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A simulation study of the economic and health impact of a diabetes prevention programme in Ireland

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Abstract

Aims: Type 2 diabetes is a major public health issue that has a large effect on society including its health and social services. The aims of this paper are to generate a projection of the number of cases and explore the potential impact of a preventive intervention targeted at people with pre-diabetes on disease prevalence, complications, mortality and cost.

Methods: A Markov simulation model of diabetes and pre-diabetes in Ireland, for the period 1991 to 2036, was generated based on international epidemiological data. The simulation was calibrated with the available Irish data on the prevalence of pre-diabetes, diabetes and diabetic complications. The economic and health impact of a hypothetical nationwide preventive intervention programme, which reduces the incidence by a factor consistent with the international literature, was estimated under three scenarios of alternative effectiveness and uptake.

Results: The estimated number of people over 40 years of age with type 2 diabetes in Ireland is projected to increase from 216,000 in 2020 to 414,000 in 2036. A prevention programme, based on the NHS Diabetes Prevention Programme, is estimated to result in a reduction of between 2000 (0.5%) and 19,000 (4.6%) in the number of prevalent cases of diabetes in 2036 resulting in substantial health and quality of life benefits.

Conclusions: A wide range of initiatives with uncertain outcomes will be required to reduce the impact of obesity and type 2 diabetes. A diabetes prevention programme seems likely to be worth pursuing as one element of this set of initiatives.

KEYWORDS
diabetes, economics, epidemiology, pre-diabetes, simulation

1 | INTRODUCTION

Type 2 diabetes and its related complications are major contributors to disability, health care utilisation, expense and mortality.[1] The increasing prevalence of type 2 diabetes is primarily related to increasing levels of obesity, reduced physical activity and ageing.[2] No country to date has reversed its obesity epidemic,[3] and Ireland is no exception with the percentage of adults who are obese increasing from 10% in 1998 to 23% in 2018.[4,5] There are limited current or historic data available on the epidemiology of diabetes in Ireland.[6-8] Ireland does not have a national diabetes register, the epidemiological data available being based on a number of representative surveys undertaken at various time points. The information available indicates that the age-adjusted prevalence of diabetes increased substantially from 1998 to 2015.[6]

The health care cost of type 2 diabetes is primarily driven by the development of the so-called complications of the disease.[1] Reducing the incidence of diabetes complications, a state where quality of life is significantly impacted, can be achieved by one or more of three broad approaches.

The first approach is to reduce the incidence of complications in people with diabetes through screening for the condition and earlier detection of complications, for example, through the National Diabetic Retinal Screening programme.[9] This, combined with target-driven management of glucose, blood pressure and lipid levels, can reduce the incidence and impact of diabetic complications. Recent changes in the reimbursement of general practitioners (GPs) in Ireland for chronic disease management[10] and structured care for diabetes[11] aim to reduce the incidence and progression of diabetic complications through better management of the disease.

The second approach is to reduce the incidence of type 2 diabetes through targeted interventions aimed at people who have pre-diabetes. This is a cohort with a higher risk of developing type 2 diabetes for whom preventive efforts may be particularly valuable. This approach is currently being delivered in England with the NHS Diabetes Prevention Programme.[12] Ireland does not currently have a national diabetes prevention programme targeted at people with pre-diabetes. Plans are in place to pilot a diabetes prevention programme in 2021; this will be linked to the new GP contract for chronic disease management that calls for screening for type 2 diabetes among individuals known to be at increased risk. A range of trials have demonstrated the effectiveness of diabetes prevention programmes; a recent review of prevention programmes found an average reduction of 26% to 29% in the incidence of type 2 diabetes.[13] However, there is still considerable uncertainty and scepticism on the effectiveness of widespread implementation of such programmes.[14] Much of the available evidence is based on idealised conditions using self-selecting individuals over short periods.[15] Attendance rates are a key determinant of the impact that such programmes can have on reducing the national burden of diabetes. Attendance rates have been shown to be low in the United Kingdom and the United States where these programmes have been rolled out to the general population.[16,17]

