Online Supplementary Material to: The impact of periodontal prevalence trends on the costs and prevalence of dementia in England: a modelling study

1 Dementia Stage Mix and Severity

Dementia in our model was characterised by four stages (1) cognitively normal, (2) mild, (3) moderate and (4) severe, before the final absorbing death state. We used this model inspired by Brück et al. (2023) as the stage breakdown provides a more accurate evaluation of costs and QALYs [1].

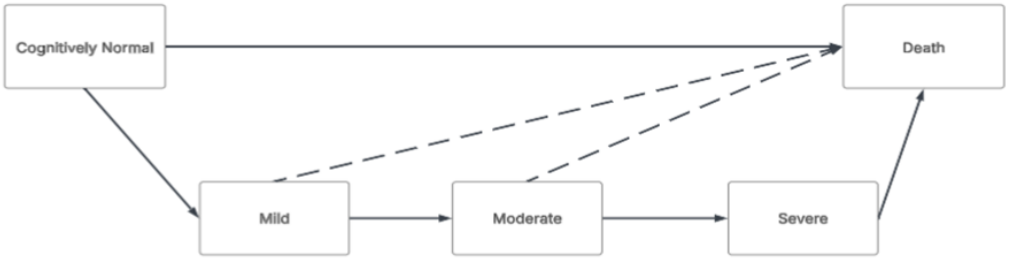

Figure 1.A Dementia model disease stage structure

We calculated the proportion of total individuals in each stage based of the Economic Impact Of Dementia CF Report, which gave percentages by each disease stage, support by NHS Primary Care Dementia Data [2]. Dementia prevalence by age band was then calculated through a calibration process to reflect that of 2023 and 2024. Final proportion reported here does not sum to 1 (0.99) due to rounding.

Table 1.A Dementia prevalence by disease stage

Stage	**Cognitively Normal**	**Mild**	**Moderate**	**Severe**
Final Proportion (%)	90	4.52376	3.39282	1.18656

Due to limitations in reporting data, disease severity proportions for males and females had to be assumed the same. The CF Report provides dementia prevalence by dementia severity for individuals over 65 years in the whole UK. Our model uses Office of National Statistics (ONS) population proportions to distribute individuals by age and sex accurate to our baseline English population [4]. Combined with the parametric age effects and sex-split of risk factor hazard ratios (HRs) (where possible), we believe this mitigates the potential downsides of our sex-split prevalence by stage assumptions. The baseline onset probability of dementia was estimated using incidence rates from previous UK-based

retrospective studies [5,6]. An incidence rate of 1.4% across men and women over age 50 was calculated using the English Longitudinal Study of Aging (ELSA), with another study using UK primary care electronic health records to calculate a higher incidence rate of 3%. We calibrated the model with empirical dementia incidence data for 2024 from NHS England to get 0.0025 as baseline probability, allowing the role of the age and risk factor effects to perform on incident dementia [3].

For average time spent in each stage, findings from Tariot et al. (2024) were used to decide due to the strength of the data [7]. The mean age of participants in that study was 72, and the mean age of simulated individuals in our model was 85. Considering this, we used 4 years as the time in state for the severe stage, supported by empirical evidence that median survival time after a dementia diagnosis in the UK is approximately 10 years [8]. We decided on not including severe mortality multipliers due to the strong mortality effects already present in our model. Background mortality was multiplied by a constant scalar of 0.46 each year between 2023 to 2040. This is a level adjustment. Each year's age/sex hazard is multiplied once by 0.46 which preserves the age/sex shape while lowering overall mortality to match the ONS projections.

Table 1.B Time in each dementia stage and associated mortality multipliers

Stage	**Onset**	**Mild**	**Moderate**	**Severe**
Time in state (years)	–	2.2	2.0	4.0

We derived annual living-setting transition probabilities from an Office of Health Economics 2023 [9] report that reported home and institution proportions for adults aged 65+ by dementia severity stage. In the model, transitions are implemented as movement from home to institution. Institutional care is treated as an absorbing state, reflecting progression of dementia and no modelled return to home.

