RESEARCH

Open Access

Annual societal cost of Alzheimer's disease in Malaysia: a micro-costing approach



Siew Chin Ong^{1*}, Lyn Xuan Tay¹, Hui Ming Ong², Ing Khieng Tiong³, Alan Swee Hock Ch'ng⁴, and Thaigarajan Parumasivam⁵

Abstract

Background Alzheimer's disease (AD) is expected to have a significant impact on resource use and economic consequences along with population aging. This study aims to investigate the annual economic burden of Alzheimer's disease along with underlying cost drivers.

Methodology Patients with AD aged 65 and above accompanied with primary caregivers were recruited in 6 tertiary care hospitals. A structured interview was conducted to collect sociodemographic, clinical and resource use information using an adapted questionnaire. Direct medical cost, direct non-medical cost and indirect cost were annualised and categorised by severity level. Generalised linear models were applied to investigate predictors of costs.

Results Among 135 patient-caregiver dyads, the annual economic burden of AD from a societal perspective was USD 8618.83 ± USD 6740.79 per capita. The societal cost of severe AD patients (USD11943.19 ± USD6954.17) almost doubled those in mild AD (USD6281.10 ± USD6879.83). IDC was the primary cost driver (77.7%) which represented the impact of productivity loss due to informal care. Besides disease severity, time spent in informal care, caregivers' employment and use of special accommodation were predictors of AD cost. This neurodegenerative disorder is estimated to impose a burden of USD1.9 billion in 2022, which represents 0.47% of Malaysia's GDP.

Conclusion This study provided real-world empirical cost estimates of AD burden in Malaysia. Informal care is a significant contributor to the societal cost of AD. Optimal healthcare resource allocation is essential in the decision making of healthcare stakeholders to address rising demands.

Keywords Alzheimer's, Societal cost, Indirect cost, Dementia, Geriatrics, Cost-of-illness, Special accommodation

*Correspondence:

Background

Alzheimer's disease (AD) is one primary aetiology of dementia that leads to progressive decline in multiple aspects such as cognitive functions, behavioural symptoms and life dependency [1, 2]. Dementia is estimated to affect 152.8 million people in 2050, along with the phenomena of population growth and ageing. The prevalence of dementia is found to be higher in women and raised with age worldwide [3, 4]. Looking from an economic perspective, it is estimated to result in \$16.9 trillion in expenditure on the treatment and care of Alzheimer's disease and related dementia (ADRD), where two-thirds of them would be borne by low-middle-income countries (LMIC) [5, 6]. With that, there is increasing concern that



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

Siew Chin Ong

siewchinong@usm.my

¹ Discipline of Social and Administrative Pharmacy, Universiti Sains Malaysia, Pulau Pinang 11800, Malaysia

² Department of Psychiatry and Mental Health, Hospital Pulau Pinang,

Ministry of Health Malaysia, Georgetown, Pulau Pinang 10990, Malaysia ³ Department of Geriatric, Pusat Jantung Sarawak, Ministry of Health

Malaysia, Kota Samarahan, Sarawak 94300, Malaysia

⁴ Department of Medicine, Seberang Jaya Hospital, Ministry of Health

Malaysia, Seberang Perai, Penang 13700, Malaysia

⁵ Discipline of Pharmaceutical Technology, Universiti Sains Malaysia, Pulau Pinang 11800, Malaysia

the scarcity of available resources has become an important consideration for policymakers in decision-making, particularly in the field of healthcare. Such an issue is more evident in LMIC due to differences in services, infrastructure, and cultural perceptions of ADRD as well as regional economic performance [6].

Prior research has indicated a rising trend in the societal cost of Alzheimer's disease (AD) across countries in past decades. By inspecting different cost components from a societal standpoint, the indirect costs associated with AD surpassed the direct costs and an increased trend could be observed from \$95.1 billion in 2000 to \$401.billion in 2016 [7]. Economic evaluations conducted by Western countries such as the UK, USA, Spain, Sweden, Finland, Italy, and Germany found that informal care cost was still the major cost driver in the economic burden of dementia [8-12]. Similar trend was observed in Asia Pacific countries, implicating the importance of country-specific estimates [13–19]. As patients with AD (PWAD) require high degree of assistance in multiple aspects of daily life, such as basic and instrumental activities of daily living (BADL/IADL), caregivers play an important role, particularly first-degree family members [10, 20, 21]. With that, productivity loss in informal caregivers could be anticipated from a societal perspective as they need to miss working hours in providing informal care [22, 23].

Apart from regional differences, the decline in cognitive function and ability loss to perform ADL were the common factors affecting disease severity and economic burden of AD, as shown in several studies [14, 22, 24-30]. Not only that, behavioural psychological symptoms of dementia (BPSD) were also proposed to influence the subjective burden of informal caregivers and the societal cost of Alzheimer's care [9, 10, 22, 26, 27, 31]. However, it was found not significant in other studies [15, 17]. All these factors exerts huge mental burden on informal caregivers, causing them to seek assistance from formal care services such as special accommodation [32]. As time spent in informal care is reduced, caregivers could take a break from such hectic tasks and engage in paid work or leisure time [33]. From an economic view, use of special accommodation such as formal caregiving services and nursing care could lead to cost shift from informal care cost to direct non-medical cost [34]. In Sweden, the cost of special accommodation could account for 70% of the total cost of AD care, depending on the types of formal services provided [22]. The surge in cost spent on special accommodation could be explained by the loss of ability to perform ADL and the occurrence of BPSD in PWAD. These increased the caregiver's subjective strain and distress as caregivers must spend more time in supervision [9, 10, 26]. As an alternative to provide better care towards PWAD in special accommodation, it indirectly reduces productivity loss which is beneficial from a societal perspective [15, 27, 28].

Previous local estimates were generated in 2018 employing top-down approach while quantifying economic burden (EB) of dementia in Malaysia [35]. Coherent with the increasing trend of annual cost in dementia care along with disease severity, the Malaysia estimates were recorded lower than neighbouring country such as Thailand [6]. Nevertheless, such methodology raised concerns on accuracy and reliability regardless of timesaving and convenient [36]. It might not reflect the actual healthcare and social resource use of PWAD and their caregivers since secondary data was analysed in a topdown approach [37]. Lack of standardised methodology renders difficulty in direct comparison between countryspecific estimates [13]. As the pattern of resource use in Alzheimer's dementia is dependent on the cultural, health and social care systems in each country; up-todate information is crucial in making policy decisions to address the socioeconomic challenges in communitydwelling patients [21].

In order to explore the cost-effectiveness of different alternatives in Alzheimer's care, reliable cost estimates are required from the local population. Extrapolation of cost data from other countries may be subject to inaccuracy as decision-making and resource allocation may change over time based on priorities, culture and social norms in different countries [25]. This study is highly valuable as input to generate annual cost estimates via bottom-up micro-costing approach. The objectives of this economic evaluation are as follows: (1) to investigate the contribution of direct and indirect costs in the annual societal cost of AD and (2) to identify potential determinants of societal cost from both patient's and caregivers' perspectives in Malaysia.

Methodology

Study design

This study was cross-sectional in which participants were recruited from 6 tertiary hospitals in Malaysia between December 2022 and November 2023. As the study comprised two parts, the first part was to quantify the direct medical cost of AD while the second part investigated direct non- medical cost and indirect cost of AD from societal perspective. By combining data from both parts, a comprehensive assessment of the economic burden imposed by AD in Malaysia could be established. This study has been designed adhering to the WMA Declaration of Helsinki (Association, 2014) and ethically approved by the Medical Research Ethics Committee Malaysia (MREC) with NMRR-ID-21–02014-VCP (IIR) to gain access and collect patient and caregiver data from the hospitals. Written consent was obtained from caregivers before the interview process.

