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Epidemiological modelling and health economic evaluation of vaccination programmes against varicella and herpes zoster in Norway

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Epidemiological modelling and health economic evaluation of vaccination programmes against varicella and herpes zoster in Norway

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Preface

This report details infectious disease modelling and health economic evaluation of potential vaccination programmes against varicella and herpes zoster in Norway. The work described was carried out as part of a health technology assessment (*metodevurdering*) performed by the Norwegian Institute of Public Health.

Oslo, January 2026

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Executive summary

We utilise a mathematical infectious disease transmission model to simulate what would happen if a vaccination programme were introduced against either (1) varicella (chickenpox) or (2) herpes zoster (shingles) in Norway. The model is calibrated to the current situation without widespread vaccination, where varicella circulates and infects most children, and many of those infected develop shingles later in life. We use the model to simulate different vaccination scenarios and compare epidemiology, health loss, lost quality-adjusted life years (QALY), and costs in vaccination scenarios with the current situation. Based on this, we calculate whether the different vaccination programmes could be considered cost-effective.

Varicella

The model shows that the introduction of vaccination against varicella in the childhood vaccination programme (BVP) will lead to near eradication of varicella in Norway within a few years, provided the vaccination coverage achieves similarly high levels as the rest of the BVP.

In our main scenario, the vaccine is offered in two doses, first at 15 months of age and then at 7 years of age. When vaccination begins, community transmission will drop quickly, resulting in children older than 15 months at the implementation time possibly lacking immunity—they are neither infected nor vaccinated. Since varicella is more dangerous to contract as an adult, this may pose a health risk. The model also indicates that there will be a temporary resurgence with increased transmission five to ten years after programme initiation due to changed transmission dynamics in the population when the group lacking immunity ages. Therefore, we also simulate a catch-up programme that ensures immunisation of all age cohorts up to adolescence.

The catch-up programme can be structured in various ways. In our main scenario, all children aged 7 years or younger at the programme's start are offered two doses of the vaccine within four years. Additionally, all 15-year-olds without known previous varicella infection are offered two doses. The model finds this approach to be almost as effective as a (logistically unrealistic) scenario where all age cohorts from 2–15 years are offered two doses at programme start. On the other hand, a catch-up programme that only offers the vaccine to 15-year-olds is insufficient to avoid the temporary resurgence five to ten years later.

In our main scenario, we have a vaccination coverage of 96 percent, in line with the high coverage seen in other BVP components. In alternative scenarios, we examine the effects of lower coverage, from 80 percent and upward. Since varicella is a highly contagious disease, the model finds that coverage below 90 percent is insufficient to achieve herd immunity. Lower coverage will nevertheless reduce the overall incidence of the disease, but the unvaccinated may have an increased risk of contracting the disease later in life.

We present health economic analyses based on simulations from the healthcare, extended healthcare, and societal economic perspectives. The analyses indicate that a vaccination programme is cost-effective from a healthcare perspective and an extended healthcare perspective and leads to better health and lower costs from a societal perspective. In healthcare and extended healthcare perspectives, vaccination has a low cost per QALY, or incremental cost-effectiveness ratio (ICER), at NOK 131,946 and 43,904 respectively over a hundred-year period, assuming vaccines are purchased at list price. If vaccines are purchased at half of the list price, the ICER is reduced to NOK 34,253 from a healthcare perspective, and

vaccination becomes dominant in the extended healthcare perspective (i.e. leading to better health and lower costs). There is marginal economic difference between scenarios with and without the catch-up programme.

The virus causing varicella disease, the varicella zoster virus, can also lead to herpes zoster later in life. This occurs when the virus, latent in the body after previous varicella disease, is reactivated. The varicella vaccine significantly reduces the risk of herpes zoster compared to contracting the disease—in the model, we assume a 90 percent risk reduction. There are hypotheses that new exposure to varicella infection helps prevent flare-ups of herpes zoster, so-called exogenous boosting. Thus, one might think that when varicella transmission disappears due to vaccination, it leads to increased incidence of herpes zoster. Recent research from countries that have had varicella vaccination for up to 30 years suggests this does not happen to a significant extent. Our model takes this re-exposure mechanism into account to keep herpes zoster in check, albeit with limited effect in line with new studies.

Herpes Zoster

Herpes zoster (HZ) is not an infectious disease, hence there is a more direct linear relationship between the number of vaccinated individuals and the amount of health gained. Still, there are a few complicating factors, notably that the HZ risk is age-dependent and that the vaccine wanes over time. To facilitate such aspects, the analysis has been carried out using the same epidemiological model as for varicella.

The model is calibrated to age-specific general practitioner (GP–in Norwegian *fastlege*) and emergency department consultations and, as for varicella, assumes a demographically stable population. Over a 100-year horizon, HZ vaccination produces a clear and lasting reduction in HZ incidence compared with no vaccination: incidence declines over the first 10–25 years after introduction and then stabilizes at a lower equilibrium. In the base case scenario, we assume 95% vaccine effectiveness (VE), 2.5% waning per year, 75% coverage at age 65 and limited catch-up during the first 5 years. In this scenario, long-term incidence is about 2.75 with vaccination, compared to 3.75 cases per 1000 person-years without vaccination. This corresponds to roughly 27% fewer cumulative HZ cases.

Catch-up vaccination mainly accelerates short- and medium-term gains. Broad catch-up in older age groups produces a sharp initial drop in HZ incidence, whereas more restricted catch-up yields smaller short-term benefits. After around two decades, however, all catch-up strategies converge to similar long-term incidence, close to that achieved with routine vaccination alone at the same target age.

Long-term HZ incidence levels depend on vaccine effectiveness, waning, coverage, and age at first dose. Programmes starting at 70 years with catch-up at 75 years achieve smaller reductions than vaccinating at 65 years, because fewer individuals spend a substantial part of their remaining lifetime protected. The model suggests that, under 95% VE, 75% coverage, and 2.5% waning per year, lowering the first-dose age below 65 years only marginally impacts overall incidence, reflecting the low baseline HZ risk at younger ages combined with waning dynamics.

We also performed health economic analyses of herpes zoster vaccination from healthcare, extended healthcare and societal perspectives. In the main scenario (vaccination at 65 years with catch-up at 70 and 75 years, 75% coverage, 95% VE, 2.5% waning per year, 100-year horizon and list-price vaccine), vaccination leads to more QALYs and higher costs, with ICERs of

approximately NOK 474 000, 574 000 and 518 000 per QALY gained, respectively for the three perspectives. Using the extended healthcare perspective recommended by the Norwegian Medical Products Agency and an assumed threshold of NOK 275 000 per QALY, the programme is therefore unlikely to be considered cost-effective at current list price. From a societal perspective, more of the upfront vaccination costs are offset by reduced healthcare use and productivity losses, but since the relevant willingness-to-pay threshold is uncertain we cannot make a firm conclusion.

One-way sensitivity analyses show that the results are particularly sensitive to assumptions about vaccine price, discounting, herpes zoster incidence and the proportion of patients with severe pain. For example, a 50% reduction in vaccine price lowers the ICER to NOK 212 680, 313 416 and 256 559 per QALY respectively from the three perspectives, improving the cost-effectiveness profile, whereas assuming fewer patients with severe pain substantially increases the ICER. When we vary the age at vaccination in scenarios without catch-up, the lowest ICER is obtained for vaccination at 70 years, reflecting a balance between increasing disease risk and remaining life expectancy. In these analyses the extended healthcare perspective gives the highest ICERs, because it includes time costs of vaccination but not all productivity gains, while the societal perspective yields similar or lower ICERs, especially in the younger age groups where work absenteeism is relevant.

Samandrag (norsk)

Vi nyttar ein matematisk smittespreiingsmodell til å simulere kva som vil skje viss eit vaksinasjonsprogram vert innført mot anten (1) varicella (vasskoppar) eller (2) herpes zoster (helveteseld) i Noreg. Modellen er kalibrert til no-situasjonen utan utstrekt vaksinasjon, der varicella sirkulerer og smittar dei fleste born, og mange av dei smitta utviklar helveteseld seinare i livet. Vi bruker modellen til å simulere ulike scenario med vaksinasjon og samanliknar epidemiologi, helsetap, tapte kvalitetsjusterte leveår (QALY) og økonomiske kostnadar i vaksinasjonsscenario med no-situasjonen. Basert på dette bereknar vi om dei ulike vaksinasjonsprogramma er kostnadseffektive.

Varicella

Modellen syner at innføring av vaksinasjon mot varicella i barnevaksinasjonsprogrammet (BVP) i løpet av få år vil føre til tilnærma utrydding av varicella i Noreg, dersom vaksinasjonsdekninga oppnår tilsvarande høge nivå som resten av BVP.

I hovudscenarioet vårt vert vaksinen tilbydd i to dosar, først ved 15 månaders alder og så ved 7 års alder. Når ein byrjar å vaksinere vil smitten i samfunnet falle raskt, og det fører til at dei borna som er eldre enn 15 månader ved innføringstidspunktet kan bli ståande utan immunitet – dei blir korkje smitta eller vaksinert. Sidan varicella er farlegare å få som vaksen, er dette risikabelt. Modellen indikerer dessutan at ein kjem til å få eit mellombels tilbakefall med auka smitte fem til ti år etter programstart, på grunn av endra smittedynamikk i befolkninga når gruppa utan immunitet vert eldre. Vi simulerer difor også eit opphentingsprogram som sikrar immunisering av alle alderskohortar opp til ungdomsalder.

Opphentingsprogrammet kan strukturerast på ulike måtar. I vårt hovudscenario vert alle born som er 7 år eller yngre ved oppstart av programmet tilbydd to dosar vaksine innan det har gått fire år. I tillegg får alle 15-åringar utan kjend tidlegare varicellainfeksjon, tilbod om to dosar. Modellen finn at dette er så å seie like effektivt som eit (logistikkmessig urealistisk) scenario der alle alderskohortar frå 2-15 år får tilbod om to dosar ved programstart. På den anna side vil eit opphentingsprogram som berre tilbyr vaksine til 15-åringane, ikkje vere nok til å unngå det mellombelse tilbakefallet etter fem til ti år.

I vårt hovudscenario har vi ei vaksinasjonsdekning på 96 prosent, i tråd med den høge dekninga BVP elles har. I alternativscenario ser vi på effekten av lågare dekning, frå 80 prosent og oppover. Sidan varicella er ein særs smittsam sjukdom, finn modellen at ei dekning under 90 prosent ikkje er nok til å oppnå flokkimmunitet. Lågare dekning vil likevel redusere totalførekomsten av sjukdom, men dei uvaksinerte vil kunne få auka risiko for å få sjukdomen seinare i livet.

Vi viser helseøkonomiske analyser basert på simuleringane frå helseteneste-, utvida helseteneste- og samfunnsøkonomisk perspektiv. Analysane indikerer at eit vaksinasjonsprogram er kostnadseffektivt frå eit helsetenesteperspektiv og eit utvida helsetenesteperspektiv, og fører til lågare kostnadar og betre helse frå eit samfunnsperspektiv. I helseteneste- og utvida helsetenesteperspektiv har vaksinasjon ein låg kostnad per kvalitetsjustert leveår (QALY), også kalla *incremental cost-effectiveness ratio* (ICER), på høvesvis 131 946 og 43 904 kroner over ein hundreårsperiode, når vi antar at vaksinane vert kjøpt til listepris. Om vaksinane vert kjøpt til halvparten av listepris så blir ICER redusert til 34 253 kroner i helsetenesteperspektiv og vaksinasjon blir dominant (fører til lågare kostnadar og

betre helse) i utvida helsetenesteperspektiv. Det er marginal økonomisk forskjell på scenario med og utan opphentingsprogram.

Viruset som gir varicellasjukdom, varicella zoster-virus, kan òg føre til herpes zoster seinare i livet. Dette skjer ved at viruset som ligg latent i kroppen etter tidlegare varicellasjukdom, vert reaktivert. Varicellavaksine reduserer risikoen for herpes zoster betydeleg samanlikna med å få sjukdomen – i modellen antar vi 90 prosent risikoreduksjon. Det er hypotesar om at ny eksponering for smitte av varicella bidreg til å hindre oppblussing av herpes zoster, såkalla eksogen boosting. Ein kunne såleis tenkje seg at når varicellasmitte forsvinn på grunn av vaksine, så fører det til auka førekomst av herpes zoster. Nyare forsking frå land som har hatt varicellavaksinasjon i opp mot 30 år, tyder på at dette ikkje skjer i stor grad. Vår modell tek omsyn til denne reeksponeringsmekanismen for å halde herpes zoster i sjakk, men med begrensa effekt i tråd med dei nye studiane.

Herpes zoster

Herpes zoster er ikkje ein smittsam sjukdom, og difor er det ein meir direkte, lineær samanheng mellom talet på vaksinerte, effekten av vaksinen og oppnådd helsevinst. Det er likevel nokre kompliserande faktorar, særleg at risikoen for herpes zoster er aldersavhengig og at vaksinen mistar effekt over tid. Analysen er difor gjort med den same epidemiologiske modellen som for varicella-vaksinasjon.

Modellen er kalibrert til talet på konsultasjonar for herpes zoster hjå fastlege og legevakt, fordelt på alder. Som for varicella, antar modellen ein demografisk stabil folkesetnad. I eit hundreårsperspektiv leier herpes zoster-vaksinasjon til ein tydeleg og varig reduksjon i herpes zoster-insidens samanlikna med scenario utan vaksinasjon: insidensen fell i løpet av dei første 10-25 åra etter introduksjon og stabiliserer seg så på eit lågare nivå. I hovudscenarioet med 95 prosent vaksineeffektivitet (VE), 2.5 prosent minska effekt av vaksinen årleg (*waning*), 75% dekning av årskullet som fyller 65 kvart år saman med eit avgrensa opphentingsprogram dei første fem åra, er den langsiktige insidensen ca. 2.75 versus 3.75 tilfelle per 1000 person-år høvesvis med og utan vaksinasjon, svarande til ein reduksjon på ca. 27% i det kumulative talet på herpes zoster-tilfelle.

Opphentingsvaksinasjon fører først og fremst til ein raskare nedgang på kort og mellomlang sikt. Brei opphenting blant eldre aldersgrupper fører til ein rask nedgang i insidens i byrjinga, medan meir avgrensa opphenting gir mindre effekt. Etter rundt to tiår stabiliserer insidensen seg på same nivå uavhengig av opphentingsprogram.

På lang sikt avheng insidensnivået av VE, *waning*, dekningsgrad og alder ved første dose. Vaksinasjonsprogram som rettar seg til 70-åringane kvart år med opphenting ved 75 år, oppnår ikkje like stor insidensreduksjon som ved vaksinasjon av 65-åringar, fordi gjennomsnittsindividet då tilbringar færre år som vaksinert. Modellen syner, gitt 95 prosent VE, 75 prosent dekning og 2.5 % *waning* årleg, at effekten av å senke vaksinasjonsalderen under 65 år gir berre marginale utslag på total insidens, grunna den relativt sett låge risikoen for å utvikle zoster i yngre alder samt effekten av *waning*.

Vi har også gjennomført helseøkonomiske analyser av herpes zoster-vaksinasjon frå dei same tre perspektiva som for varicella: helseteneste-, utvida helseteneste- og samfunnsperspektiv. I hovudscenarioet (vaksinasjon ved 65 år, opphenting 70 og 75, 75 prosent dekning, 2.5 prosent årleg *waning*, listepris for vaksina og 100 år berekningshorisont), fører vaksinasjon til fleire QALY og høgre kostnadar, med ICER på høvesvis rundt 474 000, 574 000 og 518 000 kroner per

oppnådd QALY. I det utvida helsetenesteperspektivet, som er tilrådd av Direktoratet for medisinske produkt, ved antakelse om ein kostnadsterskel på 275 000 kroner per QALY, ser eit vaksinasjonsprogram mot herpes zoster difor ikkje ut til å vere kostnadseffektivt ved noverande listepris. Frå eit samfunnsperspektiv blir vaksinasjonskostnadane i større grad oppveigd av reduserte helsekostnadar og mindre produksjonstap, men sidan det relevante terskelnivået for samfunnsperspektiv er ukjent er det ikkje mogleg å trekke ein tydeleg konklusjon her.

1 Introduction

Varicella, known colloquially as chickenpox, is one of the ubiquitous childhood diseases. The disease typically leads to the appearance of spots on the skin, accompanied by fatigue and sometimes a fever. Some people experience a more severe course of disease that requires hospitalization. People who have been infected with varicella can develop herpes zoster, or shingles, later in life due to the virus reactivating in the body and causing a painful skin rash.

This study investigates the epidemiological outcomes and cost-effectiveness of two separate interventions: the introduction of either (1) a vaccine against varicella zoster virus in the Norwegian childhood vaccination programme (*barnevaksinasjonsprogrammet*); or (2) a vaccination programme against herpes zoster targeted at older adults (*voksenvaksinasjonsprogrammet*).

We employ a stochastic compartmental mathematical model stratified by age to simulate varicella and herpes zoster transmission dynamics and epidemiology and calibrate model parameters to reproduce the current situation of endemic varicella circulation and zoster infection rates. In separate counterfactual scenarios, we simulate the impact of introducing each vaccine under various strategies for age cohorts targeted, catch-up programmes included etc.

The results are post-processed in a health-economic model that estimates the costs and quality-adjusted life year (QALY) gained resulting from each intervention. We consider three separate perspectives for the health-economic assessment: a healthcare perspective, focusing only on direct costs related to medical care; an extended healthcare perspective, incorporating certain non-medical costs associated with seeking care; and a societal perspective including costs associated with production loss due to illness. In all economic analyses, both varicella and herpes zoster diseases are considered, so that e.g. when varicella vaccination brings herpes zoster incidence down, this gain in QALYs and costs is accounted for.

The study is performed in support of health technology assessments of varicella and herpes zoster vaccines performed at the Norwegian Institute of Public Health which were finalised in early 2026.

The document is structured into two main parts: Part I presents the epidemiological scenario analysis and health-economic results for the varicella childhood vaccination programme, and Part II presents the scenario analysis of a vaccination campaign against herpes zoster.

The *Methods* section presents details of the epidemiological model and health-economic analysis used to assess both vaccination programmes.

2 Varicella vaccination

This part of the report details the epidemiological modelling and economic evaluation of introducing universal childhood varicella vaccination.

2.1 Varicella vaccine model and assumptions

In the following section we present the main modelling assumptions related to the vaccination process and the vaccine profile. Other details of the infectious disease model are presented in the section Methods and model details at the end.

Vaccination is modelled using a binary "all-or-nothing" immunity, assuming individuals are either fully protected or not protected at all (Bonanni et al, Pediatr Infect Dis J. 2013). The fraction of vaccinated individuals for whom the vaccine takes effect is equivalent to the vaccine efficacy and is denoted T_1 (T_2) for dose 1 (2). For the remaining fraction (1 - T), the vaccine has no effect. Thus, in the figure below, individuals in compartments V_1 and V_2 experience full immunity, while those in SB remain susceptible to breakthrough infection. We also allow for waning immunity, whereby individuals lose the vaccine protection over time and move from V to SB.