Table 1.C Living setting transition probabilities

Dementia Severity Stage	**To institution**
Mild	0.066
Moderate	0.143
Severe	0.179

2 Background Mortality Configuration

Annual absolute hazards by age had to be calculated to provide individuals in the model with a sex-and age-specific hazards that represent the general population risk of death.

Using ONS life tables data, the annual probability of death for 2023 for each age and sex were converted to a hazard [14]:

$$h_i = -\ln(1 - \text{prob}) \tag{1}$$

The calculated base hazard (see Appendix Table 1) is later scaled by the dementia and risk multipliers so individuals in more advanced disease stages have a higher all-cause mortality that the population baseline.

3 Parametric Proportional Hazards Age Effects On Dementia Stage

For the age effects, the per year log-hazard β's had to be chosen based on the available literature. Similar non-linear methods are used to estimate dementia incidence and prevalence in an English population [15,16]. Alzheimer's UK estimates that after age 65, the risk of developing dementia doubles every 5 years, which implies a HR = 2.0 for a 5-year age difference. This would make the corresponding onset β:

$$\beta = \frac{\ln(2.0)}{5} = 0.1386 \tag{2}$$

We can set our reference age $a_{\text{ref}} = 65$ which reduces the correlation between β_k and the baseline hazard during calibration.

$$\text{At age 70 vs 65: } e^{0.1386(70-65)} \approx 2.0 \tag{3}$$

$$\text{At age 75 vs 65: } e^{0.1386(75-65)} \approx 4.0 \tag{4}$$

This is a 2 fold increase over the 5 year difference, which is reasonable given the natural disease progression at age 70 compared to age 65. However, this combined with risk factor and baseline onset effects would result in excessive onset compounding in the model. Other βs were tested for calibration with empirical incidence data. Therefore, we calibrated to get ∼90,000 incident dementia cases in 2024 after an initial hard code of 80,000 in 2023. This was based on primary care recording data [37]. The result was an onset $\beta = 0.05$ because other model components capture additional risk.

4 Costs Associated With Dementia Care

The Economic Impact Of Dementia CF Report 2024 provided us with all the relevant cost data associated with the different stages of dementia [2]. We deflated the costs to 2023

using the UK government GDP deflator tool [33]. Costs were split by dementia stage, then by location of care. A further split of professional or informal care was made to assign who those costs were accrued by. The professional costs were composed of social care and healthcare costs, while informal where composed of unpaid care and quality of life costs. As we are estimating the costs of dementia, we held costs for cognitively normal individuals at zero.

Table 4.A Costs of dementia care per individual (£)

		Professional (Social care + healthcare)	**Informal (Unpaid care + quality of life costs)**	**Total**
Cognitively Normal	**Home**	0	0	0
	Institution	0	0	0
Mild	**Home**	7,466.70	10,189.55	17,656.25
	Institution	23,144.27	874.93	24,019.19
Moderate	**Home**	7,180.18	33,726.09	40,906.28
	Institution	15,552.58	1,643.14	17,195.71
Severe	**Home**	7,668.60	31,523.39	39,191.99
	Institution	53,084.13	501.88	53,586.01

Table 4.B Breakdown of costs by categories [2]

Healthcare	**Social care**	**Unpaid care**	**Quality of life costs**
Primary care activity	Residential care	Unpaid carers	Transport costs
Secondary care activity	Nursing care		Legal and financial
Community care	Domiciliary care		Energy costs
Mental health services	Caregiver		Criminal justice
Prescriptions			Scams

5 QALYs Associated With Dementia Care

QALY utility values (from EQ-5D sources) for each dementia stage were taken directly from a previous modelling study [34]. These were reported to be the same for males and females. Age specific and sex specific QALY utility values for the cognitively normal population were taken from University of York EQ-5D value set, commonly used in health economic evaluations [35].

Due to the impact of dementia on informal caregivers, we also used specific values for these informal caregivers by dementia stage. These were obtained from a single study due to an absence of research on caregivers, and will be ineffective at capturing the true

Table 6.A QALY utility values for dementia patients by severity stage

Stage	Mild	Moderate	Severe
QALY utility values	0.71	0.64	0.38

effects of caregiving on caregivers due to their primary role of capturing physical health [34].