Sampling criteria

Patients who were aged 65 years or older, had a confirmed diagnosis of AD by specialists according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V) and attending outpatient visits in selected hospitals were included into the study by convenience sampling. Informal caregivers of these patients with AD (PWAD) were also recruited in the study. To be eligible, caregivers had to be at least 18 years old and have been providing care to the PWAD for a minimum duration of three months. The prevalence approach was applied to calculate the required sample size by using the Scalex SP calculator. [38] For the expected prevalence of 8.5% from the National Health Morbidity Survey 2018 Elderly Health Volume 2 [39], with an absolute precision of \pm 5% and a potential loss/attrition of 10%, the required sample size was 134 [38, 40].

Data collection

Patients' demographics such as age, gender, etiology, disease severity and presence of behavioural symptoms were extracted from the hospital database. Next, a one-time structured interview employing standardised instruments was conducted with informal caregivers to gather demographic and caregiving information alongside their utilisation of social resources. Patient identification for the initial study phase relied on the hospital database and tracking healthcare resource utilisation over 12 months Information regarding informal caregivers was collected using an adapted questionnaire from the resource utilisation in dementia (RUD) instrument with a recall period of one month [41].

This questionnaire focused on two key components: direct non-medical care and informal caregiving. The direct non-medical care section captured resource utilisation, as reported by the caregiver, in areas such as transportation, special accommodation, community services, and equipment. In this study, special accommodation refers to paid formal nursing care services provided by trained personnel but not limited to temporary or permanent stay in local care institutions. In another part, time spent on basic activities of daily living (BADL), instrumental activities of daily living (IADL), and supervision (SV) were sought on a monthly basis. To ensure accuracy, caregivers' responses were cross-checked against their reported sleep duration, not exceeding 24 h per day.

Cost estimates

This study employed a bottom-up micro-costing approach in collecting data regarding utilization and

unit cost of each resource investigated in the questionnaire. Direct non-medical cost and indirect cost were quantified in annual manner based on the resource use reported in the questionnaires. Along with the direct medical cost estimates from the first part of the study [40], the annual cost of AD could be quantified from a societal perspective.

The direct medical cost was estimated from the first part of the study, where Ong et al. reported the detailed methodology [40]. In summary, the direct medical cost refers to costs incurred by healthcare resource utilisation such as outpatient, inpatient, laboratory tests, diagnostic assessments and medications. The direct non-medical cost included cost incurred by non-medical care resources. Indirect cost was quantified based on time spent on informal caregiving. The opportunity cost approach was applied in quantifying the productivity loss of working informal caregivers due to time spent on care based on age-stratified national average monthly wage in Malaysia year 2022, as shown in the supplementary material (S1) [42]. On the other hand, for those who were not employed, leisure time loss would serve as an indicator where 35% of age-stratified monthly wage was imposed during calculation as in previous studies using the RUD instrument [8, 9, 11, 14, 21, 25, 43].

Sensitivity analyses (SA) were done to test for uncertainty, particularly indirect cost, referring to previous literature [17]. As the base case analysis, time spent on BADL and IADL was valued based on the opportunity cost approach, while supervision cost was employed as zero value. Next, lower-bound estimates were generated by valuing time spent on ADL with self-reported wages (which was known as the replacement cost approach). Besides, upper-bound estimates were generated by including supervision cost on top of base case analysis. Costs were annualised and inflated to represent the 2023 value using the Consumer Price Index [44]. To enable country comparison, cost estimates were converted to USD with the average market exchange rate of USD\$1=MYR 4.56 (dated 12/12/2023).

Statistical analysis

Descriptive statistics were used to summarise characteristics of both patients (age, gender, disease severity, presence of BPSD and MMSE score) and informal caregivers (age, gender, relationship with PWAD, cohabitation, marital status, number of informal caregivers involved, use of special accommodation, presence of comorbidities, mean duration of informal care, employment and gross monthly salary). Relevant cost estimates and components were expressed in mean (standard deviation, SD) where differences between disease severity were examined using ANOVA. Univariate analyses were also conducted in each patient and caregiver variable via non-parametric methods considering the characteristics of cost data, such as non-negative positively skewed distribution [45]. Furthermore, a generalized linear model (GLM) was employed in multivariate analysis using gamma distribution and a log-link function due to its precision in accommodating skewed cost data [46, 47]. Independent factors with p < 0.10 in univariate analysis were selected for the multivariate analysis. Determinants of total societal cost were identified when p < 0.05 in GLM. The exponential of coefficients [Exp (B)] with 95% confidence interval (CI) were reported for each variable where p < 0.05 shows significance. All analyses were performed using the SPSS version 27.

Results

Socio-demographic of AD patients and caregivers

140 AD patient-caregiver dyads were recruited. After screening, five dyads were excluded from the study as the PWAD was under 65 years old during the first AD diagnosis and had missing data. Descriptives of the patient-caregiver dyads are presented in Table 1.

The mean (SD) age of AD patients was 77.87 (6.7) years, with females constituting the majority (n=97, 71.9%). Notably, 38 AD patients (28.1%) presented with co-existing etiologies such as vascular or frontotemporal dementia. Based on the criteria in DSM-V, the patients were categorised into mild (n=51), moderate (n=55), and severe (n=29) stages of AD. Additionally, BPSD were documented in 43.7% (n=59) of the patients. In terms of cognitive decline, the average MMSE score for the study population was 16.55 (SD=5.74), with statistically significant differences (p < 0.001) observed between various severity levels.

The majority of recruited caregivers were middle-aged, with a mean age of 51.5 (13.6) years. Females comprised nearly two-thirds of the caregiver group (n=86, 63.7%). Adult children (n=91, 67.4%) were the primary caregivers for a larger proportion of patients compared to spouses (n=19, 14.1%). Most caregivers co-resided with the patients (n=95, 70.4%) and were employed (n=91, 67.4%). A quarter of the caregivers (n=35) were single, while the majority were married (n=94, 69.6%). Typically, more than one caregiver (n=94, 69.6%) provided informal care to the PWAD. The average duration of care provided by informal caregivers was 2.87 years (SD=1.93) in this study. Regarding income level, 44.4% of the caregivers reported earnings above the national average monthly wage of RM3,212.

Caregivers time spent on informal care

Informal caregivers dedicated more than 10 h a day (314.8 h per month) on average to informal caregiving from

Table 1. The total caregiving time showed a significant positive correlation with the severity of AD (p < 0.01). Among components of informal care, supervision consumed a large proportion of caregivers' time followed by IADL and BADL. Among these activities, time spent in BADL per month was significantly increasing (p < 0.01) from mild (46.71 h) to severe (104.55 h) PWAD. Although no significance was detected, a similar trend was observed in IADL and supervision with advancing severity.

In this study, supervision time was employed at zero cost while valuing time spent on informal caregiving as the base case analysis. On average, caregivers spend 5.30 h per day (159 h monthly) assisting BADL and IADL of PWAD., A significant increase (p < 0.05) was observed in time spent on informal care, where severe PWAD and moderate PWAD recorded a rise of 79.4% and 52.1%, respectively, when compared to mild PWAD. When supervision cost was included (upper bound estimate), the caregiver's time displayed a significant increase (p < 0.05) across all disease severity levels, exceeding a 50% rise.

Resource use in direct non-medical care

As shown in Table 2, the annual direct non-medical cost (DNMC) for the study population averaged USD1335.30±USD2151.68 per PWAD. Significant differences (<0.001) were observed in DNMC across the spectrum of AD severity, with costs increasing from mild to severe stages. In terms of proportion, special accommodation accounted for almost half of the total Figure (47.62%), followed by consumables (17.55%), equipment and tools (15.10%), community services (14.77%) and transportation (4.95%). Further analysis revealed a significant increase in consumable use (p=0.002) in severe PWAD compared to mild and moderate PWAD.