For the 1st dose, we assume the following values:

- Efficacy (T1): 81% (meta-analysis from health technology assessment (metodevurdering) on varicella vaccination, NIPH (2026))
- Waning (W1): 2%/year (Marin et al., Pediatrics, 2016; Bonanni et al., Pediatr Infect Dis J., 2013)

For the 2nd dose, we assume the following values:

- Efficacy (T2): 95% (meta-analysis from health technology assessment (metodevurdering) on varicella vaccination, NIPH (2026))
- Waning (W2): 0 (no waning) (Povey et al. The Lancet Infectious diseases, 2019)

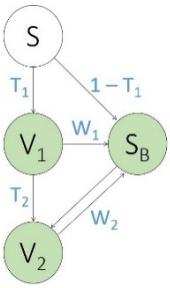


***Figure 1**: The vaccination model for varicella.*

We assume that no vaccine doses have been administered prior to the start of the vaccination campaign. This is supported by the fact that varicella vaccination is currently offered on a voluntary basis, and paid for by the individual, and Norwegian registry data indicates very low uptake.

2.2 Vaccination scenarios

We evaluate different scenarios for a vaccination programme by combining various vaccination coverages and various catch-up programmes. The purpose of the catch-up programme is to vaccinate children above the recommended age for their initial vaccine dose during the initial phase of the vaccination campaign. We have simulated three different catch-up programmes:

1. **SAC (single-age cohort):** The birth cohort turning 15 are offered two doses of vaccine each year from the start of the vaccination programme, for 14 years until all birth cohorts are covered either by catch-up or normal programme.
2. **MAC (multi-age cohort):** All children from 2-15 are offered two vaccine doses during the first year of the vaccination programme.
3. **Stretched MAC (SMAC):** Multi-age cohort catch-up but stretched out over several years. Starting the first year of the programme
    a. the cohort turning 3 is offered dose 1
    b. the cohort turning 7 is offered dose (1+)2
    c. the cohort turning 15 is offered dose 1+2

We have evaluated different age classes for the vaccine catch-up in the scenario analysis. We have assumed that the coverage of vaccination in the catch-up programme follows the values of the coverage assumed for the vaccination campaign in each scenario.

This table presents an overview of the scenarios. The baseline scenario is emphasised in bold and is the scenario used to assess economic costs and benefits.

Scenario Variable	**Value**
Vaccination coverage	80%, 85%, 90%, **96%**
Age administration dose 1	15 months
Age administration dose 2	7 years
Type of catch-up programme (see below)	No catch-up, Single age cohort (SAC), multi-age cohorts (MAC), **stretched MAC (SMAC)**
Last age of catch-up	15 years

A control scenario where no vaccination programme is implemented, i.e. simulating the status quo of endemic circulation, is also included in the analysis, and is used to contrast costs and benefits with respect to the vaccination scenarios.

2.3 Results and Discussion

In the following section we present the results of the epidemiological model and the HE analysis of introducing the vaccination programme against Varicella among children. The results are obtained by running 500 different realisations of the epidemiological model with parameters drawn from the posterior distribution of the calibration, each simulation spanning 100 years from the start of the vaccination programme.

2.3.1 Epidemiological model of varicella vaccination

In the main scenario with SMAC catch-up and 96% vaccination uptake, the model finds that over a 100-year perspective a total of 39 853 (35 782 – 44 469) cases of varicella occur, compared with an estimated 5 882 048 (95% CI: 5 868 684 – 5 896 467) cases in the control scenario with no vaccination. This amounts to a reduction of 5 842 195 (95% CI: 5 832 902 – 5 851 998) cases, a reduction of more than 99 percent. Concurrently, the model finds 1 939 529 (95% CI: 1 814 516 - 2 093 309) HZ cases in the main scenario compared with 2 815 050 (2 596 715 - 3 115 241) in the control scenario, a reduction of 31 (95% CI: 30 – 32) percent or 875 521

(95% CI: 782 199 - 1 021 932) cases. The reduction in HZ is a knock-on effect from the reduction of primary varicella infections, hence this health gain is mainly realised later in the 100-year simulation period (see also fig. 6 below).

2.3.1.1 Vaccine uptake

Our model finds that the introduction of the varicella vaccine for children will result in a rapid decrease in the incidence of varicella cases over time. The extent of this reduction depends on vaccine uptake. Figure 2 shows the yearly incidence of new varicella infections per 1000 population in Norway as estimated by the model in scenarios with varying vaccine uptake and SMAC catch-up. Our simulations indicate that achieving a high vaccination coverage of 96%, the level obtained for other children vaccination programs in Norway, would lead to nearly complete eradication of varicella in the population within few years, with only sporadic cases caused by infection from persons affected by herpes zoster or by varicella infections acquired abroad. With 96% coverage, these introductions will not lead to outbreaks in the model as vaccination has brought the effective reproduction number below 1. In scenarios with 80% or 85% coverage, while there is a notable reduction in varicella incidence overall, and an almost-zero incidence is reached 10 years after vaccination starts, a new equilibrium of approximately 1-2 yearly cases per 1000 population is reached eventually. As shown in Figure 4, a larger proportion of these cases tend to be among older persons for whom the disease may be more severe. These findings underscore the importance of a high uptake should universal vaccination be introduced, and of close monitoring of the vaccination coverage post programme-start.

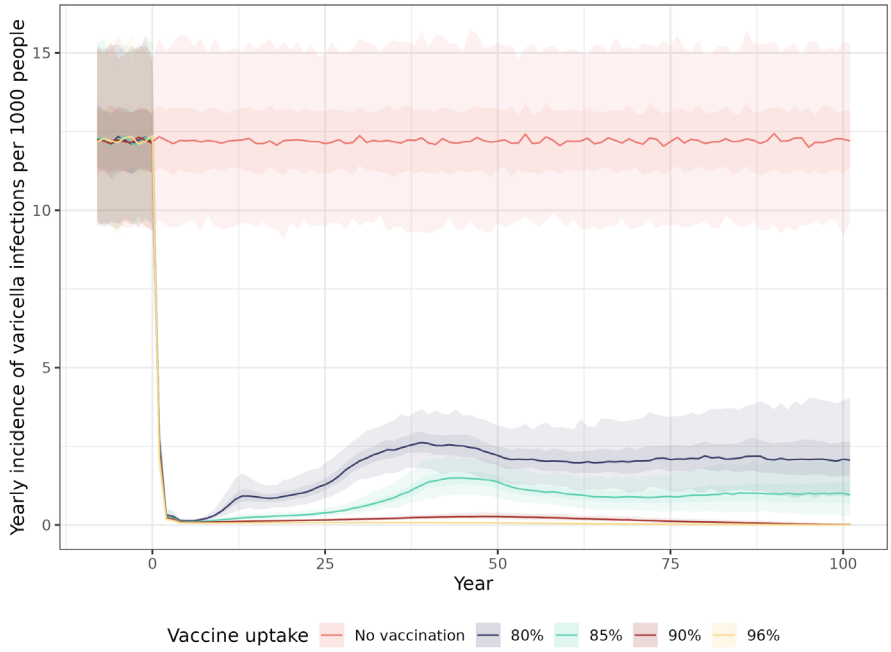


Figure 2: *Yearly incidence of new varicella infections per 1000 people in scenarios where population vaccination coverage reaches 80, 85, 90 or 96 percent. The vaccination programme is introduced at year 0. The control scenario without vaccination is shown in red. Here, the first and second dose are given at age 1 and 7 years, respectively, and catch-up vaccination is performed in the stretched multi-age cohort (SMAC) from ages 2 through 15. Inner and outer error bands show interquartile ranges (IQR) and 95 % credible intervals, respectively. See the text for details.*

2.3.1.2 Rebound and catch-up

The varicella dynamics during the first years after vaccination is introduced is sensitive to the choice of catch-up programme. Although vaccine introduction brings the infection incidence down, some scenarios find a rebound in the number of cases 5-10 years after the start of the vaccination campaign, as seen in Figure 3. The reason for the rebound is that, when societal infection pressure drops at the start of the programme, children over the age of 1 who are still susceptible to varicella will not be immunized - either by vaccine or by natural infection – without a catch-up programme in place. As time passes, this immunologically naive group ages, and because of the contact structure between age groups (see methods), the conditions for transmission suddenly become more favourable, giving rise to a varicella outbreak. Over a year or two, the outbreak leads to a build-up of immunity in the affected age groups through natural infection and virus circulation again halts, this time permanently. As shown in Figure 5, the age distribution of cases during the rebound will tend to be shifted to older age-groups, and the model indicates that it may in fact be higher than pre-vaccination incidence levels among people aged 5-20 during the rebound outbreak, although this has not to our knowledge been reported in real-world settings.

To avoid a rebound, a tailored catch-up programme can be rolled out along with the vaccination campaign, as described above. A single-year MAC programme, although the most effective, also requires more resources to implement than a multi-year SAC catch-up. On the other hand, as seen in Fig. 3, a rebound occurs not only for the scenario without catch-up but also with SAC catch-up programme implemented at age 15. The SMAC programme seems to be an optimal pragmatic choice as it has almost identical performance to the full MAC in terms of bringing down infection incidence and avoiding a rebound.

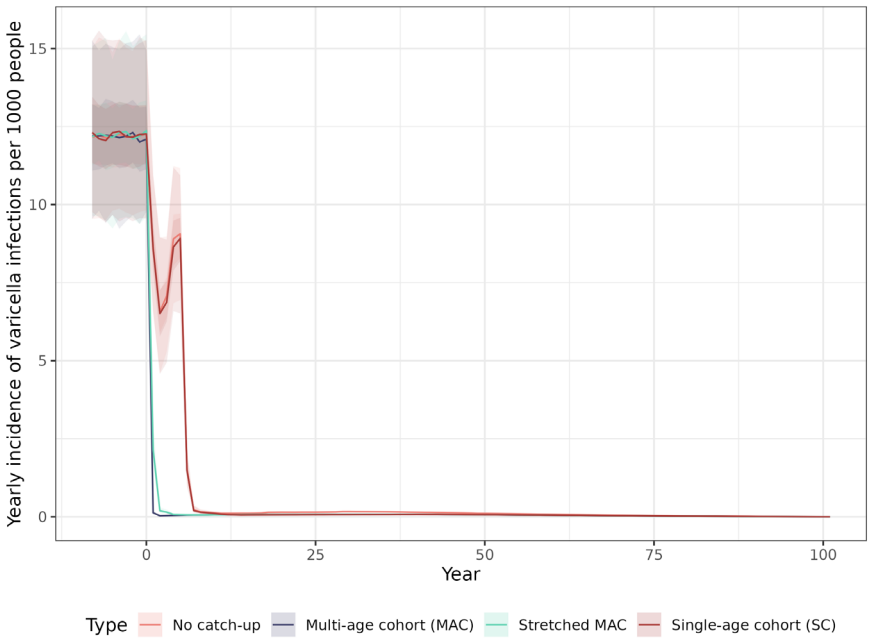


Figure 3: *The yearly incidence of varicella infections per 1000 people when varying the type of catch-up programme between no catch-up, SAC, MAC or SMAC. The vaccination programme is introduced at year 0. 96% vaccination uptake is assumed. Inner and outer error bands show IQR and 95 % credible intervals, respectively.*

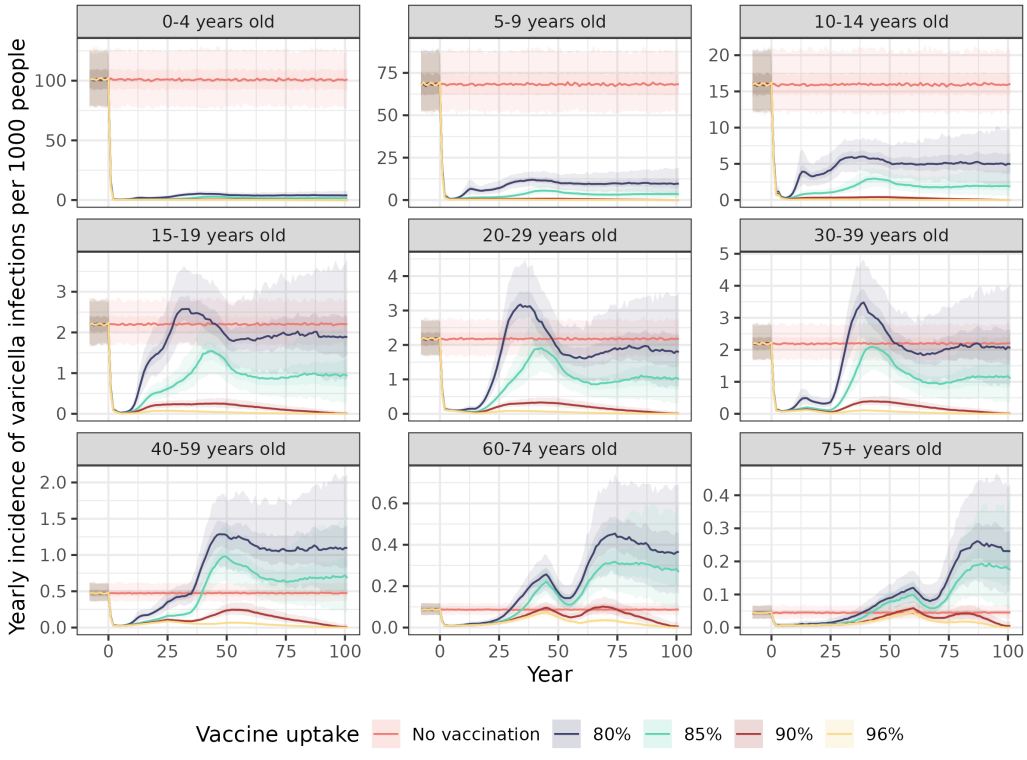


Figure 4: *Yearly incidence of varicella cases per 1000 people for different vaccine uptake scenarios, same as Fig. 2, but here divided into age groups. Inner and outer error bands show IQR and 95 % credible intervals, respectively. Note that the scale on the y axis differs between the subplots.*

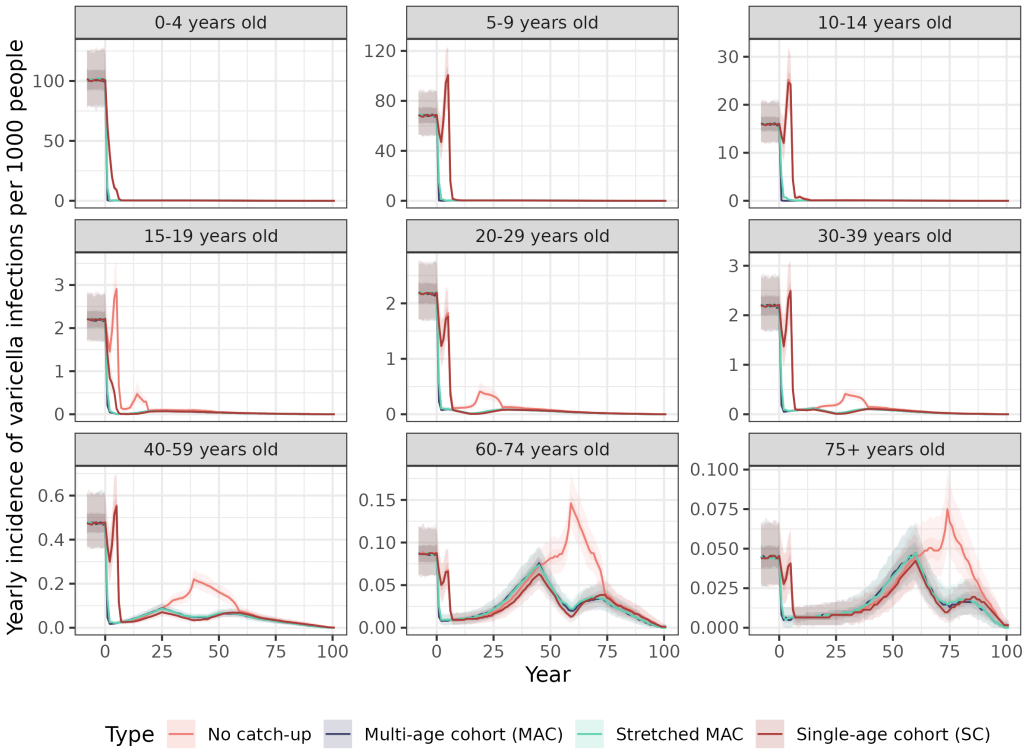


Figure 5: *Yearly incidence of varicella cases per 1000 people for different catch-up scenarios, same as Figure 3, but here divided into age groups. Inner and outer error bands show IQR and 95 % credible intervals, respectively. Note that the scale on the y axis differs between the subplots.*

2.3.1.3 Implications for Herpes Zoster infection

When a person contracts varicella, the varicella-zoster virus remains dormant in the body. As a person ages or experiences a weakening of the immune system, the virus can reactivate, causing the skin rash disease herpes zoster. The epidemiological model we use includes herpes zoster as a secondary outcome after varicella infection, with an age-dependent reactivation rate calibrated to Norwegian data.

It is hypothesized that exposure to active varicella infection, for example through contact with sick kids, boosts the immune system and reduces the risk of herpes zoster, a mechanism known as exogenous boosting. If exogenous boosting has a big effect in preventing herpes zoster, then one would expect that eradication of varicella through vaccination would lead to increased incidence of herpes zoster. To model the exogenous boosting mechanism, we adopted the temporary immunity model (Brisson et al. 2010), assuming an average protection duration of 20 years and a protection efficacy of 30% (see Methods). We have not performed sensitivity analyses with other exogenous boosting models.

Despite the removal of exogenous boosting post-vaccination, in our modelled scenarios, programmatic varicella vaccination has a positive impact on herpes zoster, reducing incidence drastically after a few decades, as seen in Figure 6. This decline is a result of the reduction or near-eradication of varicella post-vaccination, depending on vaccine uptake. There is a small risk of herpes zoster reactivation from the vaccine-strain varicella virus, and the model takes this into account by assuming a 90% reduced risk of reactivation compared to individuals infected with varicella (Widgren 2022). Our model suggests a temporary increase of herpes

zoster incidence slightly above pre-vaccination levels in age groups 30 and older, during the first 25-50 years after the vaccination programme starts (Figure 7). This is attributable to the removal of exogenous boosting.

