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On analyzing and predicting cervical cancer trends in Finland

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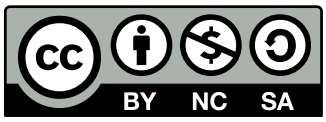

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Abstract

Cervical cancer is largely preventable because its primary cause, a persistent infection with human papillomavirus (HPV), is well understood and can be addressed through HPV vaccination and effective screening. Despite substantial progress in many high-income countries, cervical cancer remains a major burden globally, motivating the World Health Organization's (WHO) strategy to eliminate cervical cancer as a public health problem, defined by an incidence below 4 per 100 000 woman years.

In this thesis, Finnish cervical cancer trends are examined using registry-based data on incidence and mortality, together with screening participation and HPV vaccination coverage data. The work combines descriptive analyses with statistical tests (proportion tests and correlation tests) and a simplified scenario-based forecast of future incidence under differing HPV vaccination coverage assumptions.

Historically, the launch of Finland's screening program led to a strong decline in cervical cancer incidence and mortality, yet recent patterns indicate an upward trend. Age-standardized incidence reached its lowest level in 2005 (4.7 per 100 000 person years) and has trended upward since; the increase is particularly visible in young to middle-aged cohorts. In contrast, mortality has remained low and stable over the past decade (∼1.5–2 per 100 000 person years). Screening invitation coverage is close to 100% nationally, but participation remains just above 70% (71.6% in 1991, 73.1% in 2023), with lower participation among younger invitees and regional variation.

The forecast demonstrates that vaccination coverage supports long-term progress but implies a slow timeline to elimination at current levels: two-dose coverage among girls aged 13–20 is 73.8%, and full-dose coverage at age 15 (2010 cohort) is 75.7%, well below the WHO target of 90%. In the forecast, incidence declines meaningfully only after vaccinated cohorts age into high-risk groups; only the 90% vaccination scenario reaches the WHO elimination threshold within the projection period. Furthermore, there also seems to be a statistically significant negative association between cervical cancer incidence and screening participation ten years earlier (national Spearman $\rho = -0.578$), with an even stronger association for incidence at ages 40–49 compared to participation ten years prior at ages 30–39 (Spearman $\rho = -0.780$). As such, these findings reinforce the complementary need to sustain screening participation while accelerating vaccine uptake.

Keywords Cervical cancer, forecast, HPV, screening, statistical test, vaccination

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Tiivistelmä

Kohdunkaulan syöpä on suurelta osin ehkäistävissä, koska sen ensisijainen syy, pitkittynyt ihmisen papilloomaviruksen (HPV) aiheuttama infektio, tunnetaan hyvin ja siihen voidaan vaikuttaa HPV-rokotuksilla sekä tehokkaalla seulonnalla. Huolimatta merkittävästä edistyksestä monissa korkean tulotason maissa, kohdunkaulan syöpä aiheuttaa edelleen huomattavan taakan maailmanlaajuisesti. Tämä on motivoinut Maailman terveysjärjestön (WHO) strategiaa eliminoida kohdunkaulan syöpä terveysongelmana, mikä määritellään ilmaantuvuutena alle 4/100 000 naisvuotta.

Tässä diplomityössä tarkastellaan kohdunkaulan syövän trendejä Suomessa rekisteripohjaisen ilmaantuvuus- ja kuolleisuusaineiston sekä seulontaosallistumista ja HPV-rokotuskattavuutta kuvaavien tietojen avulla. Työssä yhdistetään kuvailevat analyysit tilastollisiin testeihin sekä yksinkertaistettuun skenaariopohjaiseen ennusteeseen tulevasta ilmaantuvuudesta eri rokotuskattavuusoletuksilla.

Suomessa seulontaohjelman ajoitus johti kohdunkaulan syövän ilmaantuvuuden ja kuolleisuuden selkeään laskuun, mutta viimeaikainen kehitys viittaa nousuun. Ikävakioitu ilmaantuvuus oli alimmillaan vuonna 2005 (4,7/100 000 henkilövuotta). Tämän jälkeen se on kasvanut, erityisesti nuorissa ja keski-ikäisissä kohorteissa. Kuolleisuus on pysynyt matalana ja vakaana viime vuosikymmenen ajan (noin 1,5–2/100 000 henkilövuotta). Seulontakutsujen kattavuus on lähes 100%, mutta osallistuminen on vain hieman yli 70% (71,6% vuonna 1991; 73,1% vuonna 2023), ja se on vähäisempää nuoremmissa ikäryhmissä sekä vaihtelee alueittain.