The third approach to reducing the burden of diabetes on society is to reduce the incidence of type 2 diabetes through population-wide policies. These include taxes, subsidies, regulations (e.g., food marketing), changes to the physical environment and population-wide health promotion policies.[18] Recent examples of this approach in Ireland include the 'The Healthy Ireland' programme and the tax on sugar-sweetened beverages introduced in 2018. However, there is limited guidance from the literature on the potential impact population-wide policies might have on reducing the incidence of diabetes.[19]

Previous modelling exercises in Europe and the United States have shown the potential impact of alternative scenarios and policies on the projected prevalence and impact of diabetes.[19-22] Jones et al. [20] show that more intensive management of diabetes and pre-diabetes can *slow the growth* in mortality due to diabetes. However, a substantial reduction in the prevalence of obesity in the population is required to *reduce* diabetes-related mortality. Gregg et al. [19] show a similar impact for targeted and population-wide approaches individually and that a combined strategy of population and targeted interventions is likely to have the largest effect on reducing the prevalence of diabetes.

In this study, we show the potential impact of a diabetes prevention programme, similar to the programme implemented in the United Kingdom, on the number of cases of diabetes (complicated and uncomplicated) and on the associated quality adjusted life years (QALYs) for the whole population. We also estimate the budgetary implications for the health service of introducing a diabetes prevention programme. The potential impact of a diabetes prevention programme is demonstrated by simulating a wide range of possible trajectories for the numbers of people with diabetes and pre-diabetes based on the international literature. Projections are generated based on a range of possible future trends *and* alternative scenarios for the effectiveness and uptake of a diabetes prevention programme.

What's new?

- There are limited current or historic data available on the epidemiology of type 2 diabetes in Ireland.
- Randomised controlled trials of targeted diabetes prevention programmes have been shown to be effective. There is limited evidence available on the effectiveness of population-wide diabetes prevention programmes.
- This study uses simulation methods to generate projections of the number of cases of diabetes and pre-diabetes in Ireland.
- The study shows that the impact of a diabetes prevention programme will be strongly influenced by attendance rates.
- A diabetes prevention programme (on its own) will not stop the rise in the number of cases of diabetes—a broad suite of population-wide policies aimed at reducing obesity is likely to be required in addition to a diabetes prevention programme.

2 | METHODS

2.1 | Model overview

A time-discrete Markov model is used to simulate the number of people in each of five states—normoglycaemic, pre-diabetes, uncomplicated diabetes, complicated diabetes and death—between 1991 and 2036. A macro-simulation approach was chosen for its transparency compared with a complex micro-simulation approach. In line with the NHS Diabetes Prevention Programme, the definition of pre-diabetes used in this study is having a glycated haemoglobin (HbA_{1c}) of 42–46 mmol/mol (6.0%–6.4%). Figure 1 shows the five states of the model and the flows between these states.

The aim of the simulation is to firstly generate a projection of the potential future trajectory of the number of cases in Ireland. Alternative scenarios are then generated to estimate the potential impact of a diabetes prevention programme over the projection period.

Single-year age cohorts between 40 and 98 years of age are modelled for each state; a minimum age of 40 years was used, as this is when the incidence of type 2 diabetes typically begins to increase.[23] The flows between states are determined by the number of people in each state and the transition rates between states. Men and women are modelled separately—transition rates are allowed to vary across sexes.

Detailed input data definitions, sources and values for the initial cohort sizes and transition rates between cohorts are listed in Table S1 in the Supplementary file. The size of all the initial cohorts are sourced from the 1991 census. The size of the 40-year-old age cohorts in each year is sourced from historic population estimates and projections from the national statistics office. The prevalence rates for each of the states for the original cohorts in 1991 and the new cohorts entering the model are sourced from the literature.