To explore potential cost variation between the use of special accommodation, the cost estimates were summarised in Table 3. AD patients who utilised special accommodation (USD4986.47±USD2542.35; p < 0.001) had a significantly higher DNMC than those without special accommodation (USD624.45±USD1094.91). Notably, consumable use was also significantly higher (p=0.006) for patients utilising special accommodation while use of community services (p=0.80), transportation (p=0.57), equipment and tools (p=0.50) were insignificant between these two groups.

Indirect cost (IDC) and sensitivity analysis (SA)

As shown in Table 2, the annual IDC of AD in Malaysia yielded an average of USD 6,703.69 (\pm USD 6,064.46) per patient. Caregivers of severe PWAD incurred a significantly higher annual IDC (USD 8,878.30 \pm USD 5,909.35;

Table 1 Summary of Sociodemographic of PWAD-caregivers' dyads and time spent on informal care

Severity	Mild (n=51)		Moderate (n = 55)		Severe (<i>n</i> = 29)		Total (n = 135)		p-value
Patient									
Age in years (mean, SD)	78.06	6.40	78.07	6.72	77.17	7.23	77.87	6.67	0.82
Gender, n females (n, %)	39.00	40.20	36.00	37.10	22.00	22.70	97.00	71.90	0.39
Diagnosis, (n, %)									0.78
AD	38.00	39.20	41.00	42.30	18.00	18.60	97.00	71.90	
Mixed Etiology	13.00	34.20	14.00	36.80	11.00	28.90	38.00	28.10	
Presence of BPSD (n, %)	20.00	33.90	26.00	44.10	13.00	22.00	59.00	43.70	0.70
MMSE Score (mean, SD)	20.55 ^R	4.58	15.45***	3.82	11.28***	4.43	16.55	5.74	< 0.001***
Informal Caregiver									
Age in years, (mean, SD)	51.21	12.77	51.36	15.28	52.41	12.06	51.53	13.62	0.93
Gender, n females (n, %)	30.00	34.90	37.00	43.00	19.00	22.10	86.00	63.70	0.65
Relationship with patient $(n, \%)$									0.51
Spouse	6.00	31.60	8.00	42.10	5.00	26.30	19.00	14.10	
, Adult Child	39.00	42.90	32.00	35.20	20.00	22.00	91.00	67.40	
Family members and relatives	5.00	29.40	10.00	58.80	2.00	11.80	17.00	12.60	
Paid caregiver	1.00	14.30	4.00	57.10	2.00	28.60	7.00	5.20	
Others	0.00	0.00	1.00	100.00	0.00	0.00	1.00	0.70	
Cohabitation (n. %)									0.93
Yes	35.00	36.80	39.00	41 10	21.00	22.10	95.00	70.40	0.55
No	16.00	40.00	16.00	40.00	8.00	20.00	40.00	29.60	
Marital Status (n. %)	10.00	10100	10100	10100	0.00	20.00	10.00	27.00	0.86
Married	36.00	38 30	38.00	40.40	20.00	21 30	94.00	69.60	0.00
Single	13.00	37.10	14.00	40.00	8.00	22.90	35.00	25.00	
Divorced	1.00	100.00	0.00	0.00	0.00	0.00	1 00	0.70	
Widowed	1.00	20.00	3.00	60.00	1.00	20.00	5.00	3 70	
No. of caregivers (n. %)		20.00	5.00	00.00	1.00	20.00	5100	5.7 0	
1	20.00	48 80	15.00	36.60	6.00	14.60	41.00	30.40	0.30
2_3	24.00	32.40	30.00	40.50	20.00	27.00	74.00	54.80	0.50
>3	7 00	35.00	10.00	50.00	3.00	15.00	20.00	14.80	
Employment status (n. %)	7.00	55.00	10.00	50.00	5.00	15.00	20.00	11.00	0.94
Yes	34.00	3740	38.00	41.80	19.00	20.90	91.00	67.40	0.51
No	17.00	38.60	17.00	38.60	10.00	22.50	44.00	32.60	
Presence of medical comorbidities (n. %)	17.00	50.00	17.00	50.00	10.00	22.70	11.00	52.00	0.58
Yes	19.00	33 30	26.00	45.60	12.00	21.10	57.00	42.20	0.00
No	32.00	41.00	29.00	37.20	17.00	21.10	78.00	57.80	
Duration of informal care in years (mean, SD)	2 79	1 77	3 21	2.07	2 40	1 91	2.87	1 93	0.18
Use of Special accommodation (n. %)	2.7 5	1.77	5.21	2.07	2.10	1.51	2.07	1.55	0.06
Yes	4.00	18.20	10.00	45 50	8.00	36.40	22.00	1630	0.00
No	47.00	41.60	45.00	39.80	21.00	18.60	113.00	83.70	
Monthly Income level (n. %)	17.00	11.00	15.00	59.00	21.00	10.00	115.00	05.70	0.10
< RM3212	25.00	33 30	32.00	42 70	18.00	24.00	75.00	55.60	0.10
RM3212_RM6423	15.00	35.70	16.00	38.10	11.00	26.20	42.00	31.10	
> RM6424	11.00	61 10	7.00	38.90	0.00	0.00	18.00	13 30	
Monthly time spent on informal care (mean SI	יייי (ח	01.10	7.00	50.70	0.00	0.00	10.00	15.50	
BADI	-, 46 71 ^R	70 29	85 35*	75 29	104 55**	63.28	74 87	74 21	0.001**
	68 37	74.27	89.71	64 33	101.55	66.20	84.74	69.40	0.09
SV	139.27	112.86	175 40	119.60	146.90	84 18	155.62	110.80	0.22
	1 2 2.27	112.00	17 5.10	112.00	1 10.20	00	100.02	110.00	0.22

Table 1 (continued)

Page 6 of	f 13

Severity	Mild (n=51)		Moderate (n = 55)		Severe (<i>n</i> = 29)		Total (n = 135)		p-value
Monthly CG time (hr)									
Base case (BADL + IADL)	115.08 ^R	119.97	175.05**	112.28	206.35*	112.21	159.12	120.00	0.002**
Upper bound (BADL + IADL + SV)	254.35 ^R	153.00	350.45**	152.86	353.24*	152.97	314.75	158.97	0.002**
Average CG time per day (hr)									
Base case (BADL + IADL)	3.85 ^R	4.00	5.84**	3.74	6.88*	3.74	5.30	4.00	0.002**
Upper bound (BADL+IADL+SV)	8.48 ^R	5.10	11.68**	5.10	11.77*	5.10	10.49	5.30	0.002**

Remarks: Despite minor degree of non-normality in data, this study presented results in terms of mean figures. Thus, ANOVA was utilized to test mean differences. However, nonparametric tests (Kruskal–Wallis test) were conducted and consistency was found between p-values of both approaches. *AD* Alzheimer's disease, *PWAD* Patients with Alzheimer's Disease, *CG* Caregiver, *BADL* Basic activities daily living, *IADL* Instrumental activities daily living, *SV* Supervision, *n* number of patients, *SD* Standard deviation. *P* value for comparison of differences in means across AD severity groups using ANOVA or differences in proportion using Pearson chi-square test; * denotes statistical significance of p < 0.05; ** denotes statistical significance of p < 0.001; ^R denotes reference

 $p\!<\!0.05)$ compared to those caring for mild PWAD (USD 5,162.46 \pm USD 6,723.89). When time spent on supervision was included in estimating annual IDC (upper bound SA), the estimate (USD 3565.32 \pm USD 2649.19) nearly doubled the amount obtained in base case analysis. Similar increasing trends of IDC ($p\!<\!0.05$) were also observed across all severity levels in upper-bound estimates.