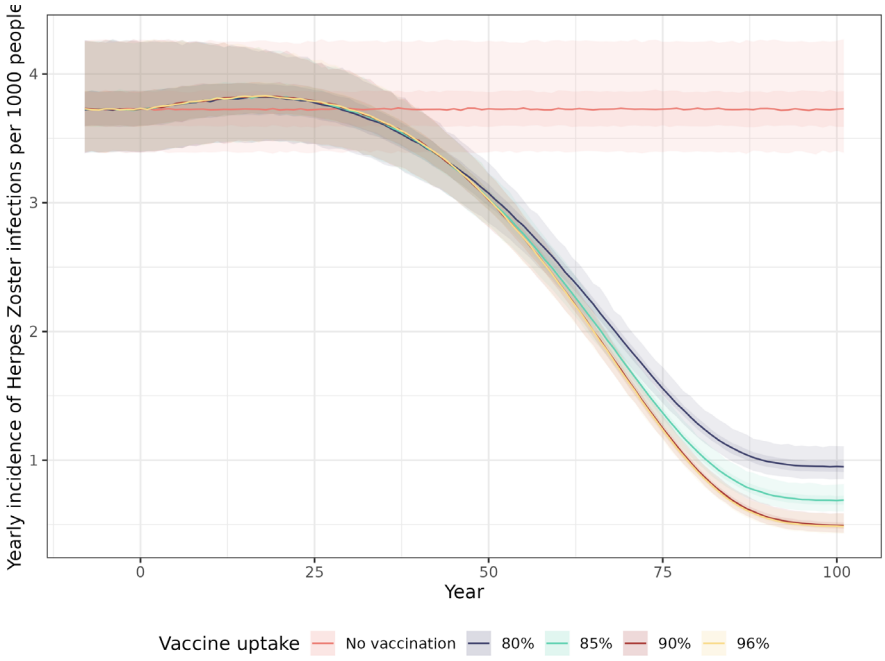


Figure 6: *Yearly incidence of herpes zoster infections per 1000 people in different scenarios for uptake of the varicella vaccine. The varicella vaccination programme is introduced at year 0. Inner and outer error bands show IQR and 95 % credible intervals, respectively.*

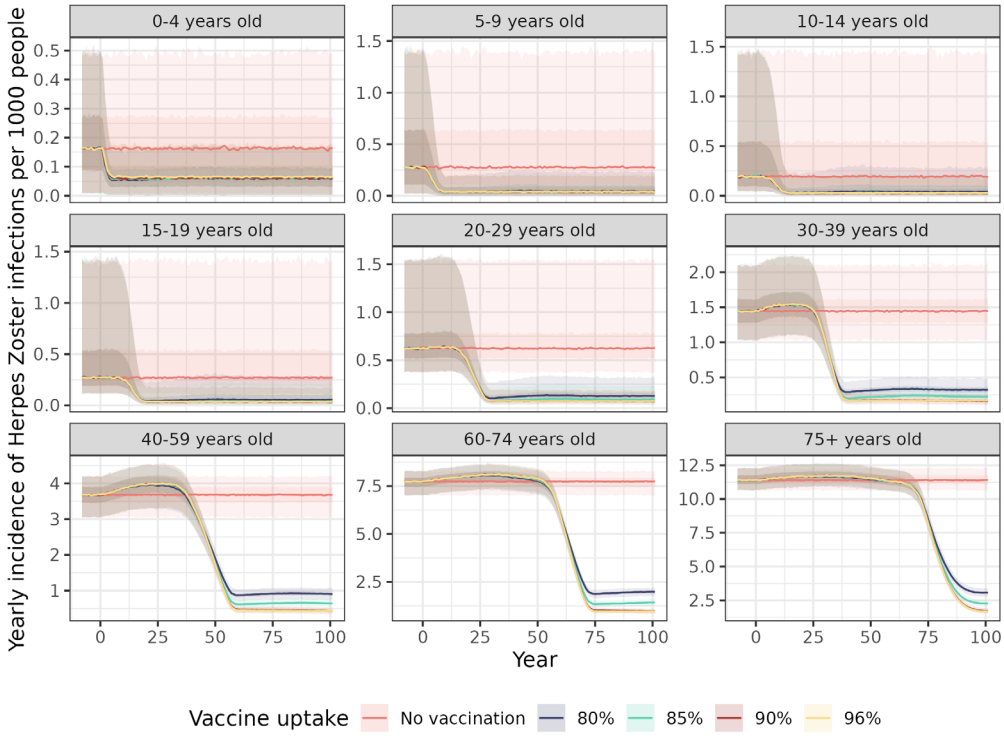


Figure 7: *Yearly incidence of herpes zoster infections per 1000 people, same as Figure 6, but here divided into age groups. Note that the scale on the y axis differs between the subplots.*

2.3.1.4 Sensitivity analyses with varied epidemiological assumptions

To assess the epidemiological model results under different conditions, we have carried out additional analyses where we vary some of the model assumptions

- For the 1st dose we also explore an alternative vaccine profile characterized by lower efficacy, T1=65%, and no waning, W1=0 (Prymula et al., The Lancet, 2014). This has a minimal effect on the results, since the vast majority of vaccinees receive two doses of vaccine within few years.
- Alternative vaccination programs with the first and/or second dose given at other years have been explored. They all give identical long-term results in the sense that varicella is eradicated given a high vaccination coverage. Other vaccination ages and intervals will have implications for the design of a catch-up program.

2.3.2 Health economic evaluation of varicella vaccination

Table 1 presents total net discounted costs and QALY gains over a 100-year time horizon with an SMAC catch-up programme compared to the control scenario without vaccination. The cost per dose of the vaccine is taken as the average between Varilrix and Varivax, which have list prices (pharmacy purchase price, AIP, excl. VAT) of NOK 330, and 444,41 respectively. With this, the net discounted costs from a healthcare perspective, which includes reduced costs due to health gains from the vaccination, for a vaccination programme with a stretched MAC, were estimated at 821 million NOK. The costs without catchup were estimated at 672 million NOK. From an extended healthcare perspective, the net cost was estimated at 271 (190) million NOK respectively with (without) catch-up. Cost savings from a societal perspective were estimated at 9.3 (8.2) billion for a vaccination programme with (without) catchup, respectively. Note that in the societal perspective, the catch-up programme is more cost-saving than no-catch-up – this is due to the avoided rebound.

The incremental cost-effectiveness ratio (ICER), expressed as cost per QALY gained, from a healthcare perspective for a national vaccination programme with SMAC catch-up was estimated at 131,946 NOK, compared to 123,399 NOK without catch-up. In extended healthcare perspective, the corresponding ICER is 43,904 and 35,264 NOK respectively with and without catch-up. For the healthcare and extended healthcare perspectives, the estimated ICER in scenarios with a catch-up are thus slightly higher but of similar magnitudes. In societal perspective, the vaccination programme is found to be cost saving and lead to better health in all scenarios due to its large impact on reducing caregiver productivity loss.

We find inclusion of varicella vaccination in the childhood vaccination programme very likely to be a cost-effective treatment strategy, when compared to current benchmarks for cost-effectiveness. This conclusion holds irrespective of the perspective on costs, but inclusion of loss of production for caregiver leads to vaccination being a dominant strategy (i.e. generating better health and cost savings).

The conclusion is robust to realistic changes in input parameters (Table 2/Figure 8). If the vaccine price was to be reduced to approximately 50% of current list prices, our analyses indicate that a national varicella vaccination program, either with a stretched MAC or without a catch-up program, would be cost-saving over a 100-year horizon. We also assessed the cost per QALY gained over shorter modelling time horizons. Higher vaccine administration cost and

healthcare costs would not affect the results in a profound way. We have also varied the discount rates in the sensitivity analysis.

Out results are similar to findings in other countries (Anderson 2023). Anderson and co-workers performed a systematic review of cost-effectiveness studies of varicella vaccination; their literature search was performed 19 April 2021. They included 55 studies evaluating universal childhood vaccination. From a health care perspective, included studies reported better health and cost increases, while studies applying a societal perspective tended to report better health in combination with cost savings. The reported ICERs from a healthcare perspective varied greatly, depending on incidence of infection, cost of treating cases and whether the effect on herpes zoster in adults was included. Studies published after this review show a similar pattern (Adams 2025, Ahern 2024), with vaccination generating better health and higher costs with ICERs below assumed threshold values. Price of the vaccine and cost of treating varicella cases seem to be important drivers, with vaccination generating better health and higher costs with ICERs below assumed threshold values.

Compared to a previous Norwegian analysis conducted by Merck (Pawaskar 2021), we find lower health gains (0.0005515 vs 0.00127), and higher costs. From a healthcare perspective, we find cost increases, while the Pawaskar analysis estimates cost savings. This divergence in findings seem to follow an overall trend, as a review of published cost-effectiveness analyses did find zoster evaluations performed by the pharmaceutical industry to generally lead to more favourable results for the vaccine, due to a combination of several "optimistic" input choices (Blicke 2018).

Limitations to our economic evaluation include measurements of health-related quality of life in small children. As small children cannot themselves answer questionnaires made to measure health related quality of life, estimates are often based on answers from parents. Although we have used the best available evidence, these estimates can be considered uncertain. However, proxy evaluations for children are routinely used in health economic evaluations and is generally considered "best practice" when the child is too young to provide an own answer (Xie 2024). If we did not include health related quality of life for children, this would disregard the obvious pain and discomfort resulting from varicella infection.

Table 1: *Main economic evaluation outcomes. 100-year perspective. SMAC catch-up. The numbers presented are mean values of costs taken with respect to both epidemiological and health-economic uncertainty distributions. Full list price of the vaccine is assumed. Costs and QALYs are discounted based on number of years into the future.*

Perspective of analysis	**Healthcare perspective**	**Extended healthcare perspective**	**Societal perspective**
Total cost difference compared to no vaccination (NOK; rounded to nearest million)	820 000 000	271 000 000	- 9 335 000 000 *(negative cost, i.e. cost saving)*
Total QALY difference compared to control	6 238	6 238	6 238
ICER (NOK/QALY)	131 946	43 904	*Better health and cost-saving*

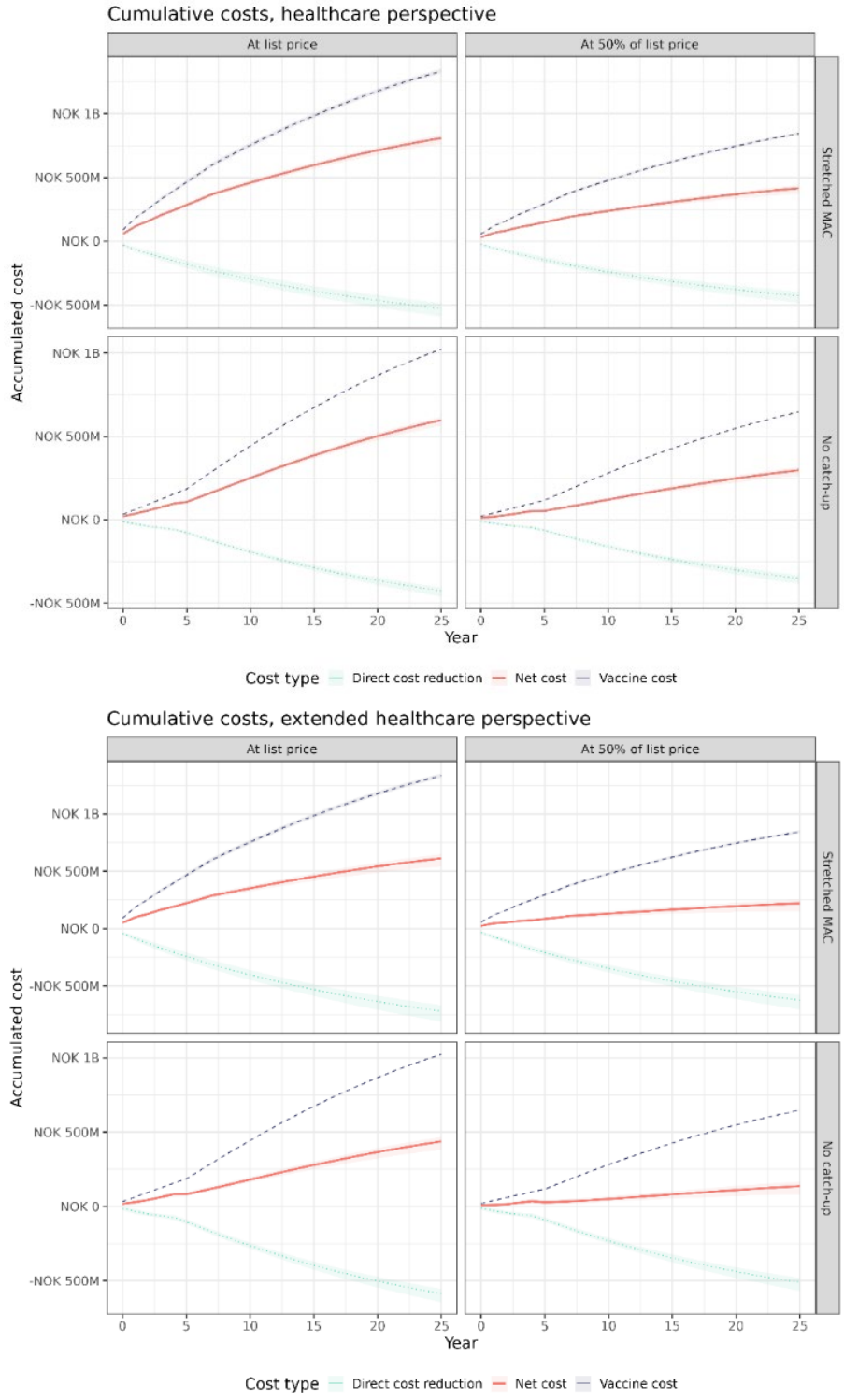
Table 2: *Cost/QALY estimates in one- and two-way sensitivity analyses. 96% vaccination coverage, SMAC catch-up, 100% of list-price for vaccines unless specified otherwise.*

Variable	Change in variable (Main values → Sensitivity values)	ICER		
		Healthcare perspective	Extended healthcare perspective	Societal perspective
Epidemiological model uncertainty	Mean estimate → Lower 95% credible interval	103 208	12 256	Better health and cost-saving
Epidemiological model uncertainty	Mean estimate → Upper 95% credible interval	148 735	61 925	Better health and cost-saving
Model horizon	100 years→ 10 years	440 778	337 969	Better health and cost-saving
Model horizon	100 years→ 25 years	461 028	349 775	Better health and cost-saving
Model horizon	100 years→ 50 years	423 802	306 772	Better health and cost-saving
Vaccine cost both doses	Vaccine price 75% of list price	83 100	Better health and cost-saving	Better health and cost-saving
Vaccine cost both doses	Vaccine price halved	34 253	Better health and cost-saving	Better health and cost-saving
Vaccine cost both doses	Vaccine price 25% of list price	Better health and cost-saving	Better health and cost-saving	Better health and cost-saving
Vaccine administration cost	NOK 175→ Doubled	220 252	132 210	Better health and cost-saving
Healthcare costs related to illness	Documented → Doubled	Better health and cost-saving	Better health and cost-saving	Better health and cost-saving
Healthcare costs related to illness	Documented → Halved	207 819	118 970	Better health and cost-saving
Discount rate QALYs & costs	4%/3%/2% → 0%	Better health and cost-saving	Better health and cost-saving	Better health and cost-saving
Discount rate QALYs & costs	4%/3%/2% → 2%/1.5%/1%	Better health and cost-saving	Better health and cost-saving	Better health and cost-saving
Discount rate QALYs & costs	4%/3%/2% → 6%/4.5%/3%	255 877	158 167	Better health and cost-saving

2.3.2.1 Budget impact analysis

Figure 9 illustrates the discounted cumulative cost over the first 25 years of the varicella programme for the vaccination scenarios with and without catch-up compared to no intervention, separately for each cost perspective. For each vaccination scenario, different panels show costs assuming either the full list price of the vaccine or a 50% reduced price. In each panel, the dotted blue line shows the cumulative cost of the vaccination programme itself, while the cyan line shows the net cumulative cost in each perspective (excluding vaccination costs) compared with the control scenario. The red line is the sum of the two other lines, and hence illustrates the total net cost or saving resulting from the programme.

The results indicate that from a societal perspective both programs would be cost-saving already from the first year due to their large impact on reducing caregiver productivity loss. Furthermore, the kink in the red line in the societal perspective in the no-catch-up scenario is due to the rebound in infections and illustrates why in the societal perspective catch-up is more cost-saving than no catch-up.


Cumulative costs, healthcare perspective
At list price
At 50% of list price
Stretched MAC
No catch-up
Accumulated cost
NOK 1B
NOK 500M
NOK 0
-NOK 500M
0
5
10
15
20
25
Year
Cost type
Direct cost reduction
Net cost
Vaccine cost
Cumulative costs, extended healthcare perspective
At list price
At 50% of list price
Stretched MAC
No catch-up
Accumulated cost
NOK 1B
NOK 500M
NOK 0
-NOK 500M
0
5
10
15
20
25
Year
Cost type
Direct cost reduction
Net cost
Vaccine cost

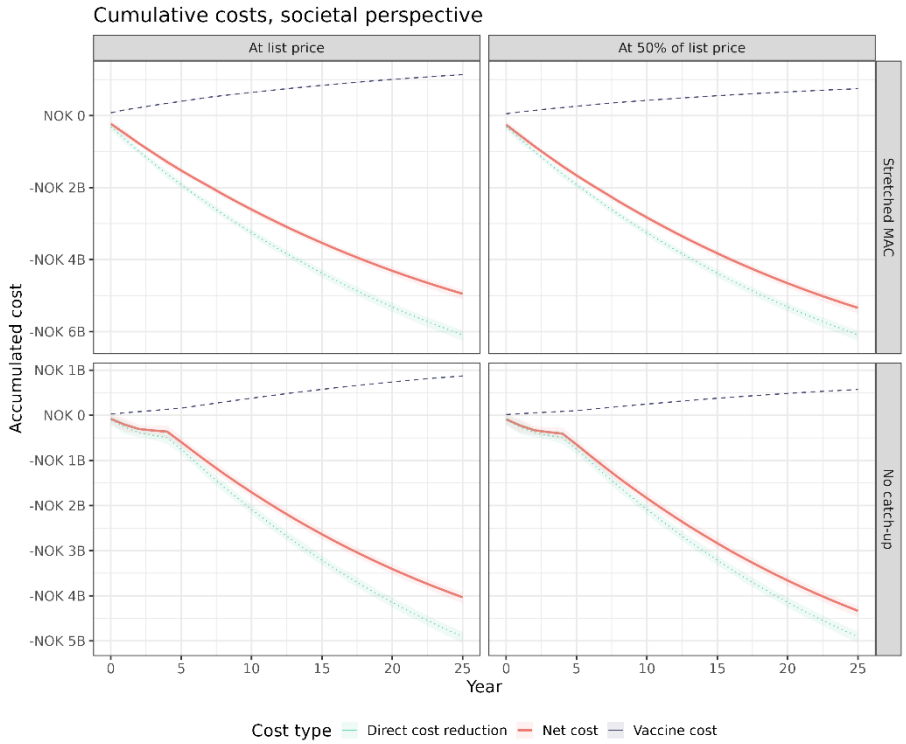


***Figure 8**: Results main scenarios in economic evaluation: discounted cumulative costs and cost savings in each perspective*

Figure 9 presents the non-discounted budget impact of a stretched MAC programme over the first 10 year of a national programme at four different vaccine prices. The annual vaccine cost will be relatively similar year on year since the bulk of the catch-up will be conducted during the first 5 years of the programme before the dose 2 administration starts as the first cohort of children in the national programme turns 7 years old.

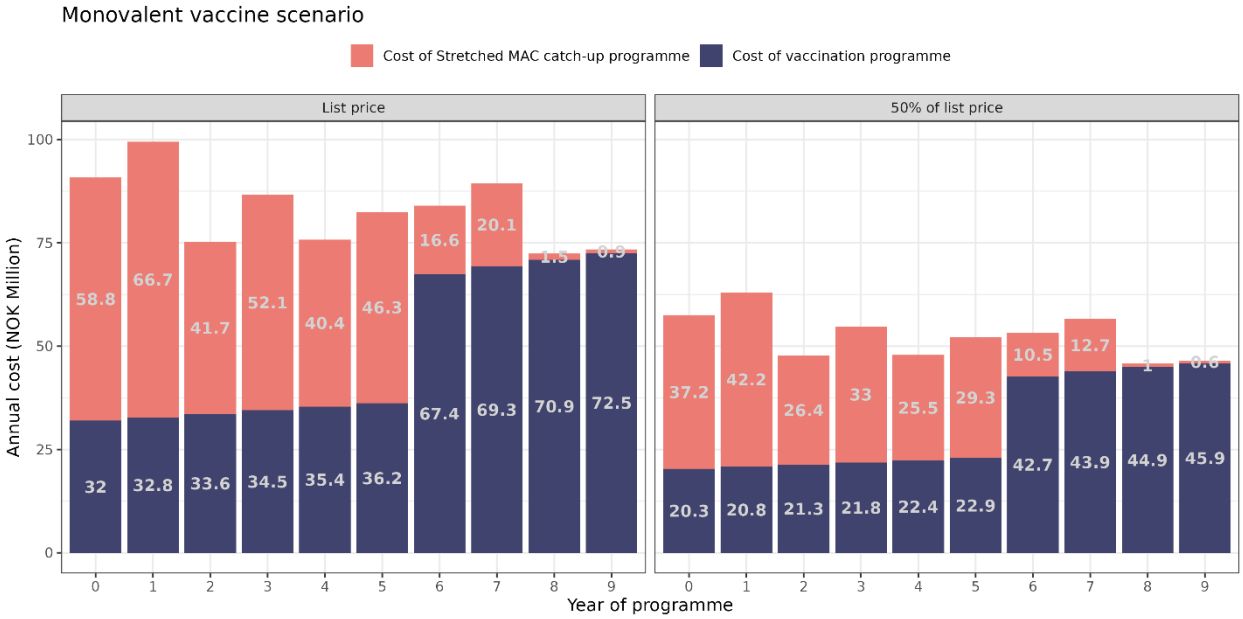


***Figure 9**: Budget impact for first 10 years of a national vaccination programme with a stretched MAC catch-up. See also table S4 in the supplemental material.*

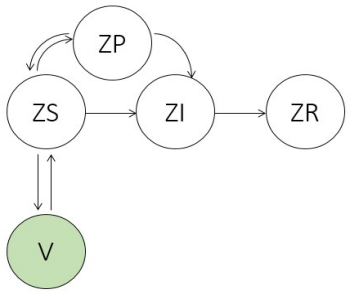
3 Herpes zoster vaccination

This part of the report details the epidemiological modelling and economic evaluation of introducing a vaccine programme against herpes zoster in the Norwegian population. The basic epidemiological model is the same as that used to assess the impact of the varicella childhood immunisation programme but is here adapted to include vaccination against HZ instead of varicella.

3.1 Herpes zoster vaccine model and assumptions

We assess the effect of the recombinant zoster vaccine (Shingrix, RZV), using efficacy estimates and waning profiles reported from RCT studies and observational studies.

Vaccine type	Vaccine Protection (%)	Waning	Study	Ref.
Shingrix (RZV)	95	2.5%/year	RCT	NIPH *metodevurdering* for herpes zoster (2026)
	80	2.5%/year	Observational	



3.2 Vaccination scenarios

We simulated HZ vaccination programmes by varying key parameters related to the implementation of the HZ vaccination programme. The **bold** values define the main vaccination scenario of the analysis.

- **Vaccine efficacy.** It was assumed to have two possible values: **95%** and 80% (meta-analysis from health technology assessment (*metodevurdering)* on herpes zoster vaccination, NIPH (2026))
- **Coverage.** Two first-dose coverage levels were considered: 50% and **75%**.
- **Target Age Group.** Vaccination was assumed to start at **65 years of age**.
- **Catch-Up Programme.** The following catch-up strategies were evaluated when targeting 65-year-olds:
    a. All individuals aged 65 years and older at the start of the vaccination campaign.
    b. Individuals turning 70 years old, for 5 years following the start of the campaign.
    c. Individuals turning **70 and 75 years** old, for 5 years following the start of the campaign.
    d. No catch-up programme

A set of alternative scenarios was also considered:

- Vaccination of 70-year-olds of age with a catch-up programme where 75-years-olds are vaccinated for 5 years following the start of the campaign.
- Different age targets (50, 55, 60, 65, 70, 75, 80) under the assumption of a 95% vaccine efficacy, 75% vaccine coverage, and no catch-up programme.
- Scenarios with alternative assumptions about waning of vaccine-induced protection, comparing a programme with vaccination at 65 years and catch-up at 70 and 75 years under (i) 95% VE with 1.5% annual waning and (ii) 80% VE with no waning, both with 75% coverage.

Combining these options resulted in a total of 28 distinct vaccination scenarios. A control scenario without vaccination was also simulated and used to contrast the health economic costs and gains.

For each scenario, the model reports yearly and cumulative incidence of herpes zoster cases as well as episodes of post-herpetic neuralgia (PHN) following HZ infection.

3.3 Results and discussion

In the following section we present the results of the epidemiological model and the health-economic analysis of introducing the vaccination programme against HZ in the adult population. The results are obtained by running 500 different realisations of the epidemiological model with parameters drawn from the posterior distribution after calibration, each simulation spanning 100 years from the start of the vaccination programme.

3.3.1 Epidemiological model of herpes zoster vaccination

The modelled herpes zoster incidence is calibrated against the yearly number of general practitioner consultations and visits to emergency departments by age. The simulated population is assumed to be in demographic equilibrium. The effects of vaccination are assessed by running scenarios over a 100-year period.

Across all scenarios, introducing an HZ vaccination programme led to a marked and sustained reduction in HZ incidence compared with no vaccination. The decline occurred during the first 10–25 years after programme introduction, after which the incidence approached a new, lower steady state (Fig. 10).

The magnitude of the effect depended both on vaccine efficacy and coverage. In the scenario targeting 65-year-olds, moving from 80% to 95% vaccine efficacy resulted in a visibly deeper and more persistent drop in HZ incidence and increasing coverage from 50% to 75% further amplified this benefit (Fig. 10). In the most favourable scenario (high efficacy and high coverage at age 65), the model predicts a long-term decrease in annual HZ incidence compared with the pre-vaccination level, i.e., around 2.7 vs. 3.7 yearly cases per 1000 population.

Catch-up campaigns mainly influenced the short- and medium-term dynamics. Broad catch-up of adults aged 65 years and older produced a sharp initial decline in HZ incidence immediately after programme introduction, while more restricted catch-up (e.g. only at 70 or 70 and 75 years) yielded smaller short-term gains. However, after approximately two decades, all catch-up scenarios converged towards similar incidence levels, close to those obtained with routine vaccination alone at the same age. This demonstrates how catch-up campaigns accelerate the benefits of vaccination but do not affect the equilibrium reduction in HZ burden on the long-term.

In the main scenario where herpes zoster vaccination is offered to the 65-year old cohort each year, with catch-up offered to age cohorts 70 and 75, assuming a vaccine effectiveness of 95% and a coverage of 75%, the model finds 2 057 393 (1 864 779 – 2 348 390) herpes zoster cases over a 100-year period, compared to 2 813 081 (2 599 257 – 3 097 804) in the control scenario without vaccination. This amounts to an absolute reduction of 27 (24 – 28) percent. The corresponding estimated number of subsequent episodes of PHN is 314 244 (290 538 – 343 193) with vaccination compared to 452 000 (423 075 – 483 158) without, corresponding to a 30% absolute reduction.

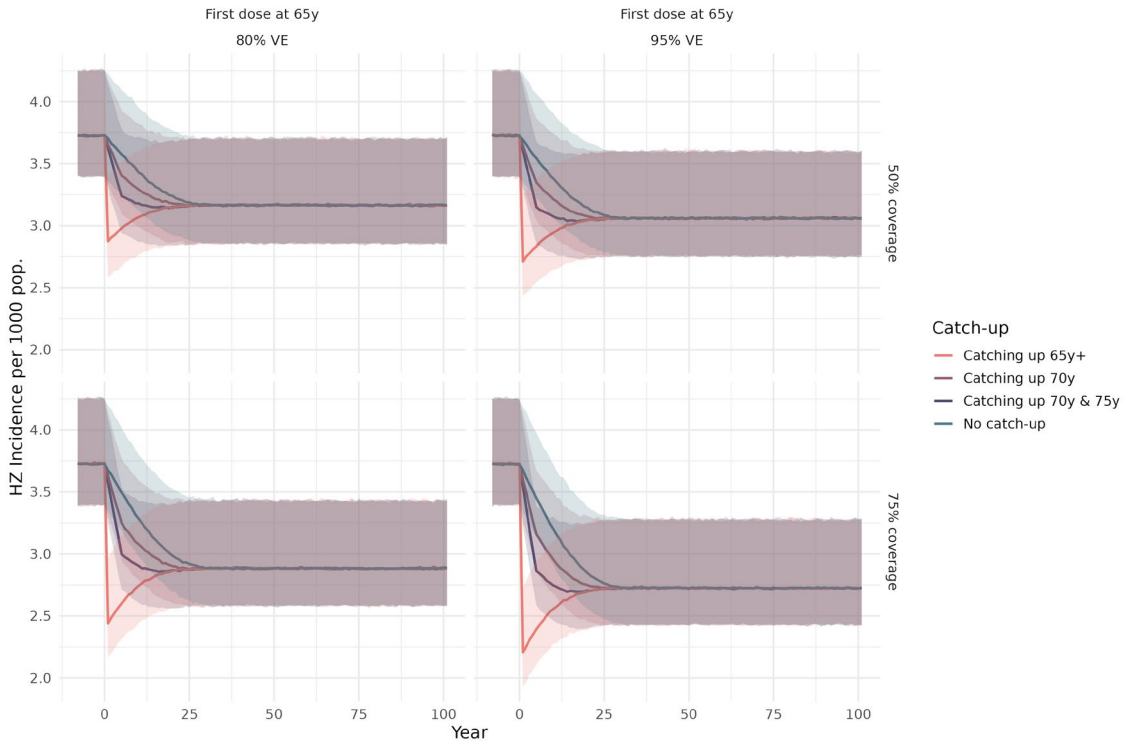


Figure 10: Modelled herpes zoster incidence over time for a vaccination programme with first dose at 65 years, under alternative vaccine effectiveness (VE), coverage, and catch-up strategies. Columns show VE of 80% and 95%; rows show 50% and 75% coverage.

3.3.1.1 Alternative scenarios

As one would expect, a vaccination programme starting at 70 years with a catch-up dose at 75 years produced slightly smaller reductions in HZ incidence than vaccinating at 65 years (Fig. 11). This reflects the smaller proportion of the population that spends a substantial part of their remaining lifetime protected by the vaccine when vaccination is delayed to older ages. In our main scenario (routine vaccination at 65 years with catch-up at 70 and 75 years, assuming 95% vaccine effectiveness and 75% coverage), the long-term mean HZ incidence stabilized at approximately 2.75 cases per 1000 population. When the target age for the first dose was increased to 70 years with catch-up at 75 years, the corresponding mean incidence slightly increased to around 2.8 cases per 1000 population.

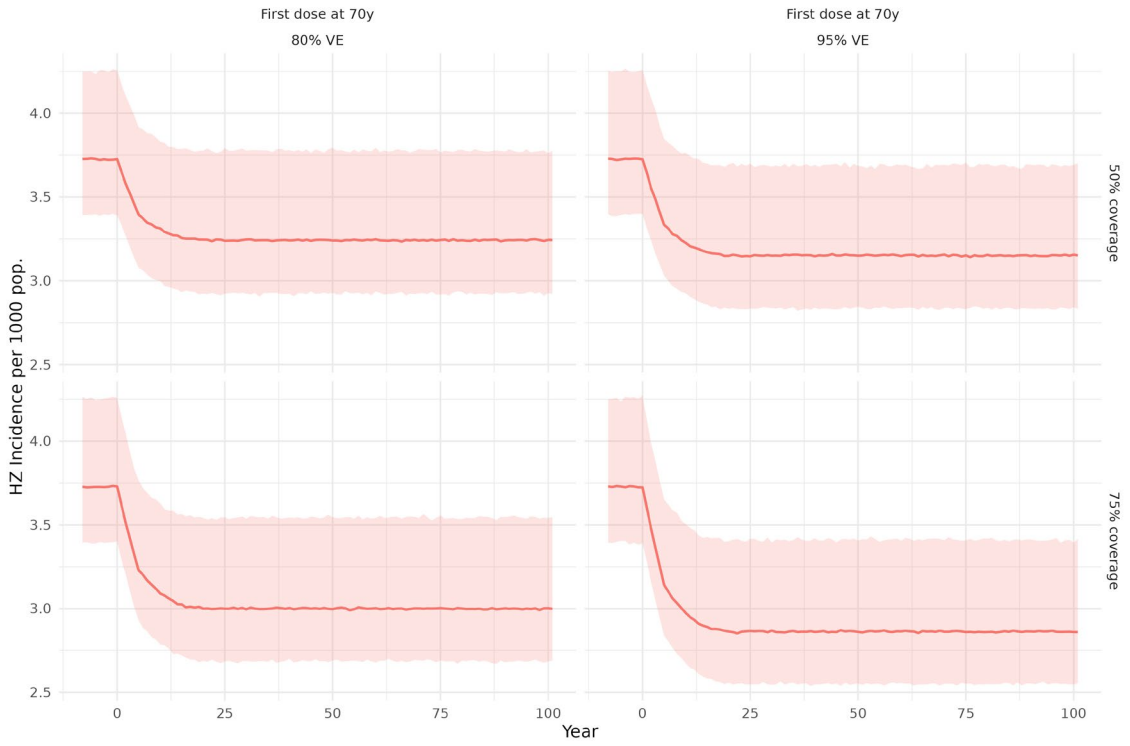


Figure 11: *Modelled HZ incidence over time for a vaccination programme with first dose at 70 years and catch-up at 75 years, under the alternative combinations of VE (80% and 95%) and coverage (50% and 75%).*

When exploring the impact of targeting different age groups (under VE=95%, coverage=75% and waning=2.5%/year), we found that lowering the age at first dose from 80 to 65 years produced additional reduction in long-term HZ incidence, with smaller gains when targeting 65 or 60 years (Fig. 12). In contrast, targeting adults younger than approximately 60 years yielded only marginal additional benefits: no significant differences were observed between the curves for first dose at 55 and 50 years, all of which converged to a mean value of about 2.6 HZ cases per 1000 population. These diminishing gains are likely explained by the fact that additional protection is conferred at ages with low baseline HZ risk, combined with the waning of the vaccine over time.

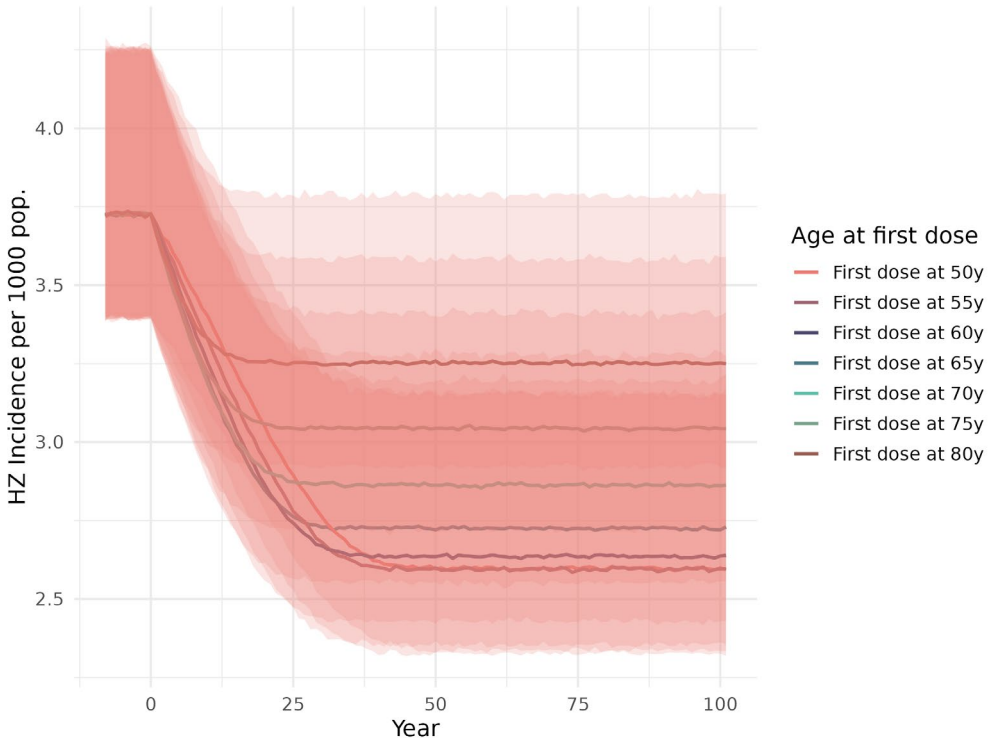


***Figure 12**: Modelled herpes zoster (HZ) incidence over time under alternative ages at first HZ vaccine dose, assuming 95% vaccine efficacy, waning of 2.5% per year, and 75% coverage. Curves with 95% confidence intervals (shaded area) show annual HZ incidence following introduction of a vaccination programme targeting different ages.*

Figure 13 shows how the assumed rate of waning of vaccine-induced protection influenced the long-term impact of vaccination. For a programme with first dose at 65 years and 75% coverage, assuming 80% VE with no waning produced the largest reduction in HZ incidence, with the final long-term level of HZ remaining below all scenarios that included waning (approximately a mean of 2.4 HZ cases per 1000 population). For the 95% VE scenarios, waning at 1.5% and 2.5% per year both yielded lower long-term incidence than 80% VE with waning at 2.5% per year, but still higher than in the 80% VE and no-waning scenario. Thus, as expected, higher baseline VE partly mitigated the loss of protection due to waning, and faster waning consistently diminished the long-term benefits of vaccination.

