The Impact on NHS Costs of Delaying the Onset of Multi-morbidity in Old Age (INCDOM)

Stuart Redding | Robert Anderson | Raphael Wittenberg
Catia Nicodemo

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Stuart Redding, Robert Anderson, Raphael Wittenberg and Catia Nicodemo

Centre for Health Service Economics and Organisation (CHSEO), Nuffield Department of Primary Care Health Sciences, University of Oxford

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Corresponding author:

Stuart Redding

Project Lead, Centre for Health Service Economics and Organisation (CHSEO), Nuffield Department of Primary Care Health Sciences, University of Oxford

stuart.redding@phc.ox.ac.uk

Plain English summary

As people get older, they tend to develop a greater number of health problems. Treating these problems, also known as morbidities, costs the National Health Service (NHS) a lot of money. Older people would have better health for longer and the NHS could save money if scientists were able to find ways of slowing down the speed at which older people develop health problems.

In this project we have analysed what might happen to NHS spending if scientists were able to find ways to prevent people aged 50+ in England and Wales from suffering more health problems and to reduce their risk of dying from them.

We do this by using data to analyse what would happen if we were able to improve patients' outcomes in certain ways. We do not interact with any patients but conduct calculations on existing data to see what would happen to NHS costs if we change the rate at which older people develop more health problems.

We spoke to experts to decide the groups of health problems we should study and the likely benefits that new treatments might offer in the future.

We studied three groups of health problems:

1) A set of 37 health conditions that other researchers have used in the past and cover a wide range of problems that people often suffer from when they get older.
2) A set of five health conditions that are very common amongst older people.
3) Cancer, which is a common disease, costs a lot of money to treat and sadly kills a lot of people.

We focus on two issues:

1) We look at the chance of a patient developing a new health problem. If new treatments can lower this chance, then the NHS won't have to spend as much money treating that patient.
2) We also look at the chance of a patient dying. If a patient stays alive for longer but isn't in good health, then they are going to cost the NHS more money.

In all three cases, these two issues count against each other. In group 1, we estimate that the total cost of NHS care for patients aged 50+ in England and Wales would actually go up by a total of £486m over five years if we were able to reduce both the chance of a patient picking up a new health problem and the chance of dying by 10%. The equivalent figure if we can reduce these probabilities by 20% is £754m.

In groups 2 and 3, we find that total costs to the NHS will go down if we lower both the chance of getting a new health problem and the chance of dying. In group 2 we predict the savings would be £2,389m or £4,350m depending on whether we can reduce these probabilities by 10% or 20%. We estimate that reducing the probability of getting cancer or dying from it by 10% or 20% would lead to savings of £127m or £502m.

We realise that there are some issues with the work we have done. The most obvious is that, whilst keeping people alive might cost the NHS money, extending someone's life has great value to

themselves, their families and society in general. This should, and would, be taken into account if new treatments were developed.

A second issue is that we have not taken account of the cost of the new treatments that may be developed: we clearly do not know what these costs would be.

These issues don't change our main conclusion though. We believe that there is the potential to reduce costs in the NHS by introducing new products that lower the chance of older people developing and dying from health problems.

1. Introduction

This report presents indicative estimates of the cost implications to the NHS if the onset of multiple morbidities in old age could be delayed by the development of new hypothetical treatments. The study was commissioned by UK SPINE from the Centre for Health Service Economics and Organisation (CHSEO), Nuffield Department of Primary Care Health Sciences, University of Oxford.

The study relates to people in later life (aged 50 and over) living in England in 2007/8 to 2017/8. It considers 37 chronic health conditions defined in a study by the University of Cambridge[1], and multimorbidity is defined as having two or more of these health conditions. It builds on analysis conducted by CHSEO for an earlier study – the MuSeCoL study – that explores the profile of multimorbidities amongst older people and the costs associated[2].

The study uses "real-world" data from the Clinical Practice Research Datalink (CPRD), linked to Hospital episode Statistics (HES) data and NHS cost data to:

- understand the potential savings in primary and secondary health care costs from preventing/slowing the onset of multimorbidity in older adults; and
- model a set of scenarios based on hypothetical new medicines (or existing medicines hypothetically repurposed) to understand the potential savings in healthcare costs they could generate.

The scenarios for the potential impact of hypothetical new or repurposed medicines were defined in consultation with an expert in ageing; a practising clinician and expert in Stroke, and scientists exploring relevant drugs in laboratory settings who provided guidance on the scope and scale of scientific developments to arrest the development of multimorbidity amongst older populations. We study three scenarios looking at different sets of morbidities, for all patients aged 50+ in England and Wales.

The scenarios we analyse are as follows:

Scenario 1: *"How will NHS costs be affected if interventions can be created that lead to a 10% or 20% reduction in the probability of each individual aged 50 or above gaining an extra morbidity per year and a 10% or 20% reduction in the annual likelihood of death?"*

Scenario 2: *"How will NHS costs be affected if interventions can be created that lead to a 10% or 20% reduction in the probability of each individual aged 50 or above with a condition in a certain "cluster" gaining an extra morbidity per year in that "cluster" of morbidities, and a 10% or 20% % reduction in the annual likelihood of death as a result of morbidity in that "cluster", allowing other morbidities to develop as "normal"."*

[1] https://www.phpc.cam.ac.uk/pcu/research/research-groups/crmh/cprd_cam/codelists/v11/

[2] https://www.cprd.com/protocol/understanding-relationship-between-multimorbidity-later-life-use-health-services-and-costs

The morbidities we include in our cluster are Hypertension, Painful condition, Hearing Loss, Diabetes and Chronic kidney disease.