When the replacement cost approach was employed in the lower bound SA estimates, a 60% decrease was observed compared to base case estimates. Lower-bound SA1 estimates (USD $3565.32 \pm USD$ USD2649.19) diminished from a range of 50.36% to 55.92% across disease severity as shown in Table 2. In another hypothetical scenario where supervision cost was included in this replacement cost approach (lower bound SA2), annual IDC (USD

 Table 2
 Breakdown of annual societal cost of Alzheimer's disease per capita based on disease severity among study population in

 Malaysia expressed in 2023 US dollar

Cost Categories (USD)	Mild AD $(n = 51)$		Moderate AD ($n = 55$)		Severe AD ($n = 29$)		P value	Per capita	
	Mean	SD	Mean	SD	Mean	SD		Mean	SD
Direct cost									
DMC	539.83	385.95	580.06	485.98	677.82	585.68	0.189	579.84	468.33
DNMC									
Transportation	57.72	71.14	81.02	123.60	52.56	56.95	0.31	66.10	94.24
SA	231.15	825.40	766.36	2071.01	1100.67	2021.71	0.07	635.99	1718.37
Equipment & Tools	139.11	202.02	227.69	341.76	261.85	536.98	0.26	201.57	353.69
Consumables	98.78	222.58	191.27	536.92	554.67	885.84	0.002**	234.39	573.23
Community Care	52.04	209.59	215.86	867.40	417.33	1369.74	0.18	197.25	854.56
DNMC Total	578.80	1086.26	1482.20	2310.78	2387.08	2742.45	< 0.001***	1335.30	2151.68
Indirect Cost									
Base case	5162.46	6723.89	6986.22	5141.03	8878.30	5909.35	0.024**	6703.69	6064.46
Lower-bound SA 1	2600.35	2654.27	3907.22	2465.75	4613.90	2493.29	0.003**	3565.32	2649.19
Lower-bound SA 2	5657.83	3342.09	7757.77	3352.74	7838.71	3397.34	0.018**	6981.85	3490.36
Upper-bound SA	10,743.78	8381.12	14,196.60	8325.18	15,741.14	9725.33	0.043**	13,223.99	8832.02
Societal cost									
Base case	6281.10	6879.83	9048.47	5706.84	11,943.19	6954.17	0.001**	8618.83	6740.79
Lower-bound SA 1	3718.98	3004.63	5969.48	3422.66	7678.80	3740.74	< 0.001***	5486.48	3652.15
Lower-bound SA 2	6776.47	3789.97	9820.02	3986.35	10,903.61	4391.07	< 0.001***	8903.00	4327.23
Upper-bound SA	11,862.42	8656.07	16,258.86	8666.48	18,806.04	10,611.18	0.003**	15,145.15	9447.97

Remarks: *DMC* Direct medical cost, *DNMC* Direct non-medical cost, *IDC* Indirect cost, *SA* Sensitivity analysis; Base case analysis: Opportunity cost approach without supervision time; upper-bound SA estimates include supervision cost in opportunity cost approach; lower-bound SA 1 estimate valued IDC via replacement cost approach without supervision cost while lower bound SA 2 estimates valued IDC via replacement cost approach including supervision cost. *P* value for comparison of differences in means across AD severity groups using ANOVA; * denotes statistical significance of p < 0.05; ** denotes statistical significance of p < 0.01; *** denotes statistical significance of p < 0.001

Use of Special Accommodation	Yes (n = 22)		No (<i>n</i> = 113)		<i>p</i> -value
	Mean (USD)	SD	Mean (USD)	SD	
Direct Medical Cost	608.29	55.80	581.49	49.69	0.025*
Transportation	55.67	41.46	68.13	101.38	0.57
Special Accommodation	3902.63	2342.24	-	-	<0.001***
Equipment and tools	248.52	253.30	192.42	370.31	0.50
Consumables	540.46	1062.34	174.80	399.43	0.006**
Community care services	239.19	656.60	189.09	890.21	0.80
Total Direct Non-Medical Cost	4986.47	2542.35	624.45	1094.91	<0.001***
Indirect cost (Base Case)	7045.07	6072.72	6637.23	6087.69	0.77
Societal cost (Base Case)	12,639.82	6906.66	7843.17	6452.64	0.002**

 Table 3
 Breakdown of annual societal cost of Alzheimer's disease per capita based on use of special accommodation among study

 population in Malaysia expressed in 2023 US dollar

Remarks: P value for comparison of differences in means across AD severity groups using ANOVA; * denotes statistical significance of p < 0.05; ** denotes statistical significance of p < 0.01; *** denotes statistical significance of p < 0.001

 $6981.85 \pm \text{USD}$ 3490.36) were recorded slightly higher than those in base case analysis across disease severity.

Annual societal cost of AD per capita

Figure 1 illustrates the mean annual societal cost of AD was USD 8618.83±USD 6740.79 per capita. Severe PWAD incurred the highest annual expenditure (USD $11,943.19 \pm \text{USD}$ 6,954.17; p < 0.001) compared to those with mild AD (USD 6,281.10±USD 6,879.83), which was significant. Similarly, moderate PWAD recorded a cost estimate of USD 9048.47 ± USD 5706.84. Sensitivity analyses summarised in Table 2 further confirmed substantial increase of total societal cost (p < 0.01) across disease severity. As with annual societal costs, caregivers' indirect cost constituted a significant part of the total cost estimate (77.73%) when compared to the direct cost (22.27%), even with sensitivity analyses. Moreover, a significant upward trend was observed in both caregivers' indirect costs (p < 0.05) and direct non-medical costs (p < 0.001) as the severity of AD increased.

Factors influencing societal cost of alzheimer's disease

In univariate analysis, substantial impact was found in several factors (p < 0.05), such as disease severity, MMSE score, BADL monthly time, IADL monthly time, caregiver age, relationship with PWAD, caregivers' employment, caregivers' marital status, and use of special accommodation. When GLM was used and covariates were controlled, most of them remained significant towards the annual economic burden of AD in Malaysia except caregivers' age, relationship with PWAD and marital status.

It is apparent from Table 4 that a one-unit decrease in MMSE score results in a 3% increase in societal cost. In each additional hour spent monthly in BADL and IADL, the societal cost was anticipated to increase by 6% and

7%, respectively. Disease severity was a significant predictor as the societal cost of AD in mild patients was slightly over half (54.8%) of that in severe patients. In addition, severe PWAD incurred an estimated 20% higher cost than moderate PWAD. Furthermore, the societal cost of AD was significantly high (p < 0.001) for PWAD with working caregivers and those who utilised special accommodation in Alzheimer's care with an increase of 95–112%.

Total economic burden of alzheimer's disease from a societal perspective in Malaysia

Based on the latest population statistics from DOSM [48] and World Population Prospectus [49], there are an estimate of 2,376,600 – 2,546,220 individuals in Malaysia who aged 65 and above in 2022. The exact prevalence of Alzheimer's dementia is not known due to a lack of studies. Using the expected prevalence of dementia of 8.5% obtained from National Health Morbidity Survey 2018 [50], the size of aged population who is suffering from Alzheimer's disease is around 202,011 – 216,429 in 2022. As Table 5 shows, the economic burden of AD from a societal perspective in Malaysia ranged between RM7.9–8.5 billion (USD 1.7–1.9 billion). In terms of Gross Domestic Product (GDP), the economic burden of this neurodegenerative disorder also accounted for 0.44–0.47% of GDP.