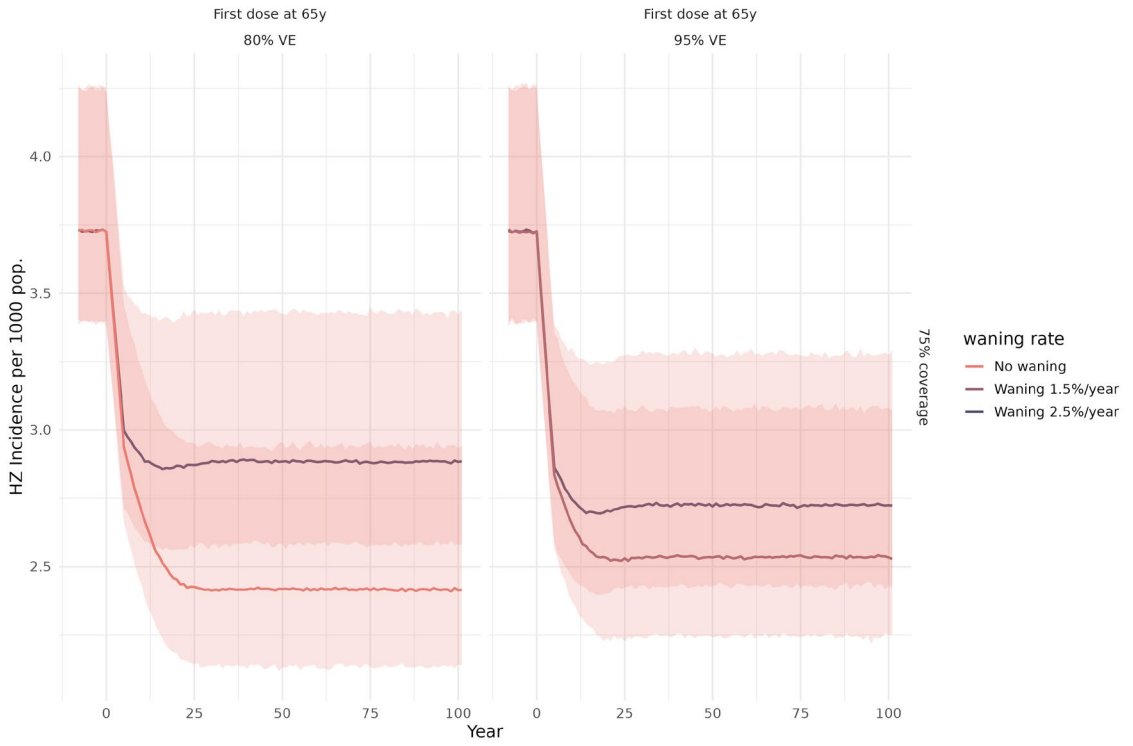


Figure 13: *Modelled herpes zoster (HZ) incidence per 1000 population over time for alternative assumptions about waning of vaccine protection. All scenarios assume routine vaccination at 65 years with 75% coverage and catch-up of 70 and 75 years for the first 5 years of vaccination programme.*

3.3.2 Health economic model of herpes zoster vaccination

Vaccinating 65 years olds against herpes zoster resulted in more quality adjusted life years (QALY) gained and higher costs compared to the control scenario without vaccination. The additional costs vary across the three different cost perspectives, i.e. healthcare, extended healthcare and societal, with the societal perspective leading to least cost increases, since more of the upfront vaccination cost is offset by savings in other areas. The incremental cost-effectiveness ratio is NOK 473 738, 574 474 and 517 616 per QALY respectively (Table 3).

If we assume an extended healthcare perspective, as recommended by the Norwegian Medical Products Agency (Direktoratet for medisinske produkter, DMP), and assume a threshold value for cost-effectiveness of NOK 275,000 per QALY, herpes zoster vaccination is unlikely to be considered a cost-effective alternative. If we assume a societal perspective as recommended in recent policy documents, the cost-effectiveness threshold (i.e. the opportunity cost) from this perspective is unknown, hence we cannot conclude. If we apply the value of a statistical life year in the societal perspective, vaccination would be considered very cost-effective. These findings are based on the official list price of the vaccine. In one-way sensitivity analyses (Table 4), we found a 50% discount to result in an ICER of NOK 212 680, 313 416 and 256 559 per QALY from a healthcare, extended healthcare and societal perspective respectively. Figure 15 shows the estimated ICER as function of vaccine price obtained, demonstrating that the ICER in the extended healthcare perspective crosses below the 275 000 threshold at a price reduction of 57%.

Table 3: Main economic analysis outcomes of herpes zoster vaccination. Costs are estimated in a 100-year perspective on the main vaccination scenario, which consists of offering the vaccine to the 65-year-old age cohort together with a catch-up programme offering the vaccine to 70- and 75-year old cohorts, assuming a vaccine uptake of 75%. Numbers presented are mean values of costs taken with respect to both epidemiological and health-economic uncertainty distributions. Full list price of the vaccine is assumed. Costs and QALYs are discounted based on number of years into the future.

Perspective of analysis	**Healthcare perspective**	**Extended healthcare perspective**	**Societal perspective**
Total cost difference compared to control (NOK; rounded to nearest million)	5 541 000 000	6 719 000 000	6 053 000 000
Total QALY difference compared to control	11 711	11 711	11 711
ICER (NOK/QALY)	473 738	574 474	517 616

Results are sensitive to assumptions made, including likelihood of developing severe persistent pain after infection, incidence of herpes zoster and price of the vaccine (Table 4), however none of the changes made the ICER drop below NOK 275,000 per QALY, the assumed threshold value for the extended healthcare perspective.

Table 4: Cost/QALY estimates in one- and two-way sensitivity analyses (healthcare perspective) for the main vaccination scenario (VE=95%, Waning=2.5%/year, Coverage=75%, Catch-up=70 and 75-year-olds, Age-target=65).

Variable	**Change in variable (Main values→ Sensitivity values)**	**ICER**		
		Healthcare perspective	**Extended healthcare perspective**	**Societal perspective**
Epidemiological model uncertainty	Mean estimate → Lower 95% credible interval	442 588	534 791	476 661
Epidemiological model uncertainty	Mean estimate → Upper 95% credible interval	515 889	628 191	387 088
Model horizon	100 years→ 10 years	1 109 358	1 384 745	1 315 194
Model horizon	100 years→ 25 years	658 252	809 800	747 873
Model horizon	100 years→ 50 years	535 654	653 472	594 193
Vaccine cost both doses	Vaccine price 75% of list price	343 209	443 945	387 088
Vaccine cost both doses	Vaccine price halved	212 680	313 416	256 559
Vaccine cost both doses	Vaccine price 25% of list price	82 151	182 887	126 030
Vaccine administration cost	NOK 175→ Doubled	533 979	634 715	577 858
Healthcare costs related to illness	Documented → Doubled	365 119	467 950	411 093
Healthcare costs related to illness	Documented → Halved	528 047	627 735	570 878

Discount rate QALYs & costs	4%/3%/2% → 0%	312 789	369 171	317 640
Discount rate QALYs & costs	4%/3%/2% → 2%/1.5%/1%	380 154	455 121	401 054
Discount rate QALYs & costs	4%/3%/2% → 6%4.5%/3%	581 280	711 584	652 185
Lower assumed herpes zoster incidence	Using only GP consultations averaged over 2010-2021 as a proxy for HZ incidence in the epidemiological model calibration, resulting in a substantially lower burden of HZ disease in line with previous studies (Marangi 2017, Marchetti 2018)	739 461	912 624	857 185
Less QALY loss assumed due to pain from herpes zoster	Changed assumptions about share of mild/moderate/severe pain to numbers from (Gauthier 2009)	791 785	960 151	865 124
QALY loss herpes zoster-related mortality	QALY loss due to HZ-associated stroke and premature death included as in sensitivity analysis in (Folkhälsomyndigheten 2024)	457 768	555 108	500 167
Pension age	Work force participation change: 60-70 yrs: 0.45 → 0.80 70+yrs: 0.11 → 0.50	473 738	574 474	418 291

Most published health economic evaluations of herpes zoster vaccination of the age group 65+ find herpes zoster vaccination to generate better health and higher costs, with ICERs exceeding cost-effectiveness thresholds if evaluations are based on official list prices (Pieters 2022, de Boer 2018) but reaching cost-effectiveness if discounts are realized. A recent Swedish analysis highlights the impact of input uncertainty on the cost-effectiveness conclusions (Nystrand 2025), this is similar to our experience, the conclusion on herpes zoster vaccination is very sensitive to assumptions made and even small changes in input parameters can substantially impact results.

For the herpes zoster case, the driving uncertainty seems to lie in the epidemiology of the disease, i.e. in estimates of incidence rate and the proportion and prognosis of those developing postherpetic neuralgia. There is a limited number of studies following patients over time with repeated measurements and definitions of postherpetic neuralgia seem to differ. Since the QALY loss to severe pain is very high and the duration of this ailment can be up to one year, the results become very sensitive to the proportion of patients in this state. Our sensitivity analyses indicate that lowering the proportion of patients in the severe pain state (i.e. using another study for input data), increases the ICER to NOK 791 785, 960 151 and 865 124 per QALY gained from the healthcare, extended healthcare and societal perspective.

We further explored the impact of changing the age at vaccination in a scenario without catch-up programme (Figure 14). We see that the optimal age to vaccinate from a purely health economic perspective is 70 years old, as this gives the lowest ICER from all three perspectives. The reason that age 70 is optimal is a balance between the risk of getting HZ, balanced against remaining years to benefit from vaccine protection with waning. Counterintuitively, we find ICERs from the extended healthcare perspective to be highest in this case. For the lower age groups (below 55), the healthcare and societal perspective results in similar ICERs. At the higher age groups, the societal perspective approaches the extended healthcare perspective. This pattern follows from time cost spent on vaccination in the younger age groups in the extended and societal perspective. At lower age, this time cost is offset by reductions in work absenteeism from the societal perspective. For the older age groups, work absenteeism is no

longer a factor, as they are retired, hence the societal perspective approaches the extended healthcare perspective.

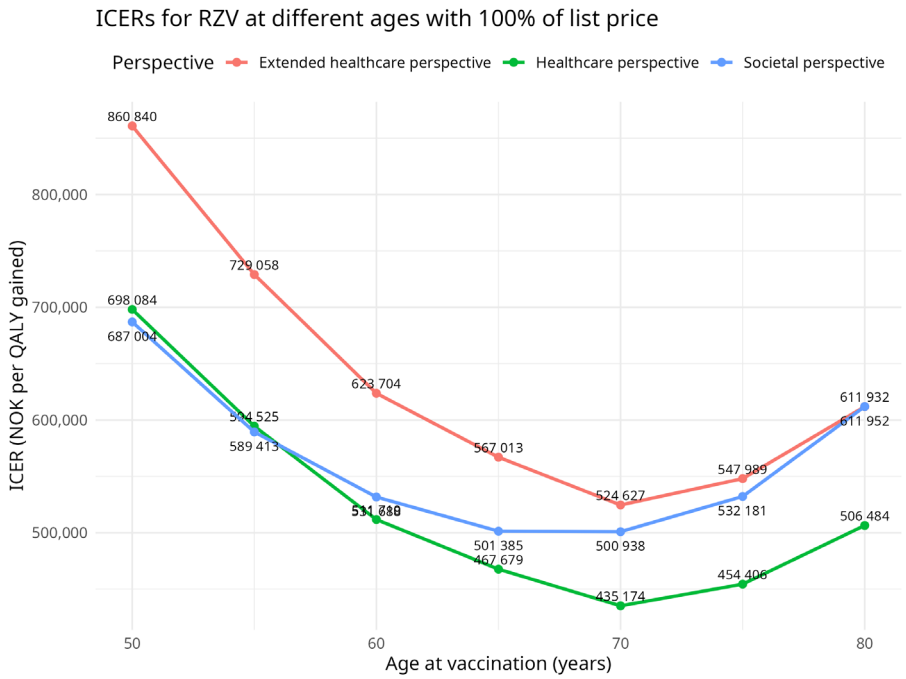


Figure 14: *Incremental cost-effectiveness ratios (ICERs) for herpes zoster vaccination at different ages without any catch-up programme, assuming 100% of list price. Curves show ICERs from the healthcare, extended healthcare and societal perspectives.*

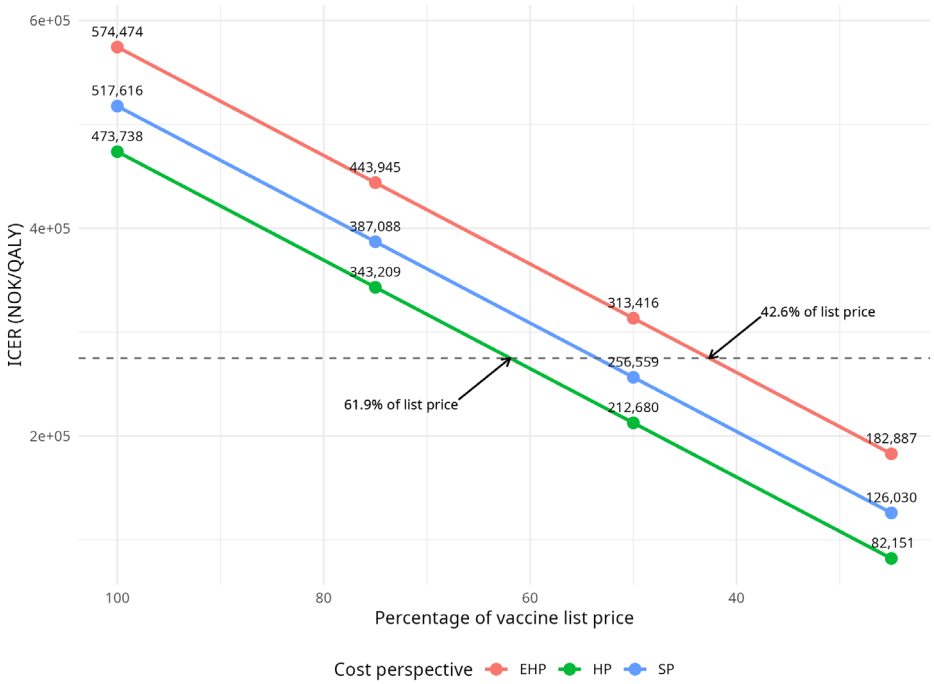


Figure 15: *Incremental cost-effectiveness ratios (ICERs) for herpes zoster vaccination as function of vaccine price obtained. Curves show ICERs from the healthcare, extended healthcare and societal perspectives.*

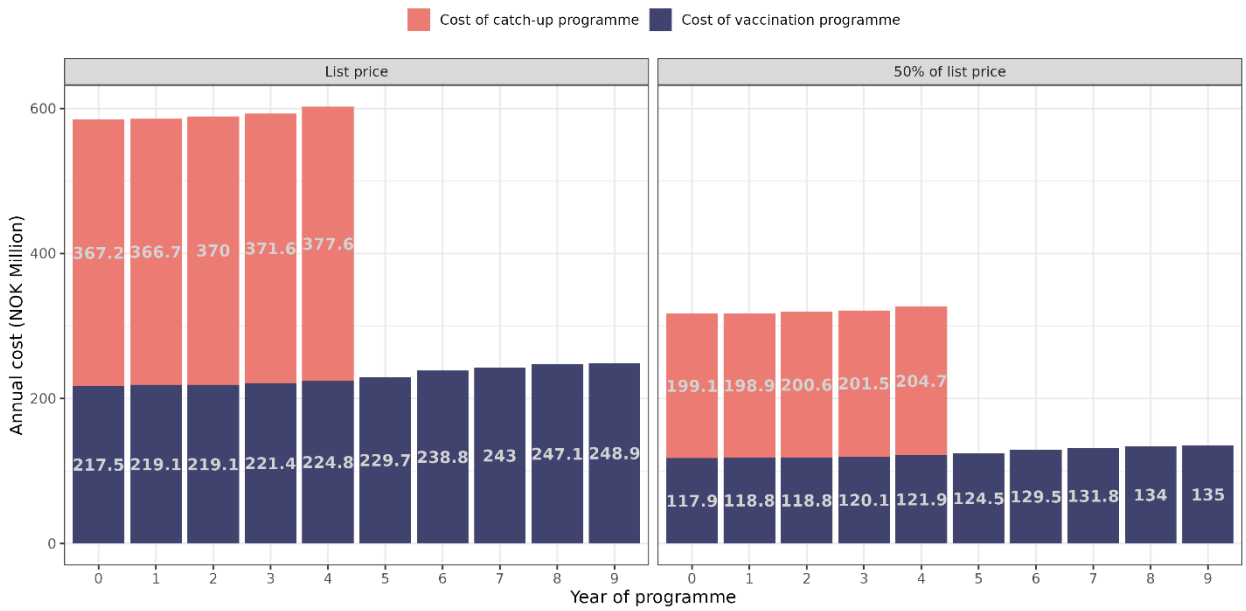


Figure 16: *Budget impact for first 10 years of a national vaccination programme against herpes zoster, in the scenario where vaccination is offered to 65-year olds with catch-up to 70- and 75-year olds, assuming vaccination coverage of 75%. See also table S6 in the supplemental material.*

4 Limitations

The assessment of long-term disease dynamics over a 100-year period is associated with substantial uncertainties. It is important to consider these inherent uncertainties when interpreting the results of long-term disease modelling. The dynamic nature of infectious diseases demands ongoing monitoring to effectively address evolving disease patterns. Among the primary sources of uncertainties are:

- Population dynamics and societal changes. Demographic shifts, population growth, migration patterns, and unpredictable changes in human behaviour significantly influence disease dynamics. The results presented in this report are obtained for a static population at equilibrium, thus not exactly demographically equivalent to the true Norwegian population, in order to isolate and assess the effect of vaccination and do not consider any of these factors. Moreover, the study does not explicitly consider the effect of importation of varicella from other countries, although infection is in practice seeded continuously even after varicella eradication due to herpes zoster-infected individuals having some varicella infectiousness.
- Contact structures: The patterns and frequency of contacts significantly influence transmission dynamics. This study relies on survey-based contact matrices obtained in Norway in 2017 stratifying the population by age groups. While these matrices encapsulate data on the frequency of contacts across age groups in various settings, they are susceptible to sample biases and may not fully reflect current or future contact patterns. Any alterations in the contact matrices could lead to variations in epidemiological patterns. Subsequent studies could be required to assess the model outcomes by incorporating updated contact matrices. Furthermore, the model assumes homogenous mixing of all individuals subject to the contact matrix, and homogenous vaccine uptake in the population. In reality, there could be subgroups of the population where vaccination uptake is low and/or the contact structure is significantly different, and this might lead to outbreaks even with a high overall vaccination coverage.
- Natural history of disease and mechanisms of exogenous boosting. The natural history of disease and mechanisms of exogenous boosting are still not well elucidated. Exogenous boosting might occur when individuals are exposed to the varicella virus through contact with infected individuals, enhancing their immune response and potentially reducing the likelihood of Herpes Zoster infection. Reduced Varicella-zoster virus circulation due to vaccination may limit opportunities for individuals to receive this natural boost, potentially resulting in an increase in Herpes Zoster cases, particularly among older individuals with weakened immune systems. Our model assumes minimal boosting effects, and to date, no significant increase in Herpes Zoster has been observed in countries where the varicella vaccine has been introduced, suggesting limited or negligible exogenous boosting effects (Leung 2022). Nonetheless, the scarcity of historical data related to the introduction of the varicella vaccine constrains the calibration of mathematical models and further research is needed.
- Logistics of the vaccine distribution. The mathematical model assumes that vaccination of individuals occurs in one time step (one week) each year, without considering the logistical challenges of vaccine distribution. In reality, vaccine distribution involves complex logistics, including manufacturing, storage, transportation, and

administration. It is more than likely that vaccines will be administered throughout the year as individual children come in for healthcare appointments. Although we do not expect that such dynamics would affect the overall result of the vaccination campaign, some differences could arise between the model's predictions and observed dynamics. Future studies could incorporate more detailed models of vaccine distribution to better capture its effects on disease dynamics.

- Unforeseen events**.** Occurrences, such as pandemics, climate change, and technological advancements, can disrupt disease dynamics and add another layer of uncertainty. These scenarios cannot be anticipated and quantified and thus are not considered in this modelling work.