Table 6.B QALY utility values for informal caregivers by severity stage

Stage	Mild	Moderate	Severe
QALY utility values	0.86	0.85	0.82

6 External Validation Calibration

We simulated our model from its base year 2023 to 2024 ensure population structure accuracy, and to 2024 and 2025 for dementia prevalence accuracy. The model was calibrated using observed prevalence and population for England [3,4]. We used regression-based calibration to compare our model predictions by regressing the observed values on model-predicted values across age and sex strata.

$$\text{Observed}_i = \alpha + \beta\,(\text{Predicted}_i) + \varepsilon_i \tag{5}$$

Equation 6.A Simple linear regression for calibration

Perfect calibration would result in $\alpha \approx 0$, $\beta \approx 1$, and a R^2 close to 1. If our parametric age and risk factor effects are correctly specified and calibrated, they should mirror the true age pattern of onset and population change.

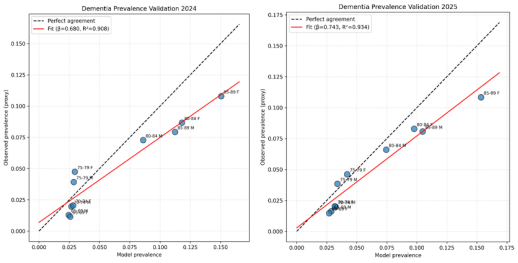

Figure 6.A External validation for prevalence for 2024 and 2025

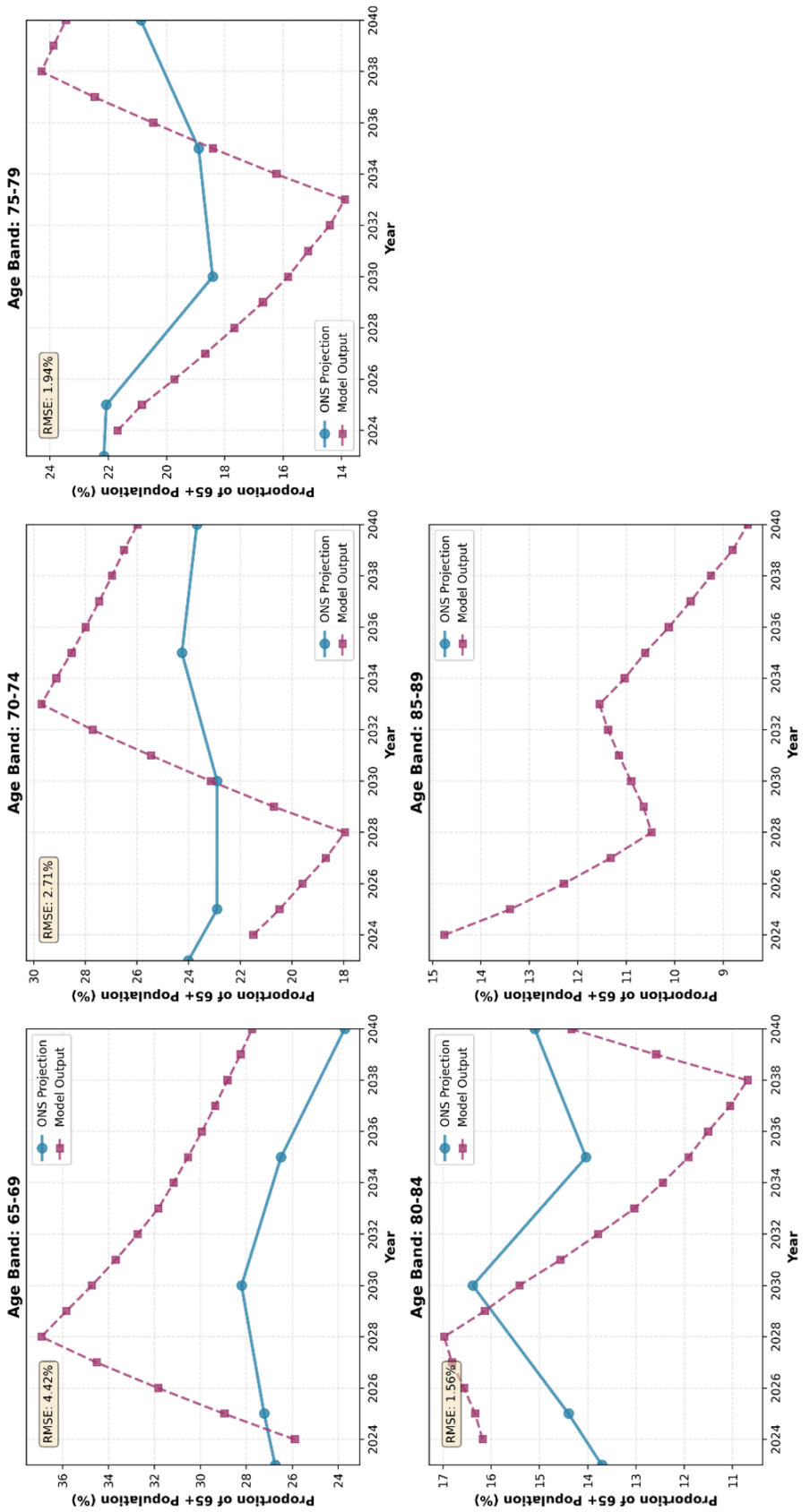

Figure 6.B External validation for population age structure. Note: RMSE = root mean squared error was calculated as the difference between our predicted model results and ONS predicted values

7 Probabilistic Sensitivity Analysis

Table 7.A provides all the values, distributions and relative standard deviations of all the variables that are tested under probabilistic sensitivity analysis.

Table 7.A Model Dementia Onset and Disease Prevalence Probabilistic Sensitivity. * = Approximate values calculated from mean and 10% relative SD.

Parameter	Base Value	Distribution	Relative SD	Alpha*	Beta*
Base onset probability	0.05	Beta	10%	N/A	N/A