Discussion

Our findings contribute valuable real-world data on the economic impact of Alzheimer's care in Malaysia, thereby addressing the gap in cost evidence from LMICs. We found a substantial and increasing societal cost associated with AD care in Malaysia, mirroring trends observed in numerous studies on communitydwelling patients [8, 9, 11, 13, 14, 16, 24, 25]. From our findings, the annual societal cost of AD in Malaysia (USD



■ DMC ■ DNMC ■ IDC

Fig. 1 Figure 1 Mean annual societal cost of Alzheimer's disease per capita stratified by disease severity in Malaysia expressed in 2023 USD figures. Remarks: DMC Direct medical cost; DNMC direct non-medical cost; IDC Indirect cost; AD Alzheimer's disease; DSM-V Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition. *ANOVA p-value for comparison between AD dementia severity groups for total societal costs

8,624.85) was recorded much lower than that in developed nations with extensive access to medical services and social health insurance systems [21, 25, 43]. Within Asian countries, higher cost estimates were obtained in neighbouring countries except Filipino and Korea [13–17, 19]. However, these discrepancies highlight the influence of methodological variations across studies and structural differences in the healthcare system [13, 15, 35, 51]. Not only that, differences in income level particularly the hourly wage rates likely contribute to the observed cost variations between countries [24].

Looking from the perspective of the country's income group, our cost estimates fall below the average dementia cost among upper-middle-income countries [52]. According to the World Bank classification of country income group in 2019, the annual dementia cost per capita in LMIC (USD 10,052) surpassed the cost estimate in this study, while HIC reported cost five times higher than our findings [52]. Extrapolating to population level, the national economic burden of AD had reached approximately RM 7.9 billion (USD 1.7 billion) in 2022. This accounted for 0.47% of Malaysia's GDP, which was relatively modest compared to other non-communicable diseases with an estimated range of 0.65–0.95% of national GDP [53]. However, our result exceeded the average of LMIC (0.45% of unweighted GDP) in 2019, highlighting the economic impact of resource use and productivity loss in Alzheimer's care on Malaysia [6].

A significant association emerged between disease severity and societal cost, particularly for indirect costs, which aligned with previous studies [9, 11, 14, 15, 17,
 Table 4
 Predictors of annual societal cost of AD in Malaysia using generalised linear model with gamma distribution and log link function

GLM with gamma distribution log link function	В	Std. E	Exp(B)	95% Confidence interval		<i>p</i> -value
				Lower	Upper	
Constant	8.275	0.5236	3924.52	7.248	9.301	0.000
Patient						
Patient Severity						0.000 *
Mild	-0.600	0.1293	0.5488	-0.854	-0.347	0.000***
Moderate	-0.228	0.0998	0.7961	-0.423	-0.032	0.023*
Severe	R					
MMSE Score	-0.027	0.0126	0.9734	-0.052	-0.003	0.031*
Monthly duration in BADL (hr)	0.006	0.0006	1.006	0.004	0.007	0.000***
Monthly Duration in IADL (hr)	0.007	0.0006	1.007	0.006	0.008	0.000***
Caregiver						
Age	0.000	0.0044	1	-0.008	0.009	0.943
Caregivers' relationship with PWAD						0.009 *
Spouse	-0.041	0.4170	0.9598	-0.858	0.777	0.922
Adult–Child	0.228	0.4101	1.2561	-0.576	1.031	0.579
Family members/ Relatives	0.391	0.4251	1.4785	-0.442	1.224	0.357
Paid caregiver	0.045	0.4429	1.0460	-0.823	0.913	0.918
Others	R					
Employment						0.000 *
Yes	0.752	0.0933	2.1212	0.569	0.935	0.000***
No	R					
Marital status						0.013 *
Yes	-0.009	0.0802	0.9910	-0.167	0.148	0.907
No	R					
Use of Special Accommodation						0.001 #
Yes	0.669	0.0967	1.9522	0.479	0.858	0.000***
No	R					

Remarks: AD Alzheimer's disease, PWAD Patient with Alzheimer's disease, BADL Basic Activity of Daily Living, IADL Instrumental Activity of Daily Living, SV Supervision, BPSD Behavioural and Psychological Symptoms of Dementia, MMSE Mini- Mental State Examination, B unstandardised beta coefficient, Std. E Standard Error, Exp(B) Exponential form of Beta, BADL indicates basic activities daily living, IADL Instrumental activities daily living, R denoted reference group; # denotes statistical significance of p < 0.05; ** denotes statistical significance of p < 0.01; *** denotes statistical significance of p < 0.001

Table 5 Economic burden of AD from societal perspective in Malaysia expressed in percentage in GDP₂₀₂₂

	DOSM	WHO
Number of elderly aged 65 and above, E ₆₅	2,376,600 (2.38 million)	2,546,220 (2.55 million)
Expected Prevalence of AD, P	8.5%	
Mean annual societal cost of AD per capita, (RM/USD)	RM 39,287.92 or USD 8,624.85	
Estimated older people with AD	202,011	216,429
Economic burden of AD from societal perspective in Malaysia (RM)	RM 7,936,592,007.12 (RM7.9 billion)	RM 8,503,033,451.30 (RM8.5 billion)
Economic burden of AD from societal perspective in Malaysia (USD)	USD 1,740,480,703.32 (USD 1.7 billion)	USD 1,864,700,318.26 (USD 1.9 billion)
Malaysia Domestic Gross Product 2022, GDP ₂₀₂₂ (RM/USD)	RM1,791.358 billion ~ USD\$ 388.24 billion	
Percentage in GDP ₂₀₂₂ , %	0.44	0.47

Remarks: the most updated population statistics (2022) were obtained from Department of Statistics Malaysia (DOSM) and World Health Population (WHO). Conversion of currency used was USD\$1 = MYR 4.56 dated 12/12/2023

22, 24]. When PWAD condition deteriorated, health and social care resource utilisation increased along with severe cognitive and functional decline [23, 54, 55]. Time spent on informal care increased substantially in highly dependent PWAD, with corresponding economic impact [56, 57]. Traditionally, family members, especially spouses or children, are believed to have the responsibility of providing care [58]. It is an obligation to care for the older people as part of filial piety in the community [15–17]. This cultural context likely contributes to informal care costs being the dominant cost component. Such findings have important implications for developing strategies for supporting informal caregivers in balancing their personal lives and caring responsibilities. In contrast, some studies from countries like China, Korea, and Thailand reported a greater emphasis on direct costs due to factors such as rising comorbidity costs, high outpatient costs, and expensive medications [15, 17, 19].

Besides, MMSE score and ADL-ability were commonly discussed as cost predictor in dementia care. In our study, a five-point decline in MMSE score correlated with a 13.5% increase in annual societal cost, further supporting the established negative association between cognitive decline and AD cost observed in previous longitudinal studies [8, 15, 51, 59]. Furthermore, the decline in MMSE scores may linked to a higher probability of institutionalisation [8, 11, 21]. Apart from that, time spent in BADL and IADL per month were shown as significant predictors of the societal cost of AD in our study. A five-hour increase in BADL and IADL time per month corresponded to a 3% and 3.5% increase in annual AD cost, respectively. This could be attributed to the growing need for assistance in BADL and IADL with increasing disease severity [8, 11, 43, 60]. In a multinational study, ADL ability was identified to be the strongest predictor of dementia cost despite multicollinearity with MMSE and DAD scores [25]. This association was also further demonstrated quantitatively in a meta-analysis that incorporated estimates from 8 countries [59].

High caregiving demands impose a huge burden on caregivers, particularly working individuals, as they need to sacrifice working hours to provide care towards PWAD [14, 58, 61]. It was further found in our multivariate analysis that caregiver's employment status was significantly predictive of the cost of care among PWAD, where working informal caregivers recorded a higher expenditure in the annual cost of care in PWAD, particularly indirect cost. This trend was also observed in previous research [22, 26, 62]. Compared to non-working caregivers, working caregivers experience a greater societal cost burden due to productivity loss associated with informal caregiving [24, 27, 63]. Besides, the higher unit cost was employed in valuing time spent on informal care

of PWAD where unemployed or retired caregivers were assigned to a lower unit cost of time value to avoid overestimating [10, 22].