Scenario 3: *"How will NHS costs be affected if interventions can be created that lead to a 10% or 20% reduction in the probability of each individual aged 50 or above experiencing a cancer diagnosis and a 10% or 20%% reduction in the annual likelihood of death associated with cancer, allowing other morbidities to develop as normal".*

A substantial number of studies have looked at the utilisation and associated costs of treating people who suffer from multimorbidity. Lehnert et al. (2011) found in a systematic review of 35 studies that costs and utilisation (including physician visits, hospitalisations, and medication use) tend to increase with the number of conditions, although they did not find any studies at the time using English data. However, research on the costs of care associated with multimorbidity has grown in recent years and a recent systematic review Soley-Bori et al. (2021) found seven studies of healthcare costs and ten of healthcare utilisation from the UK. These studies find that multimorbidity contributes to higher healthcare utilisation. For example, Casell et al. (2018) show that patients with two or more morbidities have more than double the use of primary care relative to patients with no or one morbidity.

In studies of total cost, resource use was usually calculated by multiplying the quantity of services used by a standard unit cost for various healthcare settings. Multimorbidity is associated with higher total costs, hospital costs and out-of-hospital care costs. Charlton et al. (2013) and Hazra, Rudisill and Gulliford (2018) found that patients with 1–3 health conditions have between 1.55 and 2.85 times the mean expected total health care cost of individuals without any morbidity.

We expand on these studies by looking at the transition between different numbers of morbidity and the cost implications from new treatments that might delay the accumulation of morbidities and death.

NICE produce resource impact reports, for example on Hypertension in adults (NICE 2019) in which they model cost implications of new policy or interventions. Our work is complementary to this work, except we look at hypothetical interventions rather than those that are being implemented.

The rest of this report is structured as follows. Section 2 describes the data; Section 3 explains the methods and Section 4 presents results from the analysis of our three scenarios. Section 5 discusses and concludes.

2. Data

Patients' data

We use data on all patients aged 50 and over in the Clinical Practice Research Datalink (CPRD) Aurum database in 2017. CPRD Aurum is a large database of anonymised patient-level primary care electronic health records and included data for more than 2.5 million patients in 2017. Data are available for 800

practices, covering 7% of the UK population. It has been shown to be broadly representative of the general population with regard to age, sex and ethnic origin.[3] We exclude so-called unacceptable data (i.e., data not meeting quality criteria set by CPRD). We link the CPRD data to other datasets routinely available with the CPRD: Index of Multiple Deprivation (IMD) data, Hospital Episode Statistics (HES) data on A&E attendances, outpatient attendances, day cases and inpatient admissions, and Office for National Statistics (ONS) death registration data.

Patients are identified as having a relevant health condition in a given year if they have a current diagnosis in that year of one or more of the 37 chronic conditions defined in the University of Cambridge study (Cassell et al. 2018).

Cost data

We have linked the patient data described above with costs for their visits to **primary care**, costs for **secondary care,** and **prescription** costs.

The cost of **primary care** consultations is recovered from Unit Costs of Health and Social Care 2019 (PSSRU)[4] and consists of:

1) GP consultations undertaken face-to-face, or by phone/video
2) Practice nurse consultations undertaken face-to-face or by phone/video
3) Consultations with other professionals in primary care settings
4) Administrative activities in primary care

Costs for the use of **secondary care** are covered using the HRG 2017/2018 Reference cost grouper (NHS Digital)[5]. We have calculated the cost for:

1) Outpatient visits[6]
2) A&E attendances
3) Elective procedures
4) Emergency admissions

Unit costs of drugs were calculated from the drug tariff and applied to calculate individual prescription costs[7]. **Prescription cost per patient per year** was calculated.

We have aggregated this data by patient, calculated the annual cost for each patient and then averaged across patients within groups defined by the number of health conditions. All costs are reported at 2017 prices.

[3] For more information on CPRD data see https://www.cprd.com/

[4] https://www.pssru.ac.uk/project-pages/unit-costs/unit-costs-2019/

[5] https://digital.nhs.uk/services/national-casemix-office/downloads-groupers-and-tools/costing-hrg4-2017-18-reference-costs-grouper

[6] The 2017 national tariff cost was used for outpatient visits to which we were unable to allocate costs using the reference costs grouper.

[7] Prescriptions associated with erroneous quantities or where cost information was absent from the data were dropped (~5%). Missing prescription costs were imputed with the corresponding median cost.

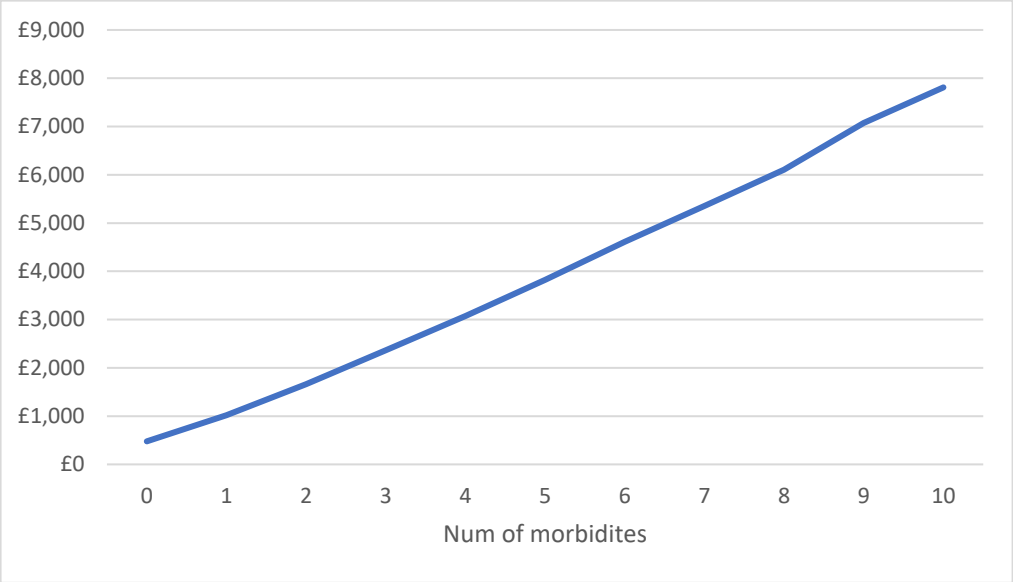
Descriptive statistics

The CPRD Aurum data we use includes on average more than 2,600,000 individuals aged 50 and over each year. The average number of health conditions among those who have multimorbidity is 3.81.