Risk Factor Prevalence					
Periodontal disease	0.75/0.50/0.25			74.75/49.5/24.25	24.25/49.5/8.0833
Hearing difficulty	36%	Beta	10%	63.640	113.138
Hypertension	45.2			54.348	65.891
Obesity	24.3%			75.457	235.066
Depression	6.8%			93.132	1276.456
Type 2 Diabetes	4.5%			95.455	2025.767
APOE ε4 carrier	25.6%			74.144	215.481

Table 7.B Probabilistic Sensitivity Analysis Values For Risk Factor Hazard Ratios

Risk Factor	Base Value	Lower 95% CI	Upper 95% CI	Distribution
Periodontal disease	1.21	1.07	1.38	
Hearing difficulty	1.21	1.15	1.27	
Hypertension	1.36	1.28	1.45	Lognormal
Obesity	1.1	1.03	1.18	
Depression	1.93	1.74	2.13	
Type 2 Diabetes	2.06	1.92	2.22	

Risk Factor	Base Value	Lower 95% CI	Upper 95% CI	Distribution
APOE ε4 carrier	3.02	2.88	3.19	

Table 7.C Probabilistic Sensitivity Analysis Values For Costs

Stage	Setting	Provider/Payer	Base Value	Distribution	Relative SD	Shape	Scale
Cog. normal	Home	Professional	0				
		Informal	0				0
	Institution	Professional	0				
		Informal	0				
Mild	Home	Professional	7,466.70				74.67
		Informal	10,189.55				101.90
	Institution	Professional	23,144.27				231.44
		Informal	874.93	Gamma	10%	100	8.75
Moderate	Home	Professional	7,180.18				71.80
		Informal	33,726.09				337.26
	Institution	Professional	15,552.58				155.53
		Informal	1,643.14				16.43
Severe	Home	Professional	7,668.60				76.69
		Informal	31,523.39				315.23
	Institution	Professional	53,084.13				530.84
		Informal	501.88				5.02

Table 7.D Probabilistic Sensitivity Analysis Values For Utility Weights

Parameter Category	Stage/Age	Setting/Sex	Base Value	Distribution	Relative SD
Patient utility multipliers	Cog. normal	Home	1.0		
		Institution	N/A		
	Mild	Home	0.85		
		Institution	0.80		
	Moderate	Home	0.70		
		Institution	0.65		