5 Methods Epidemiology

5.1 Epidemiological model description

We developed a discrete-time stochastic model with the structure presented in the figure below (Fig. 15). The model has been adapted to study vaccination dynamics for Varicella (Fig. 15A) and Herpes Zoster (Fig. 15B), separately. The compartmental model consists of two categories: non-vaccinated (white) and vaccinated (green). The compartments are:

M: maternally transferred immunity;
S: susceptible;
E: exposed;
I: varicella infectious;
ZS: herpes zoster (HZ) susceptible;
ZI: HZ infectious;
ZP: HZ protected by boosting;
ZR: HZ recovered;

V1: varicella vaccinated, 1st dose;
V2: varicella vaccinated, 2nd dose.

In the model used for the Varicella vaccination, besides natural infection, for those vaccinated (V), there are two ways to develop varicella or HZ: (i) breakthrough of vaccination (with subscript B), for which protection fails and people would be infected by varicella and HZ as non-vaccinated and (ii) reactivation of the vaccine strain (with subscript V), of which develop HZ directly without being varicella infected nor infectious. The stochasticity in the model arises from the probabilistic transitions between compartments, which are implemented as binomial processes.

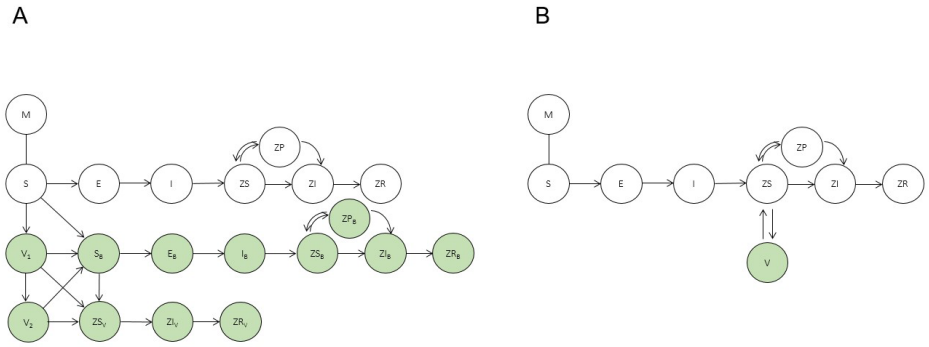


Figure 17: Structure of the compartmental model for varicella (A) and herpes zoster (B) vaccination.

For the herpes zoster vaccine, waning was estimated at 2.5%/year based on a linear fit (from health technology assessment (*metodevurdering*) on varicella vaccination, NIPH (2026)). A slower waning of 1.5% per year was used in sensitivity analyses. The epidemiological model implements this as an exponentially decaying waning, which leads to slightly better protection asymptotically. Figure 18 illustrates the difference between the linear and exponential extrapolations.

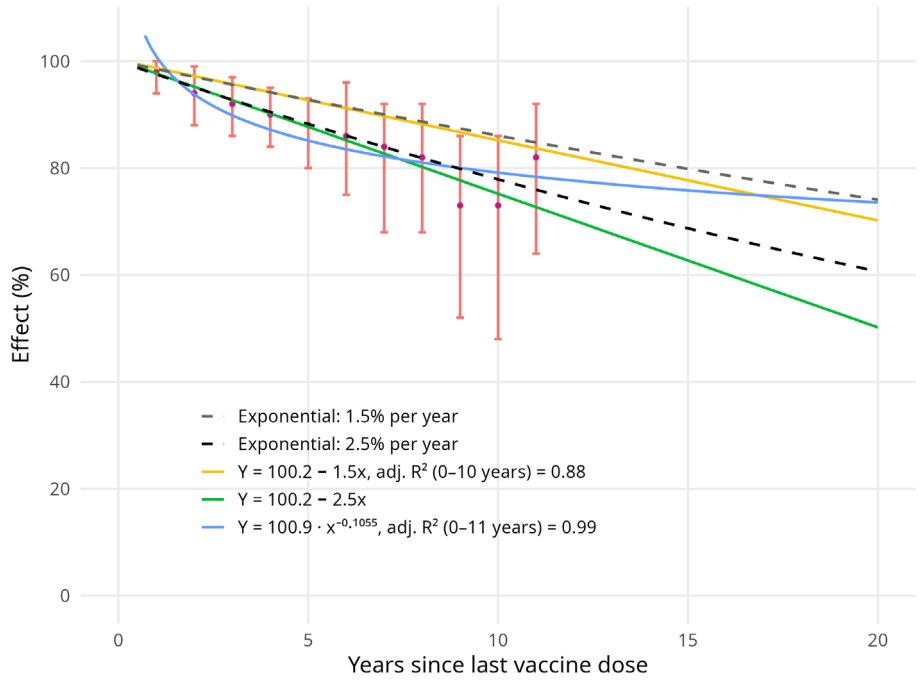


Figure 18: *Estimated waning of the RZV herpes zoster vaccine. Figure adapted from health technology assessment (metodevurdering), with exponentially decaying lines added corresponding to the epidemiological model's assumption for vaccine waning.*

To model the contact patterns in the population we used survey-based Norwegian contact data from 2017 (Fig. 1).

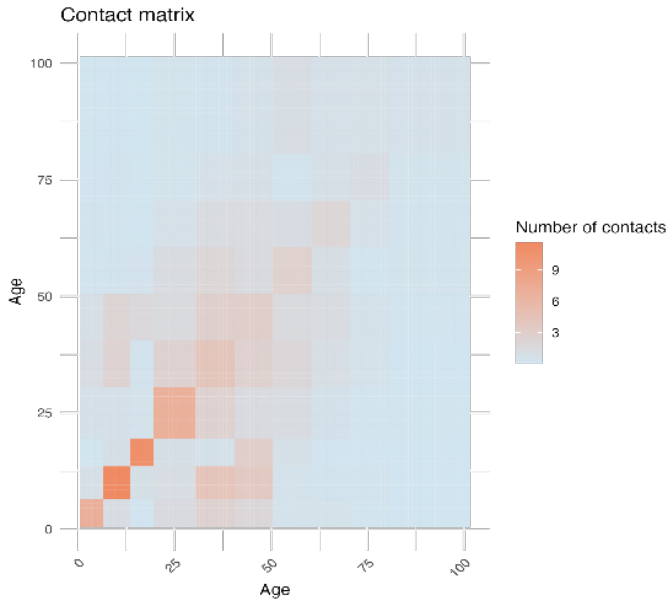


Figure 19*: Contact matrix used in the epidemiological model to define the mixing between age-groups. The data have been collected in a previous Norwegian study from 2017 (Veneti 2024).*

The model has a stationary population, achieved by assuming a constant birth rate equal to the current death rate. We ran the demographic component of the model for 1000 years, allowing the age structure to reach equilibrium before initiating the epidemiological simulations.

Figure 20: *The stationary population distribution of the model together with current and projected distributions of the true Norwegian population. The last group at age 100 includes all people aged >= 100 years.*

5.1.1 Exogenous boosting

Individuals can experience reactivation of latent varicella-zoster virus, resulting in HZ. Exogenous boosting reduces the risk of HZ by temporarily enhancing immunity following exposure to circulating varicella virus, thereby delaying or preventing reactivation. We model exogenous boosting of HZ based on the temporary immunity hypothesis described by Brisson et al. (2010), which assumes that each exposure to varicella confers temporary protection against HZ reactivation. In our model:

- The average duration of this protection is set to 20 years.
- The level of protection per boosting event is assumed to be 30%.

The force of reactivation of HZ, $\varrho(a)$, is an age-dependent parameter representing the instantaneous rate at which reactivation occurs in individuals of age a. This rate reflects the increasing risk of HZ with age, due to factors such as the age-related decline in immune function. The force of reactivation, $\varrho(a)$, is calibrated to fit age-specific HZ incidence data, as described in the calibration section below.

5.2 Calibration of the model

We calibrated the model to represent the current endemic circulation of Varicella-Zoster virus in Norway prior to the introduction of vaccination. Calibration relied on two key data sources: age-specific seroprevalence of varicella to estimate the force of infection, and age-specific incidence of zoster to estimate the reactivation rate (see Data section below).

Model parameters were sampled using Latin Hypercube Sampling (LHS) within predefined parameter ranges to efficiently explore the parameter space. For each sampled parameter set, the model was simulated, and its output was compared to the observed data using mean squared error (MSE) as the distance metric, d. After running a predefined number of simulations (n = 100,000), we retained only the top parameter sets with an MSE below the threshold. The threshold for retention was determined by visually identifying the “elbow” in

the distance distribution, indicating the point beyond which improvements in model fit yield only marginal gains. The retained parameter sets define an empirical posterior distribution consistent with the observed epidemiological data.

5.2.1 Varicella calibration

The force of infection for varicella was estimated using age-specific seroprevalence data (Rimseliene 2016). We assumed that only individuals infected with varicella contribute to transmission, neglecting the infectiousness of HZ cases at this stage. We fit an SIR-type model to the age-stratified seroprevalence data, thereby inferring the varicella force of infection required to reproduce the observed immunity profile in the population.

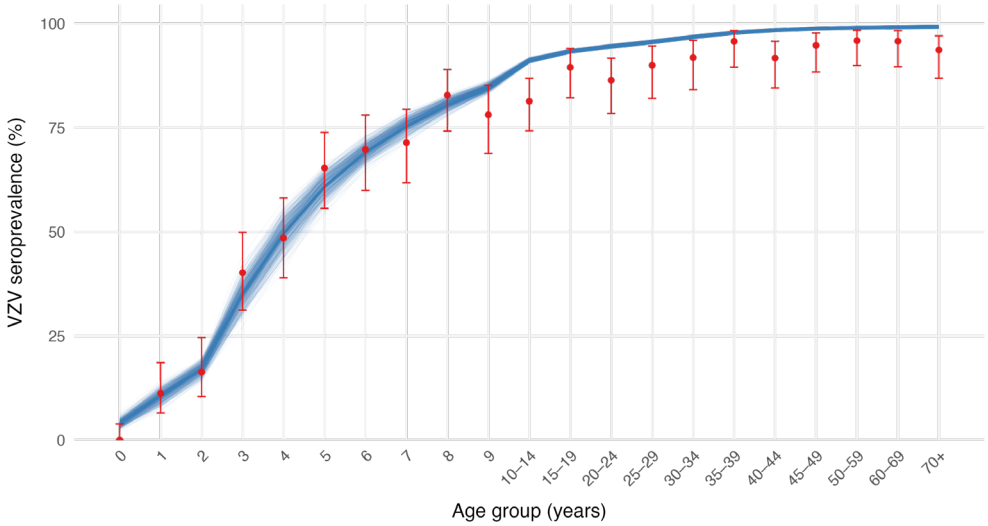


***Figure 21**: Age-specific seroprevalence of varicella infection. Red dots represent observed serological data. Each blue line shows the output from an individual model simulation.*

5.2.2 Herpes zoster calibration

To estimate the parameters governing HZ reactivation, we use Norwegian annual general practitioner (GP) consultations and emergency room visits for HZ from 2022-2024, stratified by age. The force of reactivation, ϱ(a), is modelled as an age-dependent function based on the form proposed by Brisson et al. (2010) with four free parameters:

$$\rho(a) = \psi e^{-\phi a} + \pi a^{\sigma}$$

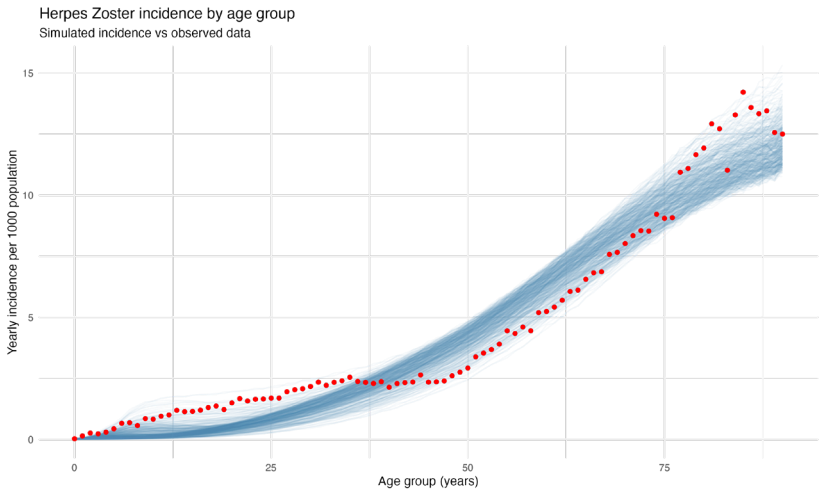


***Figure 22**: Age-specific incidence of zoster. Red dots represent the average annual GP and emergency room visit rates for zoster reported between 2022 and 2024 in Norway. Each blue line corresponds to a single simulation run of the model.*

5.2.3 Epidemiological and immunological parameters

The model relies on a set of epidemiological and immunological parameters that govern the transmission dynamics of Varicella-Zoster virus and the reactivation process leading to Herpes Zoster. These parameters include rates of infection, recovery, waning immunity, boosting, reactivation, and age-dependent transitions across immunity states. The values were selected based on literature, expert judgment, or derived through calibration against empirical data, as described above. The Varicella reproduction number estimated using next generation matrix approach is 6.9 (95%CI 6.6 - 7.2).

A summary of the main model parameters is presented in the table below.

Parameter	Value	Description	Source
wm	0.0056/days	Waning rate of maternal immunity	Brisson M et al., Epidemiol Infect, 2000
gamma	0.1429/days	Recovery rate from VZV infection (I → ZS)	Brisson M et al., Epidemiol Infect, 2000
zeta	0.1/days	Recovery rate from HZ infection (ZI → ZR)	Brisson M et al., Epidemiol Infect, 2000
alpha	0.071/days	Incubation rate from exposed to infectious (E → I)	Brisson M et al., Epidemiol Infect, 2000
delta	0.05/years	Waning rate of exogenous boosting from ZP → ZS	Widgren K et al., Vaccine, 2022; Expert opinion
eta	0.7	Modulation of reactivation rate from ZP → ZI	Widgren K et al., Vaccine, 2022; Expert opinion
beta	0.0071 (95% CI 0.0067, 0.0075)	Varicella force of infection (calibrated)	Calibrated
psi	4.95 (95% CI 0.298, 9.76) $x10^{-6}$	Parameter in the reactivation rate, ρ	Calibrated
phi	0.25 (95% CI 0.025, 0.49)	Parameter in the reactivation rate, ρ	Calibrated
pi	1.68 (95% CI 0.08, 4.02) $x10^{-9}$	Parameter in the reactivation rate, ρ	Calibrated

sigma	2.41 (95% CI 2.12, 3.01)	Parameter in the reactivation rate, ρ	Calibrated
theta	0.1	Reduction in HZ reactivation rate, ρ, in breakthrough infections (ZSb → ZIb)	Widgren K et al., Vaccine, 2022
chi	0.1	Reduction in HZ reactivation rate, ρ, in vaccinated states (V1/V2 → ZIv)	Widgren K et al., Vaccine, 2022

5.2.4 Scenario simulations

For each scenario, we conduct 500 simulations by sampling distinct parameter sets consistent with the best-fit calibration of the model to the current endemic circulation of varicella. Each simulation spans 110 years, beginning 10 years prior to the introduction of the vaccination campaign.

5.2.5 Demographic projections

For the health-economic analyses we project the modelled, stationary age distribution of the population onto the real population distribution of Norway. To be able to project 100 years into the future, we use a scenario for population demographics until 2100 from SSB (Hovedalternativ, MMM, Statistics Norway 2024 ref), see Fig. 19, and thereafter we repeat the projected demography of year 2100 year until the year 2124. The projection is performed for each epidemiological outcome (yearly incidence of varicella infections, yearly incidence of herpes zoster infections, etc) and for each age, each year. I.e., letting I_{kl} be the modelled incidence for age k at year l, N_k the number of persons age k in the model and M_{kl} the number of persons age k at year l in the SSB projections, we obtain the projected I'_{kl} as

$$I'_{kl} = I_{kl} * M_{kl} / N_k$$

5.3 Epidemiological data

5.3.1 Seroprevalence data of varicella

To calibrate the Varicella transmission rate of the epidemiological model, we used age-specific Varicella-Zoster virus seroprevalence measured among a subset of the Norwegian population (n = 2103). The data are based on residual serum samples collected in 2006, 2007, 2008, 2011, and 2014, excluding samples obtained during the 2009–2010 influenza pandemic. The data were obtain from Table 1 in Rimseliene G. et al., BMC Infectious Diseases, 2016 (https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-016-1581-4/tables/1).

5.3.2 Incidence data of zoster infections

Yearly numbers of GP consultations and emergency room visits for HZ by 1-year-age group for the years 2022, 2023 and 2024 have been used as a proxy for the HZ incidence to calibrate the reactivation rate of HZ. The data were obtained from KPR (the Municipal Patient and User Registry - Kommunalt pasient- og brukerregister, KPR).

6 Methods Health Economics

6.1 Varicella

With basis in the mathematical infection model, we have assessed the cost-effectiveness of including vaccination against varicella in the national vaccination programme for children in Norway. Due to the demographic equilibrium assumption in the model, its population age distribution does not completely match reality. For the economic calculations, we have therefore projected the epidemiological outputs of the model by age onto realistic population sizes. To be able to do this prospectively for 100 years, we have used a population projection scenario from SSB. The health economic evaluation is performed by attaching costs and decrements in quality of life to the predicted number of cases with varicella and herpes zoster.

The cost-effectiveness analysis compares two scenarios for a two-dose national vaccination programme (coverage of 96%, doses at ages 15 month and 7 years): one without a catch-up and one with a stretched MAC catch-up, both compared against a control scenario with no varicella vaccination. The results of the economic evaluation are presented from three perspectives: a healthcare perspective, an extended healthcare perspective (which is the perspective recommended for medical products in Norway (Helse 2025; Direktoratet for medisinske produkter 2025b) and a societal perspective respectively (Folkehelseinstituttet 2019). Health effects are assed as quality-adjusted life years (QALYs).

Vaccination prices for the two available monovalent varicella vaccines in Norway, were taken to be the pharmacy purchase prices of NOK 330,00 (Varilrix) NOK 444,41 (Varivax) respectively (Direktoratet for medisinske produkter 2025a). Both vaccine doses will be given during already scheduled vaccination visit in the child vaccination programme. The additional vaccine administration cost was thus set to NOK 175, which corresponds to the marginal opportunity cost of a specialist nurse for 15 minutes, which was assumed to be the extra time necessary to prepare the vaccine, inform the child's caregiver about the vaccine, administer the vaccine and register the vaccination in the patient's medical journal (Direktoratet for medisinske produkter, 2025c). Medical resource use and cost data for varicella and herpes zoster were based on scientific publications (Mirinaviciute 2017; Mirinaviciute 2020; Haugnes 2019), with the medical care costs updated to current prices (Statistics Norway 2025a; Helsebiblioteket 2012) (ref).

For the extended healthcare perspective, we include patient and care-givers direct transportation cost in relation to healthcare-seeking as well as the value of the opportunity cost of lost leisure time during care-seeking. The average transportation cost was assumed to be NOK 200 (Direktoratet for medisinske produkter, 2025c). The value of the opportunity cost of time for adults was calculated based on the net average salary (Statistics Norway). We included the opportunity time cost for adults and for a caregiver per child under the age of 18 years seeking care. There is no established method for estimating the value of lost leisure time for children (Andronis 2019), therefore this was not included in the analysis, which therefore constitutes an underestimation of the indirect costs savings for patients under the age of 18 years in the analysis. The opportunity time cost of a caregiver accompanying the child was set to 5 minutes per dose. Direct transportation costs and indirect costs of leisure time were estimated for care-seeking related to varicella in the control arm, which then constituted a cost-saving in the intervention arm following vaccination.

For the societal perspective, indirect cost caused by caregivers' time off due to illness in children was derived from days of caregiver leave reported to the Swedish Social Insurance Agency, which was deemed a reasonable proxy for the situation in Norway since statistics for caregiver time off for specific diseases is not systematically reported in Norway (Swedish Social Insurance Agency 2024). Average annual rates over the period 2011-2019 were used since the varicella epidemic showed a different pattern due to the Covid pandemic, with less cases in 2020-2021 and then an increase in older children in 2022-2023. Productivity loss for individuals 15 to 74 years old affected by varicella or herpes zoster was based on available estimates from the literature paired with expert advice (Nilsson 2015). Productivity loss was calculated based on the average gross salary rate in Norway, adjusted for age-adjusted labor market participation (Statistics Norway 2025b, 2025c). All costs are presented in NOK 2024 values. Cost and health effects were discounted over the time horizon of the model (Four percent annually over the first 39 years, 3% years 40-74 and 2% years 75 to 100) according to national guidelines (DFØ 2025; Ministry of Finance 2021, Direktoratet for medisinske produkter, 2025b). Utilities weights for varicella and herpes zoster were based on secondary sources age-adjusted to general population utility values for Norway and recalculated to disutilities applied to cases of varicella and herpes zoster (Rodrigues 2023; Oster 2005; Van Hoek 2009, 2021; Gauthier 2009; Pieters 2022; Garratt 2022). The duration and degree of reduced quality of life varied with age and the degree of medical care needed for both varicella and herpes zoster (see Table 5 for details). We have not assumed a quality-of-life reduction due to side effect of the vaccination per se, and this needs to be taken into consideration when evaluating the results. Generally, most side effects are mild and transient. Febrile seizures are possible side effect after varicella vaccines, and they are observed more frequently after the tetravalent vaccine than after the monovalent varicella vaccine (Gidengil 2021; Di Pietrantoni 2021). The cost per QALY gained from the intervention are within the lowest level of the willingness-to-pay thresholds groups in Norway which means that the results (from a healthcare perspective) are valued against a threshold of NOK 275,000 (Helse- og omsorgsdepartementet, 2015b). All input parameters used in the health economic analysis are presented in tables 5 and 6 at the end of this report.

The uncertainty ranges presented in the main results tables are based on uncertainty in the epidemiological input parameters only, arising from the stochastic nature of the model (see Methods below). Healthcare costs and production loss estimates were included as mean values without uncertainty ranges in the model analysis, however one- and two-way sensitivity analyses were conducted to assess the impact of changes in the cost estimates and other key parameters on the results. Parameter values varied in sensitivity analyses and their impact on the results are presented in Table 2.

6.2 Herpes zoster

With basis in the mathematical infection model, we have assessed the cost-effectiveness of including vaccination against herpes zoster in the national vaccination programme for adults in Norway. In our base case analysis, we analysed vaccination of 65 years old persons. The age at vaccination was varied in a scenario analysis. The list price of the vaccine was 1733,41 NOK per dose, full vaccination requiring two dosages.

The incidence of herpes zoster infection was based on the number of GP and emergency room consultations from the Norwegian Registry of Primary Healthcare. We assumed all cases would need to visit their general practitioner and that approximately half of the patients would be treated with antiviral medications and painkillers. Further, some patients would require a visit

to specialist healthcare, and some would be admitted to the hospital (Table 6). Patients with herpes zoster could experience mild, moderate or severe pain because of the rash, and to each pain category, a separate utility weight was assigned. The primary infection was assumed to last one month. For patients who are not retired, loss of production was included in the societal perspective. On average, we assumed that infection with herpes zoster would require five days of sick leave.

Dependent on age, some patients would experience pain lasting for more than one month, defined as incident post herpetic neuralgia (PHN). Patients with PHN could similarly experience mild, moderate or severe pain, again with separate utility weights assigned to each health state. For the three PHN severity levels, the duration of symptoms was assumed to be different, with mild, moderate and severe pain lasting respectively seven, ten and thirteen months. The same health-related quality of life weights was used for HZ and PHN, depending on pain severity level. The duration of HZ and PHN is different and the probability of developing mild, moderate and severe pain, respectively, differ for HZ and PHN. Treatment of PHN consisted of mediatization use (amitriptyline), over the age of 50 years old, all patients would be treated with medications. A patient with PHN in need of medical care was assumed to visit their general practitioner five times. The need for primary care related to PHN varied according to age, with older age groups needing more care (Table 6). In the extended healthcare and societal perspectives, cost of transportation was added to each healthcare visit.

Parameter values were varied in a one-way sensitivity analysis, their impact on the results are presented in Table 4.

Table 5: Health economic input parameters for varicella, all costs in NOK

Parameter	Value	Assumption and source
Healthcare costs		
Vaccine costs monovalent vaccines, AIP without (with) VAT	Varilrix: 330,- (412,50) Varivax: 444,41 (555,51) *(all cost analyses use the average price between the two vaccines)*	Legemiddelsok.no (accessed 28.11.2025)
Cost of vaccine administration	175	~15 minutes specialised nurse time; DMP 2025c
Caregiver opportunity cost of lost leisure time administration of dose 1 (5 minutes)	30	DMP 2025c
Incident cases varicella per 1000 individuals pre-vaccination, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	105.1, 53.1, 9.0, 7.0, 3.8, 0.6	Model output
Primary care visits / incident cases, %, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	23.5, 20.6, 24.5, 18.3, 27.6, 29.2	Based on Mirinaviciute 2017
Primary care visits / incident cases with varicella as secondary diagnosis, %, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	1.0, 0.8, 1.0, 0.7, 1.1, 1.2	
Pharmaceutical need /primary care visits, %, age 20+	90%	Based on Mirinaviciute 2017
Specialized outpatient care visits /incident cases, %, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.3, 0.2, 0.2, 0.3, 0.5, 1.4	Based on Mirinaviciute 2017
Specialized outpatient care visits with varicella as secondary diagnosis / incident cases, %, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.10, 0.04, 0.10, 0.10, 0.10, 0.30	

Specialized inpatient care visits /incident cases, %, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.2, 0.1, 0.2, 0.2, 0.4, 1.1	Based on Mirinaviciute 2017
Specialized inpatient care visits with varicella as secondary diagnosis /incident cases, %, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.1, 0.1, 0.1, 0.1, 0.2, 0.5	
Cost per primary care visit	386	DMP 2025c
Cost per specialized care visit	2,716	Haugnes 2019
Cost per inpatient admission	86,134	Haugnes 2019
Transportation cost	200	Caregiver or patient (if over 18 years) from DMP, personal communication)
Time cost GP visit	656	Caregiver or patient (if over 18 years) opportunity cost of lost leisure time - primary care visit (2 hours * 328)
Time cost specialist care visit	985	Caregiver or patient (if over 18 years) opportunity cost of lost leisure time - specialised care visit (3 hours *328)
Time cost hospital admission	15,755	Caregiver or patient (if over 18 years) opportunity cost of lost leisure time – inpatient admission (average 3 days * 16 hours per day * 328)
Antivirals	408.98 (545.30)	Cost pharmaceuticals varicella valaciclovir 500 mg, 42 psc) without (with VAT), only for age 20+
Loss of production: Caregiver and sick leave and salary and employment statistics		
Loss of production, %, child age 0-4, 5-9, 10-14	29, 48, 20	Caregivers taking days of caring for child with varicella / incident cases,
Caregiver days of caring for child with varicella, mean, child age 0-4, 5-9, 10-14	3.5, 3.4, 3.4	Swedish statistics and expert advice – see text for details
Days of work due to varicella, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	3.0, 3.0, 4.0	Swedish statistics and expert advice – see text for details
Workforce participation %, age 0-14, 15-19, 20-39, 40+	81, 42, 78, 41	For caregivers of children up till age 14
Unit price per day off work	4,654	Average gross production loss per workday 2024 (DMP enhetskostnader)
Quality of life impact: Health utilities and illness duration		
Utility general population, age 0-14, 15-19, 20-39, 40+	1.00, 0.96, 0.89, 0.86	Assumption for children, Garratt 2024 for adults
Quality adjusted life days (QALD) lost varicella in case of hospitalisation	9.8	Rodrigues 2023
QALD lost varicella in case of medical care seeking	2.0	Rodrigues 2023
QALD lost varicella with no need for medical care , 0-14, 15+	0.5, 1.0	estimate
QALDs lost per varicella episode age-adjusted, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.8, 0.9, 0.8, 1.1, 1.2, 1.3	Derived quantity
QALDs lost per varicella breaktrhough episode, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.5, 0.5, 0.5, 1.0, 0.9, 0.9	Derived quantity
QALY loss per varicella episode mean, age 0-4, 5-9, 10-14, 15-19, 20-39, 40+	0.0022, 0.0021, 0.0023, 0.0031, 0.0033, 0.0033	Derived quantity
QALY loss per varicella breakthrough episode, mean, age 0-14,15-19, 20-39, 40+	0.0014, 0.0026, 0.0024, 0.0023	Derived quantity

Table 6: *Cost and quality of life data used as input to health-economic model - herpes zoster.*

Parameter	Value	Assumptions and source
Cost of vaccine per dose, AIP without (with) VAT	Shingrix: 1 733,41 (2 166,76)	Legemiddelsok.no (accessed 28.11.2025)
Cost of vaccine administration	200	Expert advice
Epidemiology		
Incident cases HZ per 1000 individuals, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.5, 1.8, 3.7, 5.9, 8.9, 11.7	KPR
Primary care visits HZ %, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	116, 127, 146, 153, 165, 182	KPR
Pharmaceutical need /incident cases HZ, %, **age 10 – 49, 50 +**	54, 67	Södergren 2024
Specialized outpatient care visits/incident cases HZ, %, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	9, 5.9, 7.0, 7.8, 10.2, 14.4	Based on Haugnes 2019
Inpatient admissions /incident cases HZ, %, **age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +**	3.2, 2.1, 2.5, 2.7, 3.6, 5.1	Mirinaviciute 2020
Primary care need PHN/incident cases HZ, % , age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.0, 6.4, 10.7, 11.3, 17.1, 24.5	Södergren 2024
Primary care visit per PHN case	5.0	Secondary data Sweden (Wolff 2021/Nystrand 2023)
Pharmaceutical need /PHN cases, %, **age 10 – 49, 50+**	80, 100	Assumption
Healthcare costs		
Cost per primary care visit, mean	386	Haugnes 2019 updated with DMP rates
Cost per specialized care visit, mean (SD)	1,832 (789)	Haugnes 2019
Cost per inpatient admission, mean (SD)	93,611 (61,113)	Haugnes 2019
Transportation cost	200	Caregiver or patient (if over 18 years) transportation cost associated with care-seeking. Assumption anchored with DMP
Time cost GP visits	656	Caregiver or patient (if over 18 years) opportunity cost of lost leisure time - primary care visit (2 hours * NOK 328), time assumption * net pay
Time cost specialist care visit	985	Caregiver or patient (if over 18 years) opportunity cost of lost leisure time - specialised care visit (3 hours * NOK 328). Time assumption * net pay
Time cost hospital admission	36,761	Caregiver or patient (if over 18 years) opportunity cost of lost leisure time – inpatient admission (average 7 days * 16 hours per day *, NOK 328)Mirinaviciute 2020 * net pay
Treatment cost herpes zoster	480.56 (649.40)	Cost pharmaceuticals herpes zoster (valaciclovir 500 mg, 42 psc, Paralgin forte 400 mg/30 mg, 20 psc) AIP (AUP). Drug & dose expert estimate Sweden
Treatment cost postherpetic neuralgia (PHN)	643.58 (858.10)	Cost pharmaceuticals PHN (amitriptylin 10 mg, 100 pcs + 25 mg, 100 pcs*3?) AIP (AUP)
Loss of production: Caregiver and sick leave and salary and employment statistics		
Caregiver days of caring for child age 0-9 with HZ, mean	1.6	Swedish Social Insurance Agency

Days off work due to herpes zoster age 10 – 49, 50+	4.0, 5.0	Nilsson 2015
Workforce participation (for caregivers up till age 14), %, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	81, 70, 75, 45, 11, 0	Statistics Norway
Average gross production loss per workday 2024	4,654	DMP unit cost database
Quality of life impact: Health utilities and illness duration		
Utility mild pain	0.91	Oster 2005, Van Hoek 2009
Utility moderate pain	0.71	Oster 2005, Van Hoek 2009
Utility severe pain	0.32	Oster 2005, Van Hoek 2009
Utility general population, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	1.00, 0.90, 0.87, 0.89, 0.86, 0.81	Garratt 2024 for adults
Age-adjusted disutility mild pain HZ, age 0 – 49, 50+	0.02, 0.01	Derived quantity
Age-adjusted disutility moderate pain HZ, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.22, 0.21, 0.19, 0.19, 0.19, 0.17	Derived quantity
Age-adjusted disutility severe pain HZ, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.61, 0.58, 0.53, 0.53, 0.53, 0.48	Derived quantity
Duration HZ initial manifestation (months)	1	Assumption
Share of patients with persisting pain following HZ, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0%, 6.4%, 12.0%, 17.5%, 24.5%, 27.5%	0 <50 yrs Södergren 2024, 50+ years Gauthier 2009
Proportion of mild/moderate/severe pain during initial manifestation of HZ for ages <50 , >50	24%/4%/8%, 18.6%/17.8%/63.6%	Curran 2022, Gauthier 2009, Pieters 2022
Proportion of mild/moderate/severe persisting pain	42%/49%/9%	Gauthier 2009
Duration of persisting pain if mild/moderate/severe (months)	6.7/10.0/12.5	Gauthier 2009
Utility loss during herpes zoster episode, mean, age 0 –69, 70+	0.09, 0.11	Derived quantity
QALY loss initial manifestation HZ (month 1), mean, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.0051, 0.0049, 0.0045, 0.0053, 0.0052, 0.0048	Derived quantity
QALY loss persisting pain, mean, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.0045, 0.0043, 0.0118, 0.0157, 0.0221, 0.0237	Derived quantity
QALY loss per incident herpes zoster case (incl. persisting **pain), mean**, age 0 – 9, 10 – 49, 50 – 59, 60 – 69, 70 – 79, 80 +	0.0096, 0.0092, 0.0163, 0.0209, 0.0274, 0.0285	Derived quantity

7 Supplementary material

7.1 Supplementary tables

Table S1: *Varicella vaccination scenarios. Detailed health economic cost and QALY breakdowns for a 100-year perspective. Uncertainty intervals represent within-scenario 95% credible intervals from the epidemiological model only. Sensitivity analyses on costs and QALY are presented separately. Full list price of the vaccines is assumed.*

Scenario	Vaccination with SMAC catch-up	Vaccination, no catch-up	Control scenario (no vaccination)
	Epidemiological outcomes		
Cumulative number of varicella infections	39 853	252 045	5 882 048
Cumulative number of herpes zoster infections	1 939 529	2 019 078	2 815 050

Cumulative number of PHN cases	333 074	346 655	451 993
Cumulative number of vaccine doses administered	11 309 610	10 782 012	0
	QALYs		
Cumulative QALYs lost due to varicella infections	50	458	3 590
Cumulative QALYs lost due to herpes zoster infections	36 440	36 812	39 138
Total cumulative QALYs lost due to varicella and herpes zoster infections	36 490	37 270	42 728
Incremental QALY gain due to avoided varicella infections in vaccination scenario compared to control	3 540	3 132	0
Incremental QALY gain due to avoided herpes zoster infections in vaccination scenario compared to control	2 698	2 326	0
Total incremental QALY gained in vaccination scenario compared to control	6 238	5 458	0
Total incremental QALY gain per treated individual	0.0005515	0.0005062	0
	Cost components (NOK)		
Vaccination costs (vaccine + administration) – without VAT (A)	1 767 785 405	1 501 949 315	0
Healthcare costs varicella	12 445 322	81 823 403	604 613 614
Healthcare costs herpes zoster	4 204 127 409	4 251 269 504	4 558 878 303
Direct healthcare costs (B)	4 216 572 731	4 333 092 907	5 163 491 917
Total direct healthcare costs (A + B)	5 984 358 136	5 835 042 222	5 163 491 917
Healthcare perspective: Cost difference vs control	820 866 218	671 550 305	0
Value of lost leisure time for caregivers due to child vaccination	47 205 392	44 350 014	0
Transportation costs associated with care-seeking for varicella	1 098 246	9 798 850	77 447 151
Value of lost leisure time associated with primary care-seeking for varicella	3 458 456	31 230 621	247 095 696
Value of lost leisure time associated with secondary care-seeking for varicella	113 399	728 903	5 718 560
Value of lost leisure time associated with in-patient care-seeking for varicella	1 639 611	10 187 042	74 991 338
Transportation costs associated with care-seeking for herpes zoster	199 977 188	202 267 241	218 738 291
Value of lost leisure time associated with primary care-seeking for herpes zoster	616 270 812	623 335 521	674 421 029
Value of lost leisure time associated with secondary care-seeking for herpes zoster	68 680 252	69 454 322	74 493 561
Value of lost leisure time associated with inpatient care-seeking for herpes zoster	1 482 077 422	1 498 766 046	1 607 125 586
Total direct and indirect care-seeking costs ©	2 420 520 779	2 490 118 559	2 980 031 211
Total extended healthcare costs (A + B + C)	8 320 670 797	8 239 525 062	8 049 234 443
Extended healthcare perspective: Cost difference vs. control	271 436 354	190 290 619	0
Production loss varicella	147 763 478	1 283 453 088	9 153 479 771
Production loss herpes zoster	4 210 514 903	4 265 674 490	4 811 541 176
Total indirect production loss (D)	4 358 278 381	5 549 127 578	13 965 020 946
Total societal costs (A + B + C + D)	12 678 949 178	13 788 652 640	22 014 255 390
Societal perspective: Cost difference vs. control	-9 335 306 212	-8 225 602 750	0
Incremental cost-effectiveness ratios (ICER), expressed as NOK/QALY. Based on list price of vaccine.			
ICER in healthcare perspective: Cumulative cost per QALY gained (NOK). Vaccine price 100% of list price.	131 946	123 399	0

ICER in extended healthcare perspective: Cumulative cost per QALY gained (NOK). Vaccine price 100% of list price.	43 904	35 264	0
ICER in societal perspective: Cumulative cost per QALY gained (NOK). Vaccine price 100% of list price.	-1 497 253	-1 507 821	0

Table S2: Herpes zoster vaccination scenarios. Detailed health economic cost and QALY breakdowns.