There were an estimated 22,336,852 people aged 50+ resident in England and Wales according to the ONS mid-2019 population estimates and so we scale up our dataset to match this number.[8]

Figure 1 reports the distribution of annual average NHS costs per patient in 2017 by the number of morbidities up to a maximum of ten.[9] As expected, number of morbidities and annual costs are positive correlated, and the relationship between them is almost perfectly linear, with each additional morbidity costing approximately £743 per year in additional NHS costs. It is also notable that, despite including 37 of the most common morbidities, our data suggests that on average it costs £477 per annum for the NHS to care for patients aged 50+ without a diagnosis of any of the 37 chronic conditions in our analysis.

Figure 1: NHS average annual cost per patient by number of health conditions (2017 prices)



3. Methods

In order to model Scenarios 1 and 2, we begin by calculating costs for a "base case", using unadjusted transition rates between health states and mortality rates from our analyses of CPRD data. We then compare the estimated costs of care using these rates with costs estimated in a similar way but using

[8] This is based on the assumption that NHS costs and the transition rates are similar for English patients included in our sample and Welsh patients about whom we do not have data.

[9] We include all 37 morbidities but we limit our analysis to a maximum of 10 morbidities per patient. The small number of patients with more than 10 are omitted from our analyses because their costs may be unrepresentative of patients with more than 10 conditions in view of the small numbers in the CPRD.

a transition probability matrix modified according to our Scenarios. The process we follow to calculate these costs is as follows:

Base case

1. Estimate the numbers aged 50+ in each health state (from 0 morbidities to 10 morbidities) in the base year (year t).
2. Estimate the total annual NHS cost for this cohort in year t using the cost by health state estimates.
3. Estimate the surviving numbers aged 51+ in each health state in year t+1 using the matrix of transition probabilities (including mortality), which is presented in Table A1 (in the Appendix) for all morbidities and in Table A2 for the cluster of morbidities used in Scenario 2.
4. Estimate the total annual NHS cost for this cohort in year t+1 using the cost by health state estimates.
5. Repeat steps 3 and 4 for this cohort for years t+2, t+3, t+4 and t+5.

Scenarios

1. Adjust the transition probability matrix to take account of the scenario, e.g. reduce all transitions to more severe states (including mortality) by 10%, leave transitions to less severe states unchanged and increase the proportion remaining in the same state so that the transitions sum to 1.0 for each base year health condition.
2. Conduct steps 3 to 5 as above using the adjusted transition matrix.
3. Compare estimated total NHS cost under the scenario with total NHS cost under the base case, for each year.

There are several caveats to consider when performing this analysis.

1. The CPRD may not be perfectly representatives of the whole population of England.
2. The analysis does not include the costs of the new or repurposed drugs.
3. The analysis does not include all NHS services: exclusions include dental services, social care and community health services.
4. While the cohort is aged annually for 5 years in terms of health state transitions, it is not refreshed with people turning 50 and it does not take account of transitions to worse states (including mortality) rising as the cohort ages.
5. No account is taken on inflation or discounting of costs in future years.

A different approach is used to model Scenario 3. The annual effects on the NHS can be simulated by following the experience of a cohort of 50-year olds year by year over their lifetime.

The building blocks are as follows:

- Age specific mortality rates of people with and without cancer
- Age specific annual costs with and without cancer
- Age specific prevalence of cancer ("ever had cancer")
- Age specific incidence of cancer

These variables are incorporated into a simple Markov model, by way of a transition matrix (Table 1) which can be used to infer the lifetime cost to the NHS per person and life expectancy, both from age 50. Each year of life is represented by a cycle of the model and the age-specific costs are attached to

each cycle and accumulated over the predicted lifetime. It is then straightforward to estimate the impact of the scenario by changing the cancer incidence and mortality.

Table 1: Annual transition rates to cancer and death

		to		
		no cancer	cancer	death
from	no cancer	$1 - p_c - d_n$	p_c	d_n
	cancer	n/a[10]	$1 - d_c$	d_c

- p_c – age specific incidence of cancer
- d_n – age specific death rate without cancer
- d_c – age specific death rate with cancer

A 10% reduction in incidence of cancer can be found by factoring p_c by 90%.

Mortality rates for those without cancer are equal to population mortality rates less population cancer mortality rates. To uncover the mortality rates for those with cancer we need to know the prevalence of cancer. The rates for those with cancer are then $[d_{pop} - (1 - p)d_{cancer}]/p$, where

- d_{pop} – age specific all cause death rate
- d_{cancer} – age specific death rate with cancer
- p – age specific prevalence of cancer

Population age specific all cause and cancer mortality rates are taken from National Life Tables United Kingdom 2017-2019.[11] Combined figures for males and females were derived using age specific population weights.[12] The age specific incidence of cancer is provided by Cancer Research UK[13] and prevalence by the Long Term Conditions Compendium of Information.[14]

The availability of data dictates a different approach to estimating the age specific NHS cost with and without cancer. The starting point is a catalogue of age specific annual NHS cost undifferentiated by cause (Asaria 2017) updated from 2011/12 to 2018 using the CCEMG - EPPI-Centre Cost Converter.[15]

An estimate of the annual disease-attributable cost of all-site cancer treatment is available for an EU country with health services broadly similar to the NHS (Altini et al. 2020). It was converted from euros

[10] "Cancer" relates to "ever had cancer" and therefore in this context it is impossible to transition from "cancer" to "no cancer"

[11] National life tables: UK - Office for National Statistics
https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/datasets/nationallifetablesunitedkingdomreferencetables

[12] Population estimates for the UK, England and Wales, Scotland and Northern Ireland - Office for National Statistics
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2015

[13] Cancer incidence by age | Cancer Research UK
https://www.cancerresearchuk.org/health-professional/cancer-statistics/incidence/age

[14] Long Term Conditions Compendium of Information: Third Edition
https://www.gov.uk/government/publications/long-term-conditions-compendium-of-information-third-edition

[15] CCEMG - EPPI-Centre Cost Converter v.1.4 http://eppi.ioe.ac.uk/costconversion/default.aspx

to £ at 2018 prices using the CCEMG - EPPI-Centre Cost Converter. There are no estimates for the cost of cancer by age.

The estimate in question is £7431 at 2018 prices. To estimate the annual cost of those without cancer, the all cause annual cost per person is diminished by age specific cancer prevalence times the disease-attributable annual cost of cancer. The annual NHS cost per person with cancer is then this figure plus the disease attributable cost of cancer, assuming that cancer patients have the same prevalence of other conditions as those without cancer.

The model is run without reductions in cancer incidence and mortality before we run models with 10% and 20% reductions in cancer incidence and mortality.

4. Analysis

This research was intended to model the benefits of hypothetical treatments in terms of delaying the onset of morbidities, and the risk of death, that expert opinion based on scientific evidence suggests might be realistically achievable in the near future.

As such, we held meetings with experts (via video conference technology such as Zoom and Microsoft Teams) and email exchanges where we sought advice on the scope and scale of scientific discoveries that might be replicable in the population of older people with multimorbidities.

Our consultations consisted of meetings with an expert in ageing; a practising clinician and expert in Stroke, and scientists exploring relevant drugs in laboratory settings. They provided direct advice and references that we used to define the three scenarios we explore.

4.1 Scenario 1

"How will NHS costs be affected if interventions can be created that lead to a 10% or 20% reduction in the probability of each individual aged 50 or above gaining an extra morbidity per year and a 10% or 20% reduction in the annual likelihood of death?"

There is literature suggesting amongst humans (Willcox et al. 2006) and among rhesus monkeys (Colman et al. 2009) that calorific constrained diets can increase life expectancy and delay the onset of morbidity across the full spectrum of morbidities.

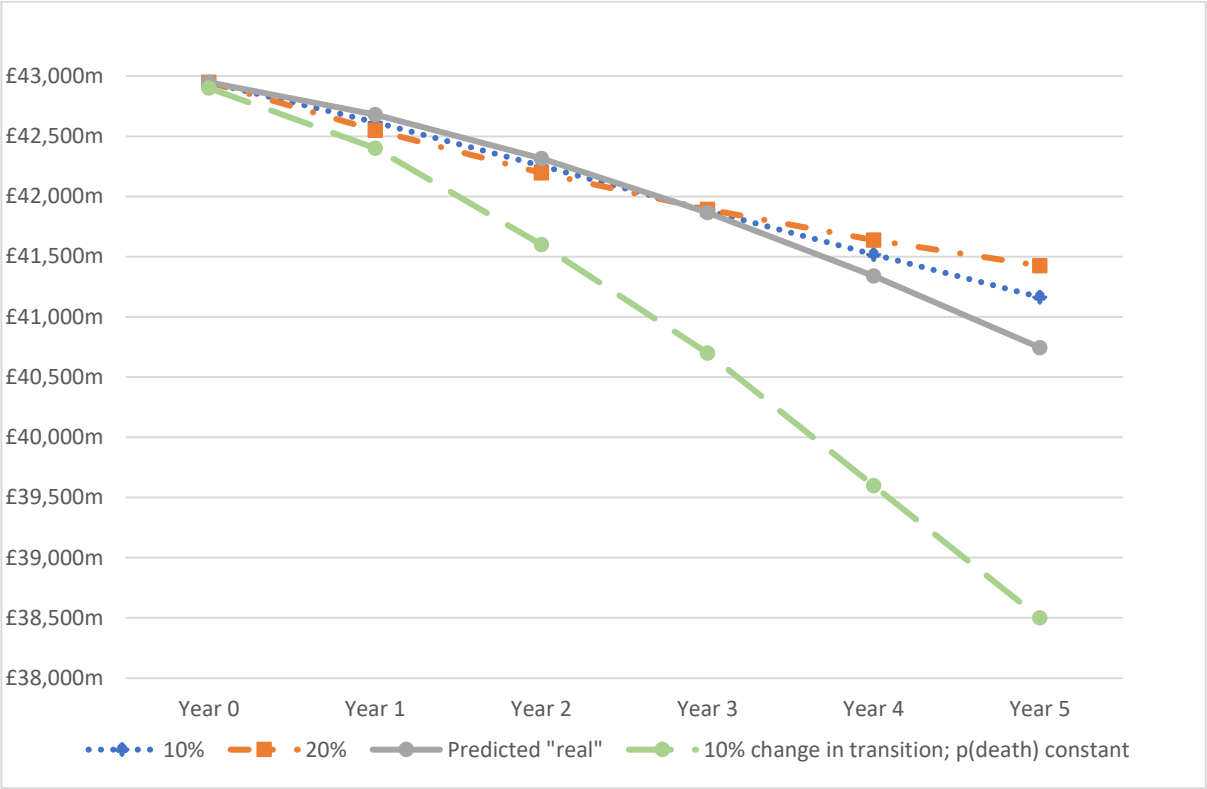
Metformin could have similar effects to calorific controlled diets (Kulkarni, Gubbi, and Barzilai 2020). Further, evidence has found that delaying the process of cellular senescence, or the clearance of senescent cells, will likely reduce age-related inflammation and frailty (Xu et al. 2015; Bussian et al. 2018; Baker et al. 2011; Mannick et al. 2018).