To reduce the impact of informal care toward working hours, caregivers opt for paid domestic help or nursing care to provide professional care to PWAD [15-17, 33]. Such arrangement relieved caregivers from physical and mental burden with increasing disease severity [14, 58, 64]. In our study, the proportion of PWAD utilizing special accommodation increased with disease severity (p=0.06). With that, PWAD who utilised special accommodation in our study incurred a significantly higher societal cost, nearly double that of those who had home care. This finding aligns with research comparing costs between homecare and institutional long-term care settings [17, 22, 27, 51]. As a consequence, utilisation of special accommodation led to cost shifting from indirect cost to direct non-medical cost [23, 34]. In our findings, DNMC of PWAD who utilized special accommodation recorded 8 times higher than community-dwelling patients. Nevertheless, contrast findings were observed in Hungary where nursing home placement has no significant effect on the cost of PWAD. Such scenario could be explained by low reimbursement level by the local government [65]

Surprisingly, BPSD was not significantly associated with societal cost trend in our study. Although similar finding was observed elsewhere [17, 24], this contrasts sharply with many studies that highlighted BPSD as a major contributor to the total cost of care in AD. [9, 22, 26, 43, 51] In addition, agitation was found to have substantial impact on informal care cost particularly in advanced AD [66, 67]. Depression symptoms in PWAD increased caregiver time of care, which could also reflect on productivity loss [68]. Findings in our study may be due to non-correlation between disease severity and behavioural problems in PWAD. Other demographic factors such as patient age [14, 22, 51], comorbidity [15], number of caregivers [14] and cohabitation [14, 62] were also found not cost predictive in our study compared to other cross-sectional studies. Most PWAD in our study were female (71.9%) which was consistent with several literature [3, 69]. However, gender was not significant in changes of societal cost, unlike studies from Germany [51, 70].

Strength of this study included the utilization of RUD instrument in data collection from both caregivers and PWAD. With structured design, the questionnaire evaluated the frequency of resource use with precision in dementia care. As its feasibility has been shown in GERAS study, data collection via structured instrument enables comparison of resource use and cost valuation in economic evaluation [21, 71]. Next, this study employed bottom-up micro-costing approach in valuing the resource use in medical, social and informal care. Although it was time-consuming and hectic, actual resource use and cost involved were quantified based on detailed stratification [37, 72]. In addition, our finding provides country specific estimates that are valuable for informing decision-makers and stakeholders about the costs and resource use associated with AD in Malaysia.

However, there were several limitations in this study. The sample size may not be nationally representative as PWAD from southern Malaysia was not included. Cross-sectional nature renders difficulty to determine causative relationship between variables [15, 51]. Longitudinal studies could be considered in future studies to investigate the long-term economic effects of AD. Next, the caregiver's response in structured interviews may be subject to recall bias that may lead to underestimation in resource use and cost valuation. Due to the retrospective nature of data collection, potential determinants of costs such as ADL ability and BPSD could not be investigated thoroughly due to a lack of assessment scores such as ADCS-ADL and NPI [15, 73, 74]. Clinical assessments could be done in future studies via collaboration with physicians and doctors to investigate possible associations.

Conclusion

In conclusion, this study shed light on the significant economic burden of Malaysian society due to Alzheimer's disease. Indirect cost associated with caregiver productivity loss emerged as the primary cost driver in the societal cost of AD. The findings emphasise the importance of prioritising strategies to support informal caregivers and exploring interventions that can potentially slow disease progression. By acknowledging the economic impact of AD, policymakers can make informed decisions regarding healthcare resource allocation and prioritise interventions that offer the greatest societal benefit.

Supplementary Information

The online version contains supplementary material available at https://doi. org/10.1186/s12877-025-05717-y.

Supplementary Material 1.

Acknowledgements

We would like to thank the Director General of Health Malaysia for his permission to publish this article. The authors would like to express appreciation to the Ministry of Science, Technology and Innovation (MOSTI), Malaysia for financially granting this study. We acknowledge the contribution of data collectors from all the participating hospitals.

Role of the Funder/Sponsor

The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Authors' contributions

LXT: Conception and design, acquisition of data, analysis and interpretation of data, drafting of manuscript, statistical analysis, Critical revision of the manuscript for important intellectual content, administrative, technical, or material support. SCO: Conception and design, Critical revision of the manuscript for important intellectual content, obtaining funding, supervision. TP: Critical revision of the manuscript for important intellectual content intellectual content, obtaining funding, supervision.

Funding

The study was financially supported by Technology Development Fund 1 (TeD1), Ministry of Science, Technology and Innovation (MOSTI), Malaysia (grant no.: 305.PFARMASI.614401 and TDF03211038).

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study has been designed adhering to WMA declaration of Helsinki (Association, 2014) and ethically approved by Medical Research Ethics Committee Malaysia (MREC) with NMRR-ID-21–02014-VCP (IIR) to gain access and collect patient and caregiver's data from the hospitals. Written consent was obtained from caregivers before interview process.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 14 May 2024 Accepted: 20 January 2025 Published online: 06 March 2025

References

- Alzheimer's Disease International. Dementia in Asia Pacific Region. 2014. https://www.alzint.org/u/Dementia-Asia-Pacific-2014.pdf. Accessed 6 Mar 2024
- Karantzoulis S, Galvin JE. Distinguishing Alzheimer's disease from other major forms of dementia. Expert Rev Neurother. 2011;11(11):1579–91.
- Nichols E, Steinmetz JD, Vollset SE, Fukutaki K, Chalek J, Abd-Allah F, et al. Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: an analysis for the Global Burden of Disease Study 2019. The Lancet Public Health. 2022;7(2):e105–25.
- Nichols E, Vos T. The estimation of the global prevalence of dementia from 1990–2019 and forecasted prevalence through 2050; an analysis for the Global Burden of Disease (GBD) study 2019. Alzheimers Dement. 2021;17: e051496.
- Nandi A, Counts N, Chen S, Seligman B, Tortorice D, Vigo D, Bloom DE. Global and regional projections of the economic burden of Alzheimer's disease and related dementias from 2019 to 2050: A value of statistical life approach. EClinicalMedicine. 2022;51.
- Mattap SM, Mohan D, McGrattan AM, Allotey P, Stephan BCM, Reidpath DD, et al. The economic burden of dementia in low- and middle-income countries (LMICs): a systematic review. BMJ Glob Health. 2022;7(4):1–14.
- 7. Xu J, Zhang Y, Qiu C, Cheng F. Global and regional economic costs of dementia: a systematic review. The Lancet. 2017;390:47–S.
- Rapp T, Andrieu S, Chartier F, Deberdt W, Reed C, Belger M, et al. Resource Use and Cost of Alzheimer's Disease in France: 18-Month Results from the GERAS Observational Study. Value in Health. 2018;21(3):295–303.
- Olazarán J, Agüera-Ortiz L, Argimón JM, Reed C, Ciudad A, Andrade P, et al. Costs and quality of life in community-dwelling patients with Alzheimer's disease in Spain: Results from the GERAS II observational study. Int Psychogeriatr. 2017;29(12):2081–93.