Ennusteen mukaan rokotuskattavuus tukee pitkän aikavälin edistystä, mutta nykyisellä tasolla eteneminen kohti tavoitetasoa on hidasta: kahden annoksen kattavuus 13–20-vuotiailla tytöillä on 73,8% ja täyden sarjan kattavuus 15-vuotiailla (2010 kohortti) 75,7%, selvästi alle WHO:n 90%:n tavoitteen. Ilmaantuvuus pienenee selvästi vasta, kun rokotetut kohortit siirtyvät korkean riskin ikäryhmiin; vain 90%:n rokotekattavuudella saavutettaisiin tavoitetaso ennustejaksolla. Lisäksi ilmaantuvuuden ja kymmenen vuotta aiemman seulontaosallistumisen välillä havaitaan tilastollisesti merkitsevä negatiivinen yhteys (Spearmanin ρ = -0,578), erityisesti 40–49-vuotiailla suhteessa aiempaan 30–39-vuotiaiden osallistumiseen (ρ = -0,780). Tulokset korostavat sekä seulontaosallistumisen ylläpitämisen että rokotuskattavuuden kasvattamisen tarvetta.

Avainsanat Ennuste, HPV, kohdunkaulansyöpä, rokote, seulonta, tilastollinen testaus

Preface

First and foremost, I would like to thank my supervisor, Pauliina Ilmonen, for her guidance and commitment throughout this thesis process. From the first meeting to the last, I felt we were on the same wavelength, and you certainly helped maintain an organized and coherent approach. I also enjoyed all our discussions, and your positivity is truly contagious – if I was ever feeling distraught prior to our meetings, all worries were wiped away the moment I walked into your office.

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Finally, the Aalto University school computers deserve a big thank you. As some may know, I have done the vast majority of my school work, on and off, for the past five and a half years in the same room (and often even in the same row of computers). As such, it is only fitting that I am now submitting this thesis from one of the same computers I have occupied on so many occasions.

Otaniemi, 15 January 2026

Daniel Aaltonen

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Abbreviations

IARC	International Agency for Research on Cancer
NCD	Non-communicable disease
YLL	Years of life lost
HPV	Human Papilloma Virus
WHO	World Health Organization
WBSC	Well-being service county
FCR	Finnish Cancer Registry
CIN	Cervical intraepithelial neoplasia
SIL	Squamous intraepithelial lesion
AIS	Adenocarcinoma in situ
LSIL	Low-grade squamous intraepithelial lesion
HSIL	High-grade squamous intraepithelial lesion
CMI	Cell-mediated immunity
VLP	Virus-like particle
VIA	Visual inspection with acetic acid
VILI	Visual inspection with Lugol's iodine
PCR	Polymerase chain reaction
THL	Finnish Institute for Health and Welfare

1 Introduction

Cancer is one of the most severe public health burdens and leading causes of death worldwide. The International Agency for Research on Cancer (IARC) estimates that in 2022, there were nearly 20 million new cancer cases with close to 10 million cancer deaths [1]. While these figures may seem small relative to the world population, it is estimated that the cumulative risk for both men and women developing cancer in a lifetime (from birth to age 74) is approximately one in five, with roughly one in nine men and one in 12 women dying from it. In addition, cancers are the cause of nearly one third of premature deaths from non-communicable diseases (NCDs) globally in those aged 30 to 69 years, posing a critical barrier for increased life expectancy. [2] As the population grows and ages, the forecasted years of life lost (YLLs) due to several cancers are expected to increase [3]. Beyond its effects on individual health, cancer also places a massive burden on the global economy. One study estimates that between 2020 and 2050, the worldwide economic cost of cancer could exceed $25 trillion (in 2017 international dollars), which is roughly equal to an annual loss of 0.55% of global GDP over the period [4]. As such, employing effective preventative measures – like routine screening – could play a significant role in not just improving the quality of life of individuals, but also curbing the growing economic burden of cancers.

Among women, breast cancer dominates as the type of cancer with the highest incidence and mortality rates globally, followed by lung, colorectal, and cervical cancer [2]. Cervical cancer stands out because one of its primary causes is well known: the Human Papilloma Virus (HPV). With the introduction of HPV vaccinations combined with measures such as screening, cervical cancer has become a largely preventable disease. [5, 6] However, cervical cancer displays large regional differences between higher-developed and lower-developed countries, and it remains the cancer with highest incidence in 25 countries and highest mortality in 37 countries [2]. In an effort to rectify this inequity and to eliminate what is regarded a preventable disease, the World Health Organization (WHO) launched in 2020 a global strategy to eliminate cervical cancer as a public health problem, with elimination threshold set at an incidence rate of 4 per 100 000 woman-years. The strategy outlines the so-called 90-70-90 targets for the year 2030: 90% of girls fully vaccinated with HPV vaccine by age 15 years; 70% of women are screened with a high-performance test by 35 years of age and again by 45 years of age; and 90% of women identified with cervical disease receive treatment. [5] Progress towards these ambitious targets depends on effective national implementation. Screening especially remains a central component in cancer elimination – even more so in areas of limited vaccination availability – as demonstrated by reduced incidence and mortality concentrated mostly in highly developed countries with long-standing screening programmes [6, 7].