Table 2: Costs for the Base case and Scenario 1

	Cost						
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Total

Base Case	£42,948m	£42,680m	£42,316m	£41,865m	£41,339m	£40,745m	
10% reduction in p(transition)	£42,948m	£42,615m	£42,253m	£41,883m	£41,517m	£41,163m	
Difference	£0	-£65m	-£62m	£17m	£178m	£418m	£486m
Per person change	£0	-£3	-£3	£1	£8	£19	£22
20% reduction in p(transition)	£42,948m	£42,550m	£42,196m	£41,892m	£41,636m	£41,425m	
Difference	£0	-£130m	-£120m	£26m	£297m	£680m	£754m
Per person change	£0	-£6	-£5	£1	£13	£30	£34
10% reduction in p(transition) (holding mortality rates constant)	£42,948m	£42,395m	£41,624m	£40,689m	£39,634m	£38,496m	
Difference	£0	-£285m	-£691m	-£1,176m	-£1,705m	-£2,248m	-£6,106m
Per person change	£0	-£13	-£31	-£53	-£76	-£101	-£273

Figure 2: Scenario 1 costs over 5 years



We estimate that the costs of primary and secondary health care incurred by the NHS for people aged 50+ is almost £43 billion (£42,948m). It would cost £42,680m to treat that same cohort in the subsequent year, when they will be aged 51+, subject to the caveats above. There is an increase in the numbers with 5 or more morbidities but its effect on costs is outweighed by the effect of mortality, such that overall NHS costs are estimated to fall.

Delaying the onset of additional morbidities and reducing the likelihood of death by 10% would reduce aggregate spending in year 1 by approximately £65m to £42,615m. This equates to a £2.90 per person

saving. Delaying the onset of additional morbidities and reducing the likelihood of death by 20% would reduce aggregate spending in year 1 by approximately £130m to £42,550m. This equates to a £5.80 per person saving.

These changes are not large in relative terms, but we make two observations. Reducing the mortality rate means that there are significantly more people requiring NHS care, especially if we consider the whole five-year period, as can be seen in Table A3 (in the Appendix). Secondly, the proportion of patients who gain a new morbidity in any given year is small (3,499,558; 16%) and so reducing this probability by 10% or 20% has fairly low effects on the number of people who do not transition to a worse health state.

Over time, due to a lower mortality rate, the estimated costs of treating this cohort of patients are higher under the scenario than under the base case (see Figure 2), so that NHS costs would go up as a consequence of this hypothetical treatment. If we reduce the probability of gaining an extra morbidity by 10% but leave the mortality rate unchanged, then cost savings to the NHS from this cohort would total £6.1 billion at constant prices over five years (£273 per person in our cohort in year 0).

4.2 Scenario 2

"How will NHS costs be affected if interventions can be created that lead to a 10% or 20% reduction in the probability of each individual aged 50 or above with a condition in a certain "cluster" gaining an extra morbidity per year in that "cluster" of morbidities, and a 10% or 20% % reduction in the annual likelihood of death as a result of morbidity in that "cluster", allowing other morbidities to develop as "normal"."

There is significant evidence that multi-morbidities tend to develop in "clusters". E.G, Prados-Torres et al. (2014) in a systematic review found 3 main clusters, the first consisting of cardiovascular (CV) disorders; the second consisting of a mix of CV, musculoskeletal, respiratory, and neurodegenerative diseases; and the third dominated by mental health disorders.

We base our analysis on the work of Zhu et al. (2020). Using CPRD data and a similar set of morbidities, they find a cluster which contains some 40% of patients aged 65-84 and in which the most common five conditions are Hypertension, Painful condition, Hearing Loss, Diabetes, and Chronic kidney disease.

Table A2 provides the transition matrix amongst these morbidities and Table A4 shows the estimated populations in each health state across 5 years. Table A5 provides the cost per condition that we allocate to patients in this scenario. These are calculated from the costs used in scenario 1, but we subtract the costs for 0 health conditions from the costs for each of the other health states. We do this so that we are only considering the costs of treating (up to) the five morbidities considered in this scenario and do not account for costs associated with treating other conditions. This will therefore only account for a proportion of total costs of NHS care for those aged 50 and over, but it is consistent with our scenario where we state that we "allow other morbidities to develop as normal" because it allows us to focus on changes associated with the effect of the scenario's assumed reduction in

transition rates from the five conditions. An intrinsic implication from this approach is that we assume that these five conditions are no more or less costly on average than any other morbidities.

We estimate in Table 3 that it costs £14,833m a year for the NHS to treat these conditions amongst the English and Welsh population aged 50+. It would cost £15,492m to treat that population in the subsequent year. There is growth in the subset of the population with 2 or more morbidities, and this more than offsets the reduction in costs arising from mortality.