Transition rates between states were identified from the international literature. There is limited available information in the literature for some of the transition rates, such as the incidence of pre-diabetes by age group, and the available

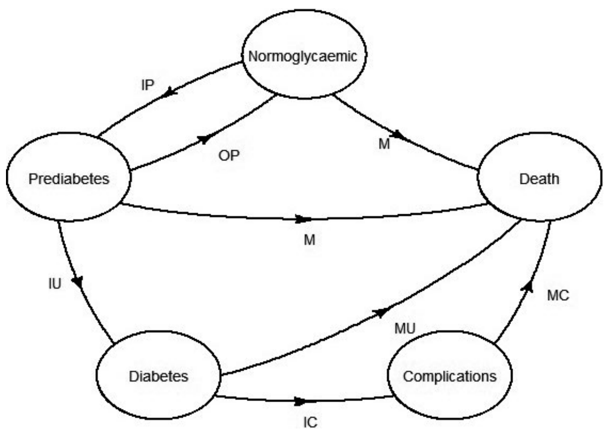

FIGURE 1 Model structure. IC, inflow to complications state; IP, inflows to pre-diabetes; IU, inflow to uncomplicated diabetes; M, base mortality; MC, complicated diabetes mortality; MU, uncomplicated diabetes mortality; OP, outflows from pre-diabetes state to normal glucose state.

rates do not always cover the time period (1991 to 2019). In addition, the transition rates from the literature are for countries that may have a different experience of diabetes. For these reasons, a range for each of the transition rate parameter values is specified based on the values identified in the literature. For a given replication, values for each parameter are selected at random from the specified range for each parameter; 2000 replications of the simulation are generated. Each replication yields a possible trajectory for the number of people in each state. Simulations were generated using R v3.6 and the *Heemod* package[24]; fanplots were created using the *fanplot* package.[25]

2.2 | Calibration

A two-stage calibration procedure is used to identify which of the simulation replications, and hence parameter value sets, are more credible. The first stage of the calibration procedure identifies which of the replications generate case numbers that are inconsistent with what we already know about the prevalence of diabetes and pre-diabetes in Ireland. A replication is deemed to be inconsistent with the observed prevalence data if the estimated number of cases of pre-diabetes or diabetes is outside a specified range or the proportion of people with diabetes with a complication is outside a specified range, as described below. This process allows a subset of replications, with corresponding parameter values, to be identified that are consistent with what we know about the epidemiology of diabetes in Ireland. The specified range for the number of cases of pre-diabetes was sourced from a nationally representative survey carried out in 2007.[7] The specified range for the number of cases of diabetes, and the proportion of these with a complication related to diabetes, was sourced from a nationally representative survey of people over 50 years of age (TILDA) carried out in 2010/2011.[26] The 95% confidence intervals of prevalence estimates from these studies were used to calculate a range of estimates of diabetes and pre-diabetes for the study year.

The second stage of the calibration procedure is applied to the subset of replications identified as being consistent with the calibration points in the first stage. This stage compares the age distribution of the modelled cohorts with the observed age distribution for each of the five census years.[1] Each replication is weighted based on the inverse of the difference between the number of people in each modelled age cohort and number of people in that cohort in the census. This ensures that aggregate mortality in the model is in line with observed mortality rates. The calibration procedure is outlined in more detail in the Supplementary File.

[1] 1996, 2001, 2006, 2011 and 2016.

2.3 | Projection period

Projections under four scenarios are generated. The first scenario assumed that no diabetes prevention programme was implemented. Four alternative scenarios show the potential impact of a diabetes prevention programme introduced in 2022. The scenarios assume different levels of effectiveness of the intervention, different durations of effectiveness and different attendance rates. The intervention effect is modelled as a percentage reduction in the transition rate from pre-diabetes to diabetes, applied equally to all age cohorts:

$$\boldsymbol{iu_{it}}\ \mathbf{Scenarios\ 2-4} = \boldsymbol{iu_{it}}\ \mathbf{Scenario\ 1} * \mathbf{1 - Intervention\ effectiveness} * \mathbf{Duration\ of\ effect} * \mathbf{Attendance\ rate}\ ) \tag{1}$$

where iu_{it} is the transition rate from pre-diabetes to diabetes for each cohort i for time t. The scenarios are shown in Table 1 and outlined in detail in the Supplementary File. For example, Scenario 2 is based on a reduction in the transition rate from pre-diabetes to diabetes of 26%; an intervention whose effects last for 4 years; and an attendance rate of 4.0% of people with pre-diabetes per year, in line with anticipated NHS Diabetes Prevention Programme attendance. The final column in Table 1 shows the reduction in the aggregate transition rates for each scenario. The aggregate transition rate from pre-diabetes to diabetes is reduced by between 1.0% and 12.5% under the various scenarios.

Data sources for the cost of excess health care utilisation and programme costs are outlined in Table S1 in the Supplementary File. The cost of excess health care utilisation would be altered by changes in screening and treatment regimens employed. Productivity losses associated with premature death/retirement, absenteeism due to sick leave and presenteeism due, for example to retinopathy, are omitted from calculations. The intervention and health care costs are assumed to increase at a rate of 4.2% in line with the current rate of medical inflation.

In all scenarios, underlying trends in the incidence of pre-diabetes and mortality are selected at random from a range. The maximum trend in these variables is set at the top of the search range used in the calibration procedure outlined above. The minimum trend is set to zero; that is, the age-adjusted incidence of pre-diabetes remains stable, and there are no further improvements in mortality rates. The transition rate from pre-diabetes to diabetes, the incidence of complications and relative mortality rates are all assumed to remain stable. The assumptions applied for each time period are outlined in detail in Table S1.

3 | RESULTS

Figure 2a,b shows the distribution of the estimated number of people with pre-diabetes and diabetes from 1991 to 2036 obtained from the simulation models under Scenario 1 (no diabetes prevention programme). The weighted average number of people with diabetes is shown in blue. These figures show the dramatic rise in the number of people with diabetes in Ireland driven by a combination of a growing and ageing population and increases in the incidence of pre-diabetes. We estimate that the number of people with diabetes (pre-diabetes) will increase from 216,000 (192,000) in 2020 to 414,000 (303,000) in 2036 in the absence of a prevention programme. This corresponds to a prevalence of diabetes (pre-diabetes) of 9.2% (8.2%) in the population over 40 years of age in 2020 and 13.9% (10.2%) in 2036.

Table 2 compares Scenario 1 (no diabetes prevention programme) with the other scenarios where the programme is implemented. If the prevention programme is implemented, the number of people with diabetes in 2036 would be projected to be reduced by between 2000 (0.5%) and 19,000 (4.6%) depending on the scenario considered. There would also be an increase in the number of people with pre-diabetes due to the associated reduction in the transition rate in people from pre-diabetes to diabetes. The total number of attendees for the period (2022–2036) ranges from 155,000 to 479,000, with the cost of the programme ranging from €67 m to €209 m. The programme is likely to be cost reducing under two of the three scenarios with the intervention cost being offset by lower health care utilisation (GP, A&E, outpatient and inpatient) costs. Under Scenario 3, where the effectiveness of the programme is lower and the effects do not last beyond 2 years, the programme is cost increasing. For the people with pre-diabetes who attend the programme from 2022 to 2036, between 3000 and 32,000 QALYs are projected to be gained, primarily through reductions in the

TABLE 1 Scenario components and aggregate reduction in the transition rate to diabetes

	Reduction in incidence (%)	Duration of effectiveness (years)	Attendance rates (%)	Reduction in the transition rate from pre-diabetes to diabetes (%)
Scenario 1: No diabetes prevention programme				
Scenario 2: Baseline programme	26	4	4.0	4.2
Scenario 3: Low effectiveness	13	2	4.0	1.0
Scenario 4: High attendance	26	4	12.0	12.5