In Finland, cervical cancer screening began already in 1963 and it was expanded into a statewide program in the early 1970s. As of today, the program invites women aged 30 to 65 years old to participate in screening every five years, with some Well-being Service Counties (WBSCs) inviting also those aged 25. [8] Not only has the program contributed to a decline in incidence and mortality rates, but screening data

has also been collected and maintained and is made available via the Finnish Cancer Registry (FCR). This comprehensive dataset spanning over 30 years enables evaluation of the program's outcomes as well as participation behavior and trends, serving as an excellent case study into the effects of cervical cancer screening.

This thesis aims to investigate the following:

1. How has the incidence and mortality of cervical cancer evolved in Finland over the last roughly seven decades?

2. How has the participation in cervical cancer screening evolved since the early 1990s and are there statistically significant differences between age groups and areas?

3. How might incidence develop over time given varying HPV vaccine coverage rates?

The thesis proceeds with a brief introduction to the topic and goals of the thesis in Section 1. Section 2 provides a background on cervical cancer, the HPV virus, HPV vaccination, and cervical cancer screening in general and in Finland. Section 3 covers descriptive statistics and statistical testing on cervical cancer incidence, mortality, and screening participation in Finland as well as forecasting the development of incidence. This is followed by a discussion of the results in Section 4. The thesis then concludes and summarizes the work and findings in Section 5.

2 Cervical cancer

Cervical cancer, as the name suggests, is a cancer developing in the cells of the cervix. The cervix resides in the lower end of the uterus, connecting it to the vagina. The cervix has two main parts: the ectocervix, which is the outer part of the cervix that can be observed in a gynecologic exam, and the endocervix, which is the inner part of the cervix forming a canal connecting the vagina to the uterus. The border where the ecto and endocervix meet is called the squamocolumnar juntion, which is where most cervical cancers begin. [9]

Cervical cancer has two main types: the more common squamous cell carcinoma, which develops from the squamous cells of the ectocervix, and adenocarcinoma, which develops from the glandular cells of the endocervix [9]. These cancers develop gradually over time and are preceded by precursor lesions, which in the case of squamous cell carcinoma is referred to as cervical intraepithelial neoplasia (CIN) or squamous intraepithelial lesion (SIL), and in the case of adenocarcinoma as adenocarcinoma in situ (AIS). CIN is further divided into three grades: CIN1 (mild), CIN2 (moderate), and CIN3 (severe). An alternative classification system labels CIN1 as low-grade squamous intraepithelial lesion (LSIL) and combines CIN2 and CIN3 under the label of high-grade squamous intraepithelial lesion (HSIL). [10, 11] The classification into LSIL and HSIL is the convention by which histological findings are classified in the FCRs screening data.

HPV has a direct link to cervical cancer, with evidence showing that the virus is the key cause in the development of both CIN/SIL and AIS [10]. This causal link was first established in the 1980s, when Harald zur Hausen and his colleagues identified that the HPV16 and HPV18 strains were responsible for a majority of cervical cancers, a discovery that earned zur Hausen the 2008 Nobel Prize in Medicine. The breakthrough transformed the understanding of cervical cancer etiology and laid the way for effective preventive measures, most notably the development of the HPV vaccine. [10, 12]

2.1 Human Papilloma Virus (HPV)

Human papillomavirus (HPV) is a type of papillomavirus belonging to the Papillomaviridae family. Papillomaviruses are species-specific, meaning that HPVs only infect humans. [10] Among both genders, HPV is the most common sexually transmitted infection worldwide, with research estimating that most sexually active men and women will acquire at least one genital HPV infection during their lives [13]. However, the majority of HPV infections show no symptoms and usually the immune system will clear the infection within two years, leaving no lasting effects [14].

HPV transmission most commonly occurs during sexual activity, primarily through skin-to-skin or skin-to-mucosa contact. Non-sexual transmission is also possible, including from contact with fomites such as medical equipment or clothing, indirect transmission via hands, and transmission from mother to child during birth. Studies have also shown that HPV can be transmitