deal with the cost thereof, than thicker urban markets [41].

This study is not free from limitations. Firstly, to yield meaningful results, the construction and reporting of a concentration measure should be conducted at the most disaggregated geographical level. Many studies are conducted to measure the concentration of ICT up to a considerable level of disaggregated geographical units in the context of USA, Brazil and China [12,16,42]. For the current study, the construction of the ICT CI at the SA4 geographical levels is impossible due to the terms and conditions of using the HILDA Restricted Release database. Geographical mapping in terms of ICT concentration at a disaggregated spatial unit like SA4 would have rendered better insights for the policy makers. Given the circumstances, the provisions and clauses of data reporting should be more flexible and user-friendly. Secondly, the concentration measure estimated in the current study is a static one. In the future, a dynamic assessment of ICT concentration can be conducted to gain better insights into whether the concentration of ICT in a particular spatial unit has changed over time. Finally, this study measures the concentration of ICT in terms of access and affordability. Further research can be conducted by incorporating various service quality dimensions (e.g. speed of Internet connection, network coverage and call drops) in measuring the concentration of ICT services.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seps.2019.100737.

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Mr. Mohammad Afshar Ali received Masters of Social Science in Economics from Jagannath University, Bangladesh. Currently he is undertaking his Ph.D. in information economics at the University of Southern Queensland. His areas of research interest include information economics and policy, digitisation, health informatics, sustainable development issues and ICT4D. He has published a number of research articles in peer-reviewed journals.

Dr. Khorshed Alam is a Professor of Economics in the School of Commerce at the University of Southern Queensland, Australia. He holds a PhD in Environmental and Resource Economics from Murdoch University, Australia and a Masters in Economics from the Institute of Social Studies of Erasmus University Rotterdam in the Netherlands. His research interests include environmental, resource and agricultural economic issues, economics of water-energy-climate change, sustainability, health economics and policy, digital economy and adoption and use of digital technologies.

Dr. Brad Taylor is a Lecturer in Economics and Political Economy at the University of Southern Queensland. His primary areas of research are public choice theory and analytic political theory. His work has been published in journals such as Kyklos and Constitutional Political Economy. He has a PhD in political science from the Australian National University.