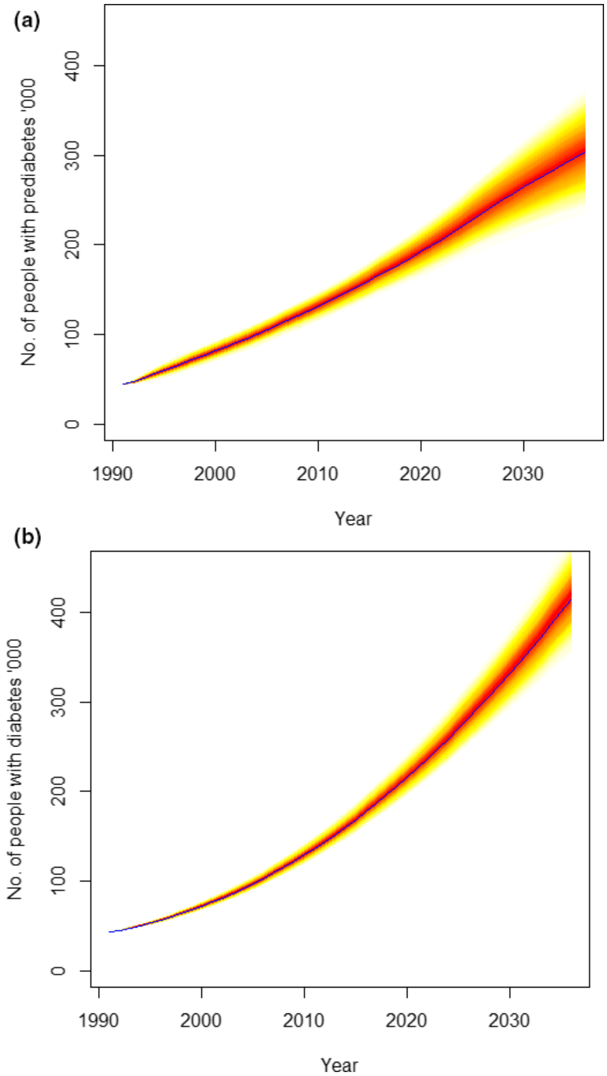

FIGURE 2 Fanplot of Scenario 1 projection; number of people with pre-diabetes (a) and diabetes (b) 1991: 2036; weighted average of all simulations shown in blue. Percentiles of the distribution shown in yellow/red.

incidence of diabetes complications, with limited impact on the number of deaths.

4 | DISCUSSION

Ireland does not have a national diabetes register, which would allow for the tracking of the number of cases of diabetes over time. In this study, we simulate the trajectory of the number of cases of diabetes and pre-diabetes in Ireland from 1991 to 2036 and calibrate the simulation using the available Irish prevalence data. Our simulation shows a dramatic rise in the number of cases over the period driven by a combination of an increasing population size, increases in the age-adjusted prevalence rates of diabetes and pre-diabetes, and an ageing population.

An important contribution of the paper is to highlight the potential impact of a diabetes prevention programme. Although there is significant uncertainty, the indications are that diabetes prevention programmes can be highly effective[27] and cost-effective.[28] This study shows the potential aggregate cost savings and QALY gains under various scenarios. Under the more optimistic scenario, there are small cost savings, relative to the overall cost of diabetes care, and material quality of life improvements; under the more pessimistic scenario, cost increases are small with fewer quality of life gains.

Key uncertainties in the potential impact of the programme relate to attendance and effectiveness. Only a small proportion of eligible cases of pre-diabetes typically attend diabetes prevention programmes.[16,17] Addressing the barriers to initial and ongoing attendance to such programmes may significantly boost the utilisation of the service.[13,29] Attendance may be particularly low among older cohorts, men and people with lower levels of education.[16,17] Low rates of referral or uptake in the latter group may exacerbate existing levels of health inequalities. Diabetes prevention programmes have been delivered through different organisation types (public, private and voluntary), by different individuals (peer volunteers and health professionals) and at different locations.[30] There is limited evidence relating to the benefits of different organisational types and locations.[31] Peer-based interventions may not provide additional benefit to the general population[32]; however, they may be useful when targeting minority groups.

Although low attendance would reduce the overall impact of the programme, this will not necessarily change the effectiveness or cost-effectiveness of the programme for the people that receive it. However, lower levels of effectiveness or a shorter duration of effectiveness will reduce the cost-effectiveness of the programme. A key challenge in the roll-out of the programme will be in achieving high attendance rates while maintaining programme effectiveness. Within the pre-diabetes cohort, different subgroups have different risks and different expectations regarding programme effectiveness. Monitoring of programme effectiveness, including the reporting of attendance rates within risk subgroups, would be useful to ensure that high overall attendance rates are not being achieved at the cost of low attendance in high-risk groups. In addition, if there are capacity constraints in the initial stages of the programme, it may be worth targeting the programme at the groups for whom the intervention is most effective—for example, high body mass index (BMI) groups,[13,28] with a focus on achieving high attendance rates in these cohorts.