Beta 10%

Parameter Category	Stage/Age	Setting/Sex	Base Value	Distribution	Relative SD
Caregiver utility mult.	Severe	Home	0.50		
		Institution	0.45		
	Cog. normal	N/A	N/A		
	Mild		0.86		
	Moderate	Home	0.85		
	Severe		0.82		
	Mild		0.71		
	Moderate		0.64		
	Severe		0.38		
Dementia stage QALYs	Female Age 65	N/A	0.78		
	Female Age 75+		0.71		
	Male Age 65		0.78		
	Male Age 75+		0.75		

8 Probabilistic Sensitivity Analysis Results

Table 8.A Full results of PSA runs

Scenario	Mean	Lower 95% CI	Upper 95% CI	CV (%)
Total Costs				
50% Prevalence	£586,245,547,083	£487,424,144,246	£683,456,725,900	8.58
Growth Scenario	£586,816,135,677	£486,128,245,547	£681,588,948,867	8.52
Formal Costs				
50% Prevalence	£331,722,151,094	£270,277,372,016	£398,030,654,871	9.95
Growth Scenario	£331,994,910,678	£268,442,641,460	£399,036,048,851	9.95

Scenario	Mean	Lower 95% CI	Upper 95% CI	CV (%)
Informal Costs				
50% Prevalence	£254,523,395,989	£208,525,623,807	£298,149,312,849	9.20
Growth Scenario	£254,821,224,999	£207,371,136,723	£299,042,362,133	9.09
Cohort Population QALYs				
50% Prevalence	163,430,925	145,448,065	177,658,398	5.67
Growth Scenario	163,426,540	145,457,465	177,659,381	4.93
Caregiver QALYs				
50% Prevalence	9,526,497	7,716,956	11,359,514	10.15
Growth Scenario	9,539,665	7,725,917	11,458,260	10.01
Incident Dementia Cases				
50% Prevalence	2,364,002	1,911,623	2,801,095	9.33
Growth Scenario	2,369,028	1,914,453	2,803,283	9.51

9 One-way sensitivity analysis results

Table 9.A Full one-way sensitivity results

	50% Prevalence			**Growth Scenario**	
	High onset HR	Low onset HR	Baseline	High onset HR	Low onset HR
Total formal cost	£325.1bn	£296.8bn	£330.5bn	£325.5bn	£297.2bn
Total informal costs	£252.3bn	£230.2bn	£253.8bn	£252.7bn	£230.5bn
Total costs	£577.4bn	£527.1bn	£584.2bn	£578.2bn	£527.7bn

Total cohort QALYs	159,836,295	160,326,705	160,295,583	159,822,849	160,282,214
Total caregiver QALYs	9,483,038	8,490,437	8,600,057	9,498,173	8,607,060
Total QALYs	169,319,334	168,817,142	168,895,641	169,321,022	168,889,274
Cumulative incident onsets	2,490,613	2,183,398	2,218,198	2,499,733	2,219,885

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Appendix

Table 1 Background mortality probabilities by age and sex

Age	Male	Female
65	0.012624353	0.008298336
66	0.013983312	0.009275888
67	0.015533015	0.010128117
68	0.017026125	0.011140829
69	0.018353398	0.012055375
70	0.020152709	0.013366941
71	0.022175059	0.014398158
72	0.024319332	0.015880429
73	0.026198195	0.017527717
74	0.028447830	0.019302093
75	0.031740440	0.021814209
76	0.035692465	0.024221998
77	0.039667453	0.027727889
78	0.044963894	0.031303894
79	0.049874302	0.035050142
80	0.057289128	0.040569943
81	0.064013859	0.045992631
82	0.072640588	0.052261131
83	0.079863890	0.058631734
84	0.089929084	0.066224208
85	0.100945830	0.075113709
86	0.113810561	0.086476611
87	0.128789510	0.097566523
88	0.146388550	0.112847361
89	0.164157919	0.127565226
90	0.187110606	0.146074877
91	0.207099203	0.166562387
92	0.235637527	0.190102953
93	0.260684476	0.213685916
94	0.291674030	0.237158808
95	0.323528963	0.265026004
96	0.353340509	0.291911002
97	0.397973242	0.327432419

Age	Male	Female
98	0.414895939	0.364047771
99	0.475423088	0.393586440
100	0.514090949	0.438461552