- Jetsonen V, Kuvaja-Köllner V, Välimäki T, Selander T, Martikainen J, Koivisto AM. Total cost of care increases significantly from early to mild Alzheimer's disease: 5-year ALSOVA follow-up. Age Ageing. 2021;50(6):2116–22.
- Lenox-Smith A, Reed C, Lebrec J, Belger M, Jones RW. Resource utilisation, costs and clinical outcomes in non-institutionalised patients with Alzheimer's disease: 18-month UK results from the GERAS observational study. BMC Geriatr. 2016;16(1):1–10.
- Hager K, Henneges C, Schneider E, Lieb M, Kraemer S. Alzheimer dementia: course and burden on caregivers: Data over 18 months from German participants of the GERAS study. Nervenarzt. 2018;89:431–42.
- Abdin E, Subramaniam M, Achilla E, Chong SA, Vaingankar JA, Picco L, et al. The societal cost of dementia in Singapore: results from the WiSE study. J Alzheimers Dis. 2016;51(2):439–49.
- Nakanishi M, Igarashi A, Ueda K, Brnabic AJM, Matsumura T, Meguro K, et al. Costs and resource use of community-dwelling patients with Alzheimer's disease in Japan: 18-month results from the GERAS-J study. Curr Med Res Opin. 2021;37(8):1331–9.
- Yan X, Li F, Chen S, Jia J. Associated Factors of Total Costs of Alzheimer's Disease: A Cluster-Randomized Observational Study in China. J Alzheimers Dis. 2019;69(3):795–806.
- Dominguez J, Jiloca L, Fowler KC, De Guzman MF, Dominguez-Awao JK, Natividad B, et al. Dementia incidence, burden and cost of care: a Filipino community-based study. Front Public Health. 2021;9: 628700.
- Kongpakwattana K, Dejthevaporn C, Krairit O, Dilokthornsakul P, Mohan D, Chaiyakunapruk N. A Real-World Evidence Analysis of Associations Among Costs, Quality of Life, and Disease-Severity Indicators of Alzheimer's Disease in Thailand. Value in Health. 2019;22(10):1137–45.
- Gnanamanickam ES, Dyer SM, Milte R, Harrison SL, Liu E, Easton T, et al. Direct health and residential care costs of people living with dementia in Australian residential aged care. Int J Geriatr Psychiatry. 2018;33(7):859–66.
- 19. Shon C, Yoon H. Health-economic burden of dementia in South Korea. BMC Geriatr. 2021;21:1–9.
- Nordberg G, Wimo A, Jönsson L, Kåreholt I, Sjölund BM, Lagergren M, et al. Time use and costs of institutionalised elderly persons with or without dementia: results from the Nordanstig cohort in the Kungsholmen Project—a population based study in Sweden. Int J Geriatr Psychiatry. 2007;22(7):639–48.
- Wimo A, Reed CC, Dodel R, Belger M, Jones RW, Happich M, et al. The GERAS Study: A Prospective Observational Study of Costs and Resource Use in Community Dwellers with Alzheimer's Disease in Three European Countries – Study Design and Baseline Findings. J Alzheimers Dis. 2013;36(2):385–99.
- Mesterton J, Wimo A, By A, Langworth S, Winblad B, Jonsson L. Cross Sectional Observational Study on the Societal Costs of Alzheimers Disease. Curr Alzheimer Res. 2010;7(4):358–67.
- Kließ MK, Martins R, Connolly MP. Major Cost Drivers in Assessing the Economic Burden of Alzheimer's Disease: A Structured, Rapid Review. Journal of Prevention of Alzheimer's Disease. 2021;8(3):362–70.
- Wang G, Cheng Q, Zhang S, Bai L, Zeng J, Cui PJ, et al. Economic impact of dementia in developing countries: An evaluation of Alzheimertype dementia in Shanghai. China Journal of Alzheimer's Disease. 2008;15(1):109–15.
- Gustavsson A, Brinck P, Bergvall N, Kolasa K, Wimo A, Winblad B, et al. Predictors of costs of care in Alzheimer's disease: A multinational sample of 1222 patients. Alzheimers Dement. 2011;7(3):318–27.
- Yu E, Liao Z, Fan W, Hu W, Tian G, Chen K, et al. The Economic Burden of Alzheimer's Disease in Zhejiang Province. J Alzheimers Dis. 2021;80(2):539–53.
- Wübker A, Zwakhalen SM, Challis D, Suhonen R, Karlsson S, Zabalegui A, et al. Costs of care for people with dementia just before and after nursing home placement: primary data from eight European countries. Eur J Health Econ. 2015;16:689–707.
- Leicht H, König H-H, Stuhldreher N, Bachmann C, Bickel H, Fuchs A, et al. Predictors of costs in dementia in a longitudinal perspective. PLoS ONE. 2013;8(7): e70018.
- Schaller S, Mauskopf J, Kriza C, Wahlster P, Kolominsky-Rabas PL. The main cost drivers in dementia: a systematic review. Int J Geriatr Psychiatry. 2015;30(2):111–29.
- 30. Angeles RC, Berge LI, Gedde MH, Kjerstad E, Vislapuu M, Puaschitz NG, et al. Which factors increase informal care hours and societal costs among

caregivers of people with dementia? A systematic review of Resource Utilization in Dementia (RUD). Heal Econ Rev. 2021;11(1):1–15.

- Herrmann N, Lanctôt KL, Sambrook R, Lesnikova N, Hébert R, McCracken P, et al. The contribution of neuropsychiatric symptoms to the cost of dementia care. International Journal of Geriatric Psychiatry: A journal of the psychiatry of late life and allied sciences. 2006;21(10):972–6.
- Park M, Sung M, Kim SK, Kim S, Lee DY. Multidimensional determinants of family caregiver burden in Alzheimer's disease. Int Psychogeriatr. 2015;27(8):1355–64.
- Nakanishi M, Igarashi A, Ueda K, Brnabic AJM, Treuer T, Sato M, et al. Costs and Resource Use Associated with Community-Dwelling Patients with Alzheimer's Disease in Japan: Baseline Results from the Prospective Observational GERAS-J Study. J Alzheimers Dis. 2020;74(1):127–38.
- Lyn Xuan T, Siew Chin O, Lynn Jia T, Trecia N, Thaigarajan P. Economic Burden of Alzheimer's Disease: A Systematic Review. Value in Health Regional Issues. 2024;40:1–12.
- Koris R. Economic burden of dementia and healthcare costs of demented elderly in Malaysia: Universiti Putra Malaysia; 2018. http://psasir.upm.edu. my/id/eprint/75797/. Accessed 2 Apr 2024.
- 36. Tan SS. Microcosting in Economic Evaluations. Rotterdam: Erasmus Universiteit Rotterdam (EUR); 2009. p. 219.
- Chapko MK, Liu CF, Perkins M, Li YF, Fortney JC, Maciejewski ML. Equivalence of two healthcare costing methods: bottom-up and top-down. Health Econ. 2009;18(10):1188–201.
- Naing L, Nordin RB, Abdul Rahman H, Naing YT. Sample size calculation for prevalence studies using Scalex and ScalaR calculators. BMC Med Res Methodol. 2022;22(1):209.
- Ganapathy SS, Sooryanarayana R, Ahmad NA, Jamaluddin R, Abd Razak MA, Tan MP, et al. Prevalence of dementia and quality of life of caregivers of people living with dementia in Malaysia. Geriatr Gerontol Int. 2020;20(Suppl 2):16–20.
- Ong SC, Tay LX, Yee TF, Teh EE, Ch'ng ASH, Razali RM, et al. Direct healthcare expenditure on Alzheimer's disease from healthcare providers' perspective in Malaysia: a micro-costing approach. Scientific Reports. 2024;14(1):18855.
- Wimo A, Gustavsson A, Jonsson L, Winblad B, Hsu MA, Gannon B. Application of resource utilization in dementia (RUD) instrument in a global setting. Alzheimers Dement. 2013;9(4):6–17.
- DOSM. Salaries & Wages Survey Report Malaysia 2022. Department of Statistics Malaysia; 2023. https://www.dosm.gov.my/uploads/release-conte nt/file_20230927122032.pdf. Accessed 6 Mar 2024.
- Bruno G, Mancini M, Bruti G, Dell'Agnello G, Reed C. Costs and Resource Use Associated with Alzheimer's Disease in Italy: Results from an Observational Study. The journal of prevention of Alzheimer's disease. 2018;5(1):1–10.
- 44. Turner HC, Lauer JA, Tran BX, Teerawattananon Y, Jit M. Adjusting for Inflation and Currency Changes Within Health Economic Studies. Value in Health. 2019;22(9):1026–32.
- Dunn G, Mirandola M, Amaddeo F, Tansella M. Describing, explaining or predicting mental health care costs: a guide to regression models: methodological review. Br J Psychiatry. 2003;183(5):398–404.
- Malehi AS, Pourmotahari F, Angali KA. Statistical models for the analysis of skewed healthcare cost data: a simulation study. Heal Econ Rev. 2015;5:1–16.
- Mihaylova B, Briggs A, O'Hagan A, Thompson SG. Review of statistical methods for analysing healthcare resources and costs. Health Econ. 2011;20(8):897–916.
- DOSM. Current Population Estimates Malaysia Malaysia: Department of Statistics Malaysia; 2023 [updated 12 April 2023. Available from: https:// www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=155& bul_id=ZjJOSnpJR21sQWVUcUp6ODRudm5JZz09&menu_id=L0phe U43NWJwRWVSZkIWdzQ4TIhUUT09.
- United Nations, World Population Prospects. 2022. https://www.un-ilibr ary.org/content/books/9789210014380. Accessed 6 Mar 2024.
- Sooryanarayana R, Wong NI, Ahmad NA, Razak MAA, Yusoff MFM, Chan YY, et al. An overview of the methodology and general findings from the National Health and Morbidity Survey (NHMS) 2018: Older persons' health in Malaysia. Geriatr Gerontol Int. 2020;20(Suppl 2):7–15.
- Reese JP, Heßmann P, Seeberg G, Henkel D, Hirzmann P, Rieke J, et al. Cost and care of patients with Alzheimer's disease: Clinical predictors in german health care settings. J Alzheimers Dis. 2011;27(4):723–36.

- Wimo A, Seeher K, Cataldi R, Cyhlarova E, Dielemann JL, Frisell O, Guerchet M, Jönsson L, Malaha AK, Nichols E, Pedroza P. The worldwide costs of dementia in 2019. Alzheimer's & Dementia. 2023;19(7):2865–73.
- MoH M. THE IMPACT OF NONCOMMUNICABLE DISEASES AND THEIR RISK FACTORS ON MALAYSIA'S GROSS DOMESTIC PRODUCT. Malaysia: Ministry of Health Malaysia; 2020. p. 23.
- 54. Sköldunger A, Wimo A, Sjögren K, Björk S, Backman A, Sandman PO, et al. Resource use and its association to cognitive impairment, ADL functions, and behavior in residents of Swedish nursing homes: Results from the U-Age program (SWENIS study). Int J Geriatr Psychiatry. 2019;34(1):130–6.
- Darbà J, Kaskens L, Lacey L. Relationship between global severity of patients with Alzheimer's disease and costs of care in Spain; results from the co-dependence study in Spain. Eur J Health Econ. 2015;16:895–905.
- Åkerborg Ö, Lang A, Wimo A, Sköldunger A, Fratiglioni L, Gaudig M, et al. Cost of dementia and its correlation with dependence. J Aging Health. 2016;28(8):1448–64.
- Deb A, Thornton JD, Sambamoorthi U, Innes K. Direct and indirect cost of managing alzheimer's disease and related dementias in the United States. Expert Rev Pharmacoecon Outcomes Res. 2017;17(2):189–202.
- Allegri RF, Butman J, Arizaga RL, Machnicki G, Serrano C, Taragano FE, et al. Economic impact of dementia in developing countries: An evaluation of costs of Alzheimer-type dementia in Argentina. Int Psychogeriatr. 2007;19(4):705–18.
- Marešová P, Dolejs J, Mohelska H, Bryan LK. Cost of treatment and care for people with Alzheimer's disease: a meta-analysis. Curr Alzheimer Res. 2019;16(14):1245–53.
- Robinson RL, Rentz DM, Andrews JS, Zagar A, Kim Y, Bruemmer V, et al. Costs of early stage Alzheimer's disease in the United States: Cross-sectional analysis of a prospective cohort study (GERAS-US). J Alzheimers Dis. 2020;75(2):437–50.
- Ferretti C, Sarti FM, Nitrini R, Ferreira FF, Brucki SM. An assessment of direct and indirect costs of dementia in Brazil. PLoS ONE. 2018;13(3): e0193209.
- Nakabe T, Sasaki N, Uematsu H, Kunisawa S, Wimo A, Imanaka Y. Classification tree model of the personal economic burden of dementia care by related factors of both people with dementia and caregivers in Japan: a cross-sectional online survey. BMJ Open. 2019;9(7): e026733.
- 63. Alzheimer's Disease International. World Alzheimer Report 2016. Improving healthcare for people living with dementia: Coverage, Quality and costs now and in the future. 2016. https://www.alzint.org/u/WorldAlzhe imerReport2016.pdf. Accessed 6 Mar 2024.
- Sadavoy J, Sajedinejad S, Duxbury L, Chiu M. The impact on employees of providing informal caregiving for someone with dementia. Aging Ment Health. 2022;26(5):1035–43.
- Érsek K, Kovács T, Wimo A, Kárpati K, Brodszky V, Péntek M, et al. Costs of dementia in Hungary. J Nutr Health Aging. 2010;14:633–9.
- Gola AB, Morris S, Candy B, Davis S, King M, Kupeli N, et al. Healthcare utilization and monetary costs associated with agitation in UK care home residents with advanced dementia: a prospective cohort study. Int Psychogeriatr. 2020;32(3):359–70.
- Costa N, Wübker A, De Mauléon A, Zwakhalen SM, Challis D, Leino-Kilpi H, et al. Costs of care of agitation associated with dementia in 8 European countries: results from the RightTimePlaceCare study. Journal of the American Medical Directors Association. 2018;19(1):95.e1–e10.
- 68. Parrotta I, De Mauleon A, Abdeljalil AB, Barreto PDS, Lethin C, Veerbek H, et al. Depression in people with dementia and caregiver outcomes: results from the European right time place care study. Journal of the American Medical Directors Association. 2020;21(6):872–8.e1.
- Li X, Feng X, Sun X, Hou N, Han F, Liu Y. Global, regional, and national burden of Alzheimer's disease and other dementias, 1990–2019. Front Aging Neurosci. 2022;14: 937486.
- Schwarzkopf L, Menn P, Leidl R, Wunder S, Mehlig H, Marx P, et al. Excess costs of dementia disorders and the role of age and gender-an analysis of German health and long-term care insurance claims data. BMC Health Serv Res. 2012;12:1–12.
- A. Wimo LJAZ. The resource utilization in dementia (RUD) instrument is valid for assessing informal care time in community-living patients with dementia. J Nutr Health Aging. 2010;14:685–90.
- Spacirova Z, Epstein D, Garcia-Mochon L, Rovira J, Olry de Labry Lima A, Espin J. A general framework for classifying costing methods for economic evaluation of health care. Eur J Health Econ. 2020;21(4):529–42.

- Galasko D, Bennett D, Sano M, Ernesto C, Thomas R, Grundman M, et al. An inventory to assess activities of daily living for clinical trials in Alzheimer's disease. Alzheimer Dis Assoc Disord. 1997;11:33–9.
- Cummings JL, Mega M, Gray K, Rosenberg-Thompson S, Carusi DA, Gornbein J. The Neuropsychiatric Inventory: comprehensive assessment of psychopathology in dementia. Neurology. 1994;44(12):2308.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.