Although the trajectory of the number of cases of diabetes will be specific to each country, the approach taken in this study could readily be applied to other regions. The finding that the impact of a diabetes prevention programme will be strongly influenced by attendance rates is generalisable. The

TABLE 2 Impact of a diabetes prevention programme

	Scenario 1: Reference	Scenario 2 Difference	Scenario 3 Difference	Scenario 4 Difference
Prevalence				
All 40- to 98-year-olds	2,983,807			
Pre-diabetes (2036)	302,967	+4396	+1088	+14,872
Uncomplicated diabetes (2036)	245,639	−5820	−1442	−14,072
Complicated diabetes (2036)	168,725	−2049	−509	−4907
Total diabetes (2036)	414,365	−7869	−1951	−18,979
Excess health care utilisation (2036)				
GP visits per year	957,544	−14,963	−3711	−36,045
A&E visits per year	51,478	−685	−170	−1647
Outpatient visits per year	510,950	−6800	−1688	−16,344
Inpatient episodes per year	82,363	−1122	−278	−2698
Attendance and outcomes (2022–2036)				
Total number of attendees (2022–2036)		155,330	154,074	478,512
Average annual attendances		10,355	10,271	31,900
Total intervention cost (2022–2036)		€67.7 m	€67.1 m	€208.8 m
Average annual intervention cost (nominal values)		€4.5 m	€4.5 m	€13.9 m
Total cost of excess health care and intervention (2022–2036) (nominal values)	€7881 m	−€13.5 m	+€46.8 m	−€39.4 m
QALYs gained (2022–2036)		10,471	2937	31,915
Deaths of people with diabetes (2022–2036)	87,456	−408	−100	−1247

Note: Change in the number of prevalent cases of pre-diabetes and diabetes (uncomplicated and complicated), change in aggregate QALYs and deaths in 2036.

Abbreviations: GP, general practitioner; QALYs, quality adjusted life years.

finding that a diabetes prevention programme will not stop the rise in the number of cases is also likely to be generalisable. As long as the stock of people in the pre-diabetes state continues to rise, due to population increases, population ageing or increases in age-adjusted prevalence of obesity, modest reductions in the overall transition rate from pre-diabetes to diabetes will not be sufficient to stop the growth in the number of people with diabetes. In addition, to maintain or improve upon the mortality rates of people with diabetes, the supply of health services will need to be increased to meet the projected rapid growth in demand.

In addition to targeted programmes, there is a strong rationale for population-wide policies given that a large majority of people become overweight and obese; in Ireland, 83% of men and 68% of women in the 55- to 65-year-old age group are overweight or obese.[33] There are a wide range of population-wide policies relating to diet and activity that can be employed.[34] These include policies relating to food advertising, taxes on unhealthy food and subsidies for healthy food. Policies to increase activity levels include urban transport policy, workplace activity policies and education policy in schools. As with targeted interventions, population-wide interventions requiring low levels of individual engagement, such as the regulation of food marketing, may have the broadest impact across socio-economic groups. However, there are very few studies that demonstrate the effectiveness of these programmes at a population level.[19]

Irrespective of the full roll-out of a diabetes prevention programme, the number of people with diabetes is likely to be increasing rapidly in Ireland. Type 2 diabetes and obesity are inextricably linked.[34] Previous research on obesity demonstrates the complex multifaceted system of determinants of this condition.[35] Reducing the prevalence of obesity and diabetes is likely to require a wide range of policies, which each impact in a small way; a diabetes prevention programme needs to be one component of a larger programme. A combined strategy of targeted and population-wide policies is likely to provide the largest reduction in the prevalence of diabetes[19] by affecting different cohorts and by reducing the agency required by people attending targeted interventions.

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CONFLICT OF INTEREST

None.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section.

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