Scenario	**Vaccination scenario assuming VE 95%, uptake 75%, vaccination 65y, catch-up 70&75y**	**Control scenario (no vaccination)**
	Epidemiological outcomes	
Cumulative number of varicella infections	5 874 039	5 881 338
Cumulative number of herpes zoster infections	2 059 590	2 815 093
Cumulative number of PHN cases	314 244	452 000
Cumulative number of vaccine doses administered	5 815 989	0
	QALYs	
Cumulative QALYs lost due to varicella infections	3 583	3 588
Cumulative QALYs lost due to herpes zoster infections	27 435	39 141
Total cumulative QALYs lost due to varicella and herpes zoster infections	31 018	42 729
Incremental QALY gain due to avoided varicella infections in vaccination scenario compared to control	5	0
Incremental QALY gain due to avoided herpes zoster infections in vaccination scenario compared to control	11 706	0
Total incremental QALY gained in vaccination scenario compared to control	11 711	0
Total incremental QALY gain per treated individual	0.0020136	0
	Cost components (NOK)	
Vaccination costs (vaccine + administration) – without VAT (A)	6 812 800 791	0
Healthcare costs varicella	601 572 304	604 338 167
Healthcare costs herpes zoster	3 289 877 749	4 559 141 005
Direct healthcare costs (B)	3 891 450 052	5 163 479 171
Total direct healthcare costs (A + B)	10 704 250 844	5 163 479 171
Healthcare perspective: Cost difference vs control	5 540 771 672	0
Transportation costs associated with care-seeking for varicella	77 307 476	77 412 666
Value of lost leisure time associated with primary care-seeking for varicella	246 675 736	246 985 780
Value of lost leisure time associated with secondary care-seeking for varicella	5 688 781	5 715 910
Value of lost leisure time associated with in-patient care-seeking for varicella	74 550 827	74 956 958
Transportation costs associated with care-seeking for herpes zoster	160 736 732	218 751 920
Transportation cost associated with vaccination against herpes zoster	704 744 549	0
Value of lost leisure time associated with primary care-seeking for herpes zoster	496 219 067	674 463 230
Value of lost leisure time associated with secondary care-seeking for herpes zoster	53 728 631	74 497 782
Value of lost leisure time associated with inpatient care-seeking for herpes zoster	1 157 783 404	1 607 216 505
Total direct and indirect care-seeking costs ©	4 133 216 264	2 980 000 752

Total extended healthcare costs (A + B + C)	14 767 715 951	8 049 187 045
Extended healthcare perspective: Cost difference vs. control	6 718 528 907	0
Production loss varicella	9 135 039 443	9 149 567 319
Production loss herpes zoster	4 160 456 729	4 811 777 971
Total indirect production loss (D)	13 295 496 172	13 961 345 289
Total societal costs (A + B + C + D)	28 063 212 124	22 010 532 334
Societal perspective: Cost difference vs. control	6 052 679 790	0
Incremental cost-effectiveness ratios (ICER), expressed as NOK/QALY. Based on list price of vaccine.		
ICER in healthcare perspective	473 738	0
ICER in extended healthcare perspective	574 474	0
ICER in societal perspective	517 616	0

Table S3: *Estimated yearly incidence of varicella infections in the control scenario without vaccination and in varicella vaccination scenario with and without catch-up. Numbers shown are mean (95% credible interval). The vaccine programme starts in year 0. Vaccination uptake is 96%.*

	Yearly incidence of new varicella infections		
year	Stretched MAC catch-up	Vaccination without catch-up	No vaccination
0	10836 (7916–14534)	41999 (31674–53027)	59247 (46443–74425)
1	1004 (648–1533)	32245 (22459–43787)	58886 (45707–72278)
2	778 (512–1147)	34847 (26060–44365)	57791 (44606–72804)
3	396 (298–532)	43540 (33573–55004)	57664 (44749–73322)
4	354 (273–459)	44286 (34065–54638)	57637 (45266–72796)
5	331 (264–424)	7606 (5130–10534)	57553 (45522–71437)
6	325 (250–428)	1136 (713–1873)	57418 (44036–72915)
7	322 (254–403)	830 (549–1208)	58310 (46919–71151)
8	332 (262–429)	753 (534–1048)	59091 (45552–73956)
9	344 (266–436)	672 (489–891)	58839 (45429–72637)
10	356 (279–443)	593 (453–779)	59476 (45856–73350)

Table S4: *Estimated budget impact (in million NOK) for the first 10 years of a varicella vaccination programme and a stretched-MAC catch-up under two price assumptions. Vaccination uptake is 96%.*

Year	Item	At list price	At 50% of list price
0	Programme	32.04	20.27
0	Catch-up	58.78	37.20
1	Programme	32.8	20.76
1	Catch-up	66.72	42.22
2	Programme	33.61	21.27
2	Catch-up	41.71	26.39
3	Programme	34.47	21.81
3	Catch-up	52.1	32.97
4	Programme	35.37	22.38
4	Catch-up	40.36	25.54
5	Programme	36.16	22.88
5	Catch-up	46.25	29.27
6	Programme	67.45	42.68
6	Catch-up	16.6	10.51
7	Programme	69.34	43.88
7	Catch-up	20.06	12.7
8	Programme	70.91	44.87

8	Catch-up	1.52	0.96
9	Programme	72.48	45.87
9	Catch-up	0.88	0.56

Table S5: *Estimated yearly incidence of herpes zoster infections in the control scenario without vaccination and in selected vaccination scenarios.*

Year	Baseline scenario: Coverage 75%, Efficacy 95%, Catch-up for 5 years to ages 70;75, First dose at age 65	Lower-coverage scenario: Coverage 50%, Efficacy 95%, Catch-up for 5 years to ages 70;75, First dose at age 65	No vaccination
0	18630 (16688–21420)	18972 (16913–21812)	19630 (17545–22532)
1	18009 (16031–20882)	18656 (16706–21482)	19953 (17866–22876)
2	17379 (15432–20246)	18344 (16314–21137)	20256 (18157–23148)
3	16769 (14892–19608)	18041 (16061–20830)	20561 (18450–23336)
4	16148 (14273–18878)	17713 (15754–20533)	20859 (18718–23776)
5	16239 (14331–19080)	17870 (15896–20717)	21161 (19032–24032)
6	16329 (14367–19138)	18036 (16095–20876)	21458 (19298–24338)
7	16407 (14487–19221)	18187 (16171–21052)	21748 (19649–24623)
8	16498 (14605–19277)	18340 (16349–21188)	22048 (19915–24848)
9	16582 (14623–19519)	18503 (16537–21350)	22314 (20224–25173)
10	16688 (14742–19560)	18644 (16638–21480)	22573 (20384–25492)

Table S6: *Estimated budget impact (in million NOK) for the first 10 years of a herpes zoster vaccination programme targeting 65-year-olds and a catch-up programme targeting 70- and 75-year-olds under two price assumptions. Vaccination uptake is 75%.*

Year	Item	At list price	At 50% of list price
0	Programme	217.47	117.92
0	Catch-up	367.23	199.13
1	Programme	219.06	118.79
1	Catch-up	366.75	198.87
2	Programme	219.1	118.81
2	Catch-up	369.98	200.62
3	Programme	221.44	120.08
3	Catch-up	371.58	201.49
4	Programme	224.78	121.89
4	Catch-up	377.56	204.73
5	Programme	229.67	124.54
5	Catch-up	0	0
6	Programme	238.84	129.51
6	Catch-up	0	0
7	Programme	243.05	131.79
7	Catch-up	0	0
8	Programme	247.15	134.02
8	Catch-up	0	0
9	Programme	248.92	134.98
9	Catch-up	0	0

7.2 Supplementary figures

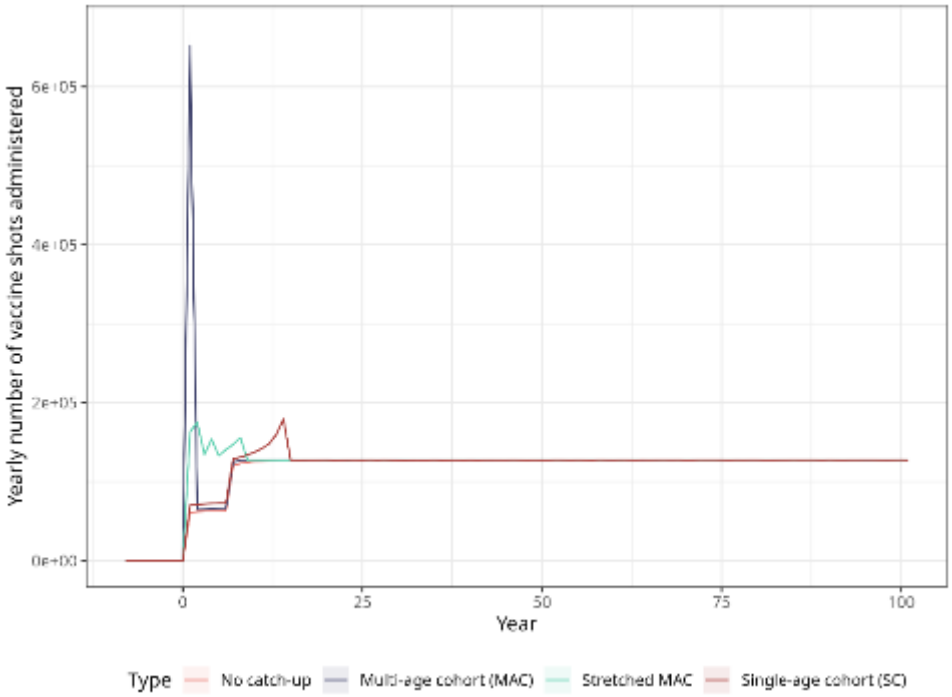


Figure S1: *Total yearly number of vaccine shots (dose 1+2) administered to the population, for different catch-up scenarios. Population vaccine uptake 96%.*

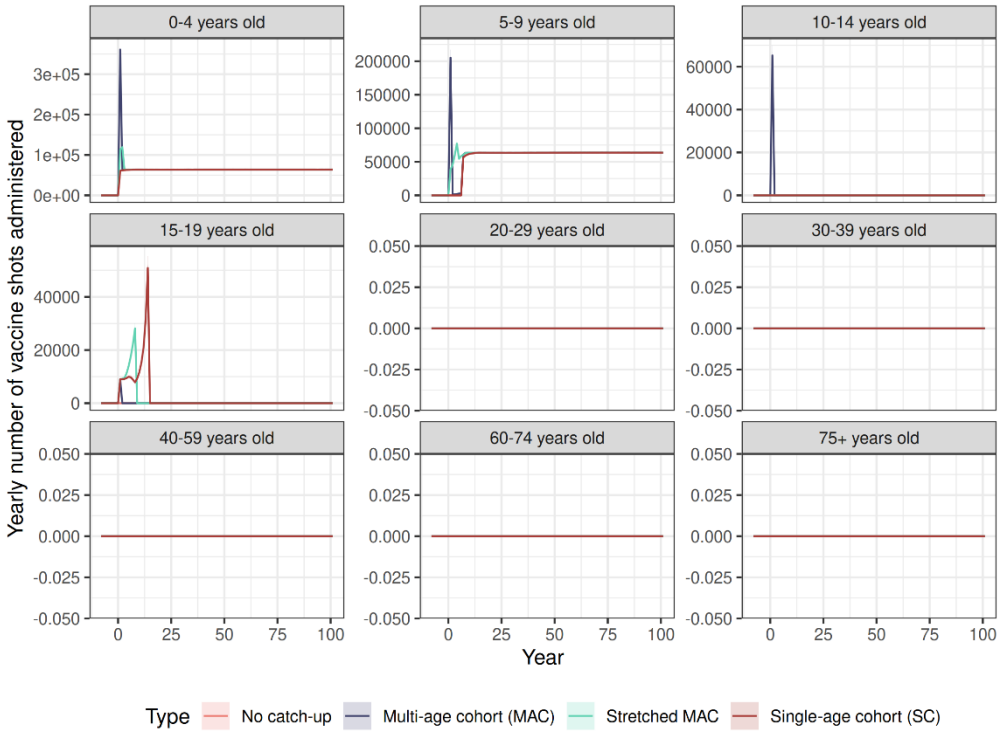


Figure S2: *Total yearly number of vaccine shots (dose 1+2) administered to each age group, for different catch-up scenarios. Population vaccine uptake 96%.*

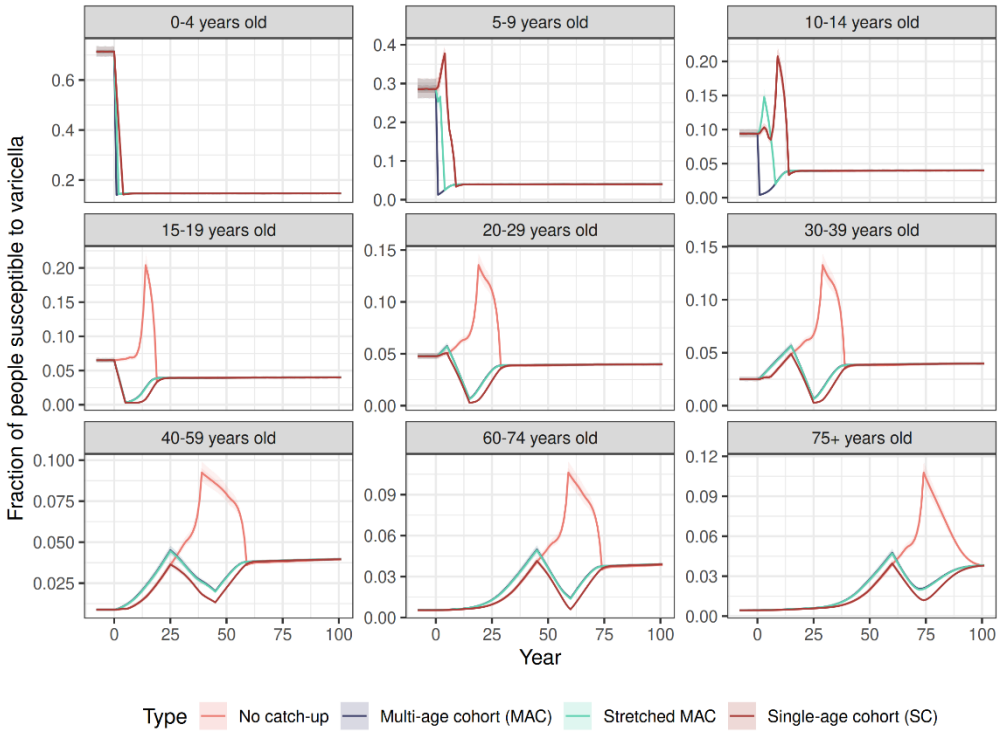


Figure S3: *The fraction of susceptible individuals in each age group, in scenarios with different catch-up programmes. The vaccine programme start in year 0. Vaccination uptake is 96%.*

7.3 Supplementary tables

Table S3: *Estimated yearly incidence of varicella infections in the control scenario without vaccination and in varicella vaccination scenario with and without catch-up. Numbers shown are mean (95% credible interval). The vaccine programme starts in year 0. Vaccination uptake is 96%.*

	Yearly incidence of new varicella infections		
year	Stretched MAC catch-up	Vaccination without catch-up	No vaccination
0	10836 (7916–14534)	41999 (31674–53027)	59247 (46443–74425)
1	1004 (648–1533)	32245 (22459–43787)	58886 (45707–72278)
2	778 (512–1147)	34847 (26060–44365)	57791 (44606–72804)
3	396 (298–532)	43540 (33573–55004)	57664 (44749–73322)
4	354 (273–459)	44286 (34065–54638)	57637 (45266–72796)
5	331 (264–424)	7606 (5130–10534)	57553 (45522–71437)
6	325 (250–428)	1136 (713–1873)	57418 (44036–72915)
7	322 (254–403)	830 (549–1208)	58310 (46919–71151)
8	332 (262–429)	753 (534–1048)	59091 (45552–73956)
9	344 (266–436)	672 (489–891)	58839 (45429–72637)
10	356 (279–443)	593 (453–779)	59476 (45856–73350)

Table S4: *Estimated budget impact (in million NOK) for the first 10 years of a varicella vaccination programme and a stretched-MAC catch-up under two price assumptions. Vaccination uptake is 96%.*

Year	Item	At list price	At 50% of list price
0	Programme	32.04	20.27
0	Catch-up	58.78	37.20
1	Programme	32.8	20.76
1	Catch-up	66.72	42.22
2	Programme	33.61	21.27
2	Catch-up	41.71	26.39
3	Programme	34.47	21.81
3	Catch-up	52.1	32.97
4	Programme	35.37	22.38
4	Catch-up	40.36	25.54
5	Programme	36.16	22.88
5	Catch-up	46.25	29.27
6	Programme	67.45	42.68
6	Catch-up	16.6	10.51
7	Programme	69.34	43.88
7	Catch-up	20.06	12.7
8	Programme	70.91	44.87
8	Catch-up	1.52	0.96
9	Programme	72.48	45.87
9	Catch-up	0.88	0.56

Table S5: *Estimated yearly incidence of herpes zoster infections in the control scenario without vaccination and in selected vaccination scenarios.*

Year	Baseline scenario: Coverage 75%, Efficacy 95%, Catch-up for 5 years to ages 70;75, First dose at age 65	Lower-coverage scenario: Coverage 50%, Efficacy 95%, Catch-up for 5 years to ages 70;75, First dose at age 65	No vaccination
0	18630 (16688–21420)	18972 (16913–21812)	19630 (17545–22532)
1	18009 (16031–20882)	18656 (16706–21482)	19953 (17866–22876)

2	17379 (15432–20246)	18344 (16314–21137)	20256 (18157–23148)
3	16769 (14892–19608)	18041 (16061–20830)	20561 (18450–23336)
4	16148 (14273–18878)	17713 (15754–20533)	20859 (18718–23776)
5	16239 (14331–19080)	17870 (15896–20717)	21161 (19032–24032)
6	16329 (14367–19138)	18036 (16095–20876)	21458 (19298–24338)
7	16407 (14487–19221)	18187 (16171–21052)	21748 (19649–24623)
8	16498 (14605–19277)	18340 (16349–21188)	22048 (19915–24848)
9	16582 (14623–19519)	18503 (16537–21350)	22314 (20224–25173)
10	16688 (14742–19560)	18644 (16638–21480)	22573 (20384–25492)

Table S6: *Estimated budget impact (in million NOK) for the first 10 years of a herpes zoster vaccination programme targeting 65-year-olds and a catch-up programme targeting 70- and 75-year-olds under two price assumptions. Vaccination uptake is 75%.*

Year	Item	At list price	At 50% of list price
0	Programme	217.47	117.92
0	Catch-up	367.23	199.13
1	Programme	219.06	118.79
1	Catch-up	366.75	198.87
2	Programme	219.1	118.81
2	Catch-up	369.98	200.62
3	Programme	221.44	120.08
3	Catch-up	371.58	201.49
4	Programme	224.78	121.89
4	Catch-up	377.56	204.73
5	Programme	229.67	124.54
5	Catch-up	0	0
6	Programme	238.84	129.51
6	Catch-up	0	0
7	Programme	243.05	131.79
7	Catch-up	0	0
8	Programme	247.15	134.02
8	Catch-up	0	0
9	Programme	248.92	134.98
9	Catch-up	0	0

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