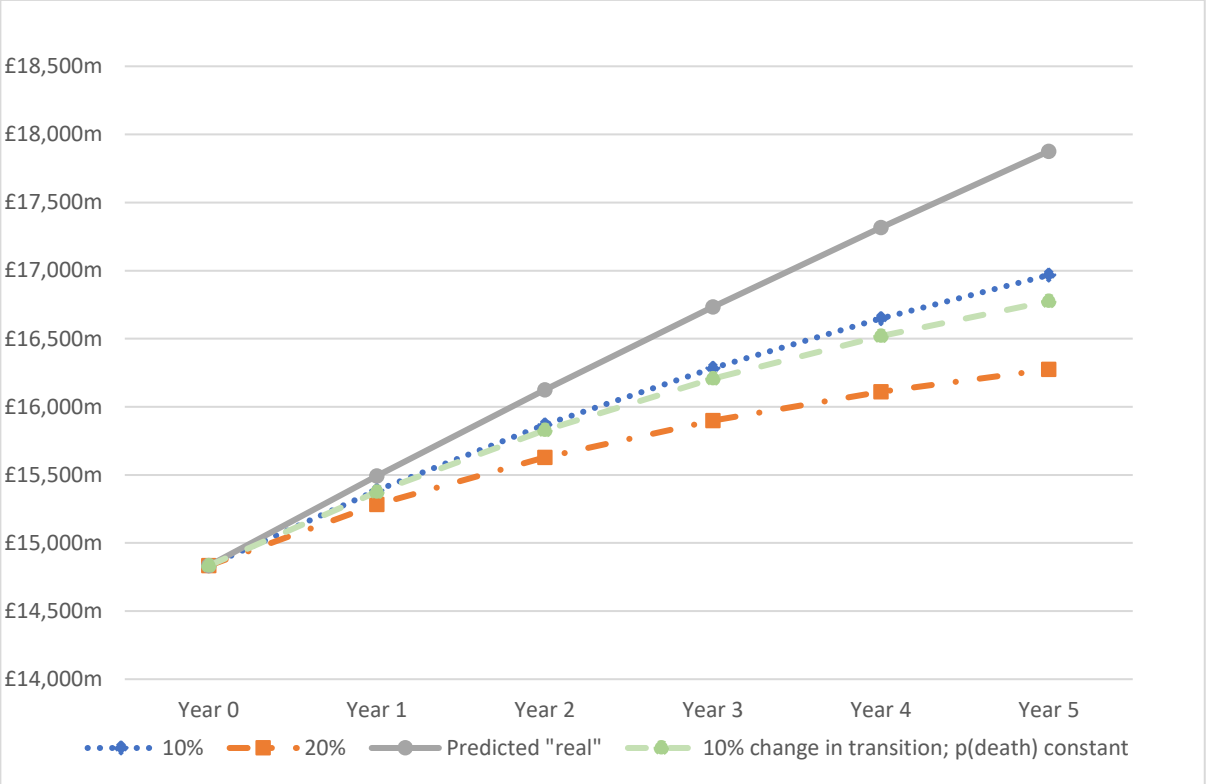
Delaying the onset of additional morbidities and reducing the likelihood of death by 10% would reduce aggregate spending on these conditions in year 1 by approximately £105m to £15,387m, a per-person saving of approximately £4.68. Delaying the onset of additional morbidities and reducing the likelihood of death by 20% would reduce aggregate spending by approximately £209m to £15,283m, or by £9.37 per person.

Table 3: Costs for the Base case and Scenario 2

	Cost						
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Base Case	£14,833m	£15,492m	£16,125m	£16,734m	£17,317m	£17,876m	
10% reduction in p(transition)	£14,833m	£15,387m	£15,867m	£16,285m	£16,649m	£16,967m	
Savings	£0	-£105m	-£258m	-£449m	-£668m	-£909m	-£2,389m
Per person savings	£0	-£5	-£12	-£20	-£30	-£41	-£107
20% reduction in p(transition)	£14,833m	£15,283m	£15,629m	£15,899m	£16,109m	£16,274m	
Savings	£0	-£209m	-£496m	-£835m	-£1,208m	-£1,602m	-£4,350m
Per person savings	£0	-£9	-£22	-£37	-£54	-£72	-£195
10% reduction in p(transition) (holding mortality rates constant)	£14,833m	£15,374m	£15,828m	£16,207m	£16,520m	£16,775m	
Savings	£0	-£118m	-£297m	-£527m	-£798m	-£1,101m	-£2,840m
Per person savings	£0	-5.27	-13.30	-23.59	-35.71	-49.29	-127.15

In scenario 2 we see constant growth in savings over time (Figure 3), so that by the end of year 5 the NHS would have saved approximately £106.93 per person if the probability of an additional morbidity (among the five conditions considered) or death was reduced by 10% and £194.74 if that probability was reduced by 20%. Mortality due to these five conditions is relatively low and, as such, unlike in Scenario 1, holding mortality rates constant while reducing the probabilities of transition does not have much impact on the profile of cost savings.

Figure 3: Scenario 2 costs over 5 years



4.3 Scenario 3

"How will NHS costs be affected if interventions can be created that lead to a 10% or 20% reduction in the probability of each individual aged 50 or above experiencing a cancer diagnosis and a 10% or 20%% reduction in the annual likelihood of death associated with cancer, allowing other morbidities to develop as normal".

There is literature showing that certain drugs can lead to reduced incidence of certain cancers and mortality associated with them. For example, in a sample of post-menopausal women treated with an oral bisphosphonate (Pazianas et al. 2012), the reduction in risk comprised both a lower incidence of colon cancer-adjusted HR 0.69 (95% CI 0.60-0.79) and a lower mortality once colon cancer had been diagnosed, adjusted HR 0.82 (95% CI 0.70).

Table 4: Change in life expectancy and lifetime NHS expenditure per person from age 50 per person: by various reductions in cancer incidence and cancer mortality rate

	Reduction in age specific cancer incidence	Reduction in age specific mortality rate from cancer	Both together
	10%	10%	
Life years	0.05	0.25	0.28
Expenditure	- £3,040	+ £3,158	- £134
	20%	20%	
Life years	+ 0.1	+ 0.54	+ 0.55
Expenditure	- £6,192	+ £6,767	- £531

TableTable 4 provides estimates of the cost implications of reducing incidence of cancers and death due to cancer. The reduction in incidence alone does not lead to savings: the increases in expenditure entailed by the increase in longevity outweigh the cancer related savings.

The effect on annual NHS expenditure in steady state can be inferred by multiplying the lifetime expenditure changes by the population of 50-year olds, about one million for the UK. For example, the incidence effect alone is a saving of about £1.5 billion a year in steady state.

Table 5 provides annual cost consequences for the NHS. As with the other scenarios, reducing the incidence of cancer leads to cost savings for the NHS, but reducing mortality means that more patients need treatment and for longer. These two effects offset each other to a large degree, but our evidence suggests there are cost savings of £127m for a 10% reduction in cancer onset and incidence, or £502m for a 20% reduction.

Table 5: Change in annual NHS expenditure for 10% and 20% reductions in cancer incidence, cancer mortality and both together[16]

	10%	20%
Incidence	-£2,876m	-£5,858m
Mortality	£2,988m	£6,402m
Both together	-£127m	-£502m

5. Conclusion

In this project we have explored the potential cost consequences of treatments that might be designed and implemented in the NHS to delay the onset and consequences of multimorbidities. We find that a treatment that delays transitions to higher numbers of morbidities and mortality and includes all morbidities could actually increase NHS expenditure due to the impact of reduced mortality rates. There would however be gains in life years and quality-adjusted life years. If the probabilities of transition were reduced but mortality rates remained unchanged, there could be cost savings to the NHS.

A treatment aimed at reducing the onset of a subset of morbidities could be more likely to yield savings to the NHS, as we demonstrate in Scenario 2 where our analysis generates savings to the NHS as well as increasing life years.

Scenario 3 shows that a cancer treatment could incur additional costs for the NHS if it extends time spent in treatment rather than time spent in good health.

There are three caveats to these results. Firstly, we have not considered the QALY (quality-adjusted life-year) gains that the patients whose lives were extended would accrue and which are a key component of any cost-effectiveness assessment undertaken when deciding whether the NHS should offer a treatment. Our modelling suggests that approximately 1.4 million extra people would survive to the end of the five years studied instead of dying during that period if we can reduce annual

[16] The values in this table do not sum up because the estimation includes the expansion of a Taylor's series and we do not present the individual interaction terms in this table.

morbidity rates by 20%. The NICE guidelines value a full QALY at £20,000, so the benefits associated with this reduced mortality are very sizable.

Secondly, we have considered all people aged 50+ when performing this calculation. It is highly likely that the majority of the benefits would accrue to a subset of this population. Whether that is a certain age group or those with a particular combination of morbidities, more effective identification of these patients would enable better targeting of treatment and would almost certainly increase the savings per person to the NHS.

A third caveat is that we are studying just one cohort of patients in Scenarios 1 and 2, namely those who are 50+ in 2019. These results do not consider anyone who will turn 50 in the future and then become relevant to this study. They also do not allow for transition rates to more severe health states and mortality rates to rise as the cohort ages. This could have cost consequences that deserve further study.

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Appendix

Table A1: Scenario 1 Transition probability matrix

Number of morbidities	Death	0	1	2	3	4	5	6	7	8	9	10	Total
0	22,936	4,687,664	417,713	66,273	11,782	2,198	391	75	13	3	0	0	5,209,048
	0.44	89.99	8.02	1.27	0.23	0.04	0.01	0	0	0	0	0	100
1	36,312	184,884	3,350,648	496,704	84,336	14,112	2,532	391	73	7	2	1	4,170,002
	0.87	4.43	80.35	11.91	2.02	0.34	0.06	0.01	0	0	0	0	100
2	54,746	11,329	228,397	2,434,218	462,035	82,328	13,686	2,299	377	43	4	0	3,289,462
	1.66	0.34	6.94	74	14.05	2.5	0.42	0.07	0.01	0	0	0	100
3	72,836	453	15,228	204,590	1,835,422	391,984	70,959	11,924	1,926	300	43	2	2,605,667
	2.8	0.02	0.58	7.85	70.44	15.04	2.72	0.46	0.07	0.01	0	0	100
4	84,996	18	669	13,518	160,562	1,314,818	302,776	55,864	9,424	1,487	199	24	1,944,355
	4.37	0	0.03	0.7	8.26	67.62	15.57	2.87	0.48	0.08	0.01	0	100
5	84,342	1	32	677	10,755	116,362	865,928	211,341	40,031	6,895	1,027	144	1,337,535
	6.31	0	0	0.05	0.8	8.7	64.74	15.8	2.99	0.52	0.08	0.01	100
6	72,779	0	2	26	523	7,754	77,720	526,318	135,007	26,291	4,183	649	851,252
	8.55	0	0	0	0.06	0.91	9.13	61.83	15.86	3.09	0.49	0.08	100
7	55,513	0	0	3	26	407	5,176	48,568	297,587	79,435	15,220	2,432	504,367
	11.01	0	0	0	0.01	0.08	1.03	9.63	59	15.75	3.02	0.48	100
8	37,369	0	0	0	0	26	259	3,200	28,451	157,466	42,843	8,209	277,823
	13.45	0	0	0	0	0.01	0.09	1.15	10.24	56.68	15.42	2.95	100
9	22,374	0	0	0	0	1	11	162	1,856	15,178	76,017	20,970	136,569
	16.38	0	0	0	0	0	0.01	0.12	1.36	11.11	55.66	15.35	100
10	12,056	0	0	0	0	0	0	8	78	962	7,502	34,597	55,203
	21.84	0	0	0	0	0	0	0.01	0.14	1.74	13.59	62.67	100
Total	556,259	4,884,349	4,012,689	3,216,009	2,565,441	1,929,990	1,339,438	860,150	514,823	288,067	147,040	67,028	20,381,283

Footnote: The rows represent the number of patients with each number of morbidities in year 0 in the CPRD data we use for this analysis. The columns represent the number of patients with each number of morbidities in year 1. The intersections represent the transition of people between numbers of morbidities. Eg, row "0", column "1" = 417,713 means that 417,713 people had 0 morbidities in year 0 and then 1 morbidity in year 1. The numbers below these cells represent the proportion of people with the number of morbidities in t=0 who are in that health state in year t=1.

Table A2: Scenario 2 Transition probability matrix

Number of morbidities	Death	0	1	2	3	4	5	Total
0	15,940	7,606,548	578,344	38,681	2,247	79	1	8,241,840
	0.19	92.29	7.02	0.47	0.03	0.00	0.00	100
1	24,293	238,656	4,764,661	499,017	28,499	903	16	5,556,045
	0.44	4.30	85.76	8.98	0.51	0.02	0.00	100
2	28,407	0	193,121	3,193,148	319,054	12,388	155	3,746,273
	0.76	0.00	5.16	85.24	8.52	0.33	0.00	100
3	22,541	0	0	105,227	1,843,414	128,870	2,221	2,102,273
	1.07	0.00	0.00	5.01	87.69	6.13	0.11	100
4	9,799	0	0	0	33,653	643,554	20,571	707,577
	1.38	0.00	0.00	0.00	4.76	90.95	2.91	100
5	1,416	0	0	0	0	4,263	87,947	93,626
	1.51	0.00	0.00	0.00	0.00	4.55	93.93	100
Total	102,401	7,845,302	5,536,225	3,836,174	2,226,970	790,160	111,009	20,381,283

Footnote: The rows represent the number of patients with each number of morbidities in year 0 in the CPRD data we use for this analysis. The columns represent the number of patients with each number of morbidities in year 1. The intersections represent the transition of people between numbers of morbidities. Eg, row "0", column "1" = 578,344 means that 578,344 people had 0 morbidities in year 0 and then 1 morbidity in year 1. The numbers below these cells represent the proportion of people with the number of morbidities in t=0 who are in that health state in year t=1.

Table A3: Scenario 1 estimated population by number of morbidities

Number of morbidities	Raw data				10% reduction in transition			20% reduction in transition		
	Year 0	Year 1	Year 3	Year 5	Year 1	Year 3	Year 5	Year 1	Year 3	Year 5
Dead	0	609,606	1,833,157	3,050,643	548,646	1,486,059	2,240,540	487,685	1,186,526	1,630,407
0	5,708,852	5,352,680	4,720,720	4,178,867	5,409,826	4,946,165	4,608,920	5,466,972	5,144,642	4,952,729
1	4,570,111	4,397,786	4,053,252	3,718,589	4,421,512	4,167,978	3,966,394	4,445,239	4,266,071	4,152,772
2	3,605,083	3,524,745	3,342,927	3,144,222	3,530,516	3,391,727	3,272,620	3,536,287	3,432,146	3,363,423
3	2,855,679	2,812,142	2,712,852	2,597,653	2,811,201	2,729,624	2,658,183	2,810,260	2,743,347	2,699,329
4	2,130,914	2,115,074	2,071,890	2,014,184	2,111,150	2,071,264	2,033,647	2,107,227	2,070,448	2,045,377
5	1,465,870	1,468,076	1,461,153	1,441,053	1,462,972	1,451,480	1,436,920	1,457,868	1,442,991	1,431,681
6	932,929	942,629	953,562	954,272	937,929	941,404	939,998	933,228	930,888	927,864
7	552,761	563,752	580,615	590,524	560,041	569,428	574,153	556,330	559,810	560,993
8	304,480	315,791	334,328	347,603	312,930	324,865	332,263	310,068	316,694	320,062
9	149,673	161,146	180,367	194,567	158,935	172,341	180,878	156,724	165,362	169,907
10	60,500	73,424	92,029	104,676	71,195	84,517	92,337	68,966	77,927	82,309
Total	22,336,852	22,336,851	22,336,852	22,336,853	22,336,853	22,336,852	22,336,853	22,336,854	22,336,852	22,336,853

Footnote: this table presents the number of people from our initial cohort that we estimate would have each number of morbidities or be dead in years t=0, 1, 3 and 5 under the assumptions that i) transition probabilities are as identified in our data; ii) transition probabilities are reduced by 10% from those identified in our data; iii) transition probabilities are reduced by 20% from those identified in our data.

Error! Reference source not found.**: Scenario 2 estimated population by number of morbidities**

Number of morbidities	Raw data				10% reduction in transition			20% reduction in transition		
	Year 0	Year 1	Year 3	Year 5	Year 1	Year 3	Year 5	Year 1	Year 3	Year 5
Dead	0	111,857	343,854	586,060	100,671	277,896	425,836	89,485	221,253	307,282
0	9,003,328	8,570,046	7,797,413	7,129,266	8,639,445	8,074,487	7,662,481	8,708,844	8,317,180	8,084,262
1	6,069,385	6,047,625	5,942,209	5,782,007	6,044,827	5,966,914	5,880,130	6,042,029	5,983,839	5,937,819
2	4,092,402	4,190,499	4,351,374	4,464,953	4,171,088	4,284,443	4,356,633	4,151,677	4,225,264	4,265,101
3	2,296,508	2,432,614	2,691,280	2,928,792	2,411,185	2,597,941	2,739,718	2,389,755	2,517,858	2,595,849
4	772,952	863,053	1,046,997	1,233,541	850,832	985,287	1,094,593	838,612	933,076	993,262
5	102,276	121,158	163,724	212,233	118,805	149,884	177,461	116,451	138,380	153,275
Total	22,336,851	22,336,852	22,336,851	22,336,852	22,336,853	22,336,852	22,336,852	22,336,853	22,336,850	22,336,850

Footnote: this table presents the number of people from our initial cohort that we estimate would have each number of morbidities or be dead in years t=0, 1, 3 and 5 under the assumptions that i) transition probabilities are as identified in our data; ii) transition probabilities are reduced by 10% from those identified in our data; iii) transition probabilities are reduced by 20% from those identified in our data.

Error! Reference source not found.**: Scenario 2 cost per morbidity**

Number of morbidities	Average cost per morbidity
Dead	£0
0	£0
1	£543
2	£1,186
3	£1,886
4	£2,598
5	£3,347

Footnote: this represents the marginal cost of treating a patient with the appropriate number of five morbidities, namely Hypertension, Painful condition, Hearing Loss, Diabetes, and Chronic kidney disease, ignoring any other morbidities that they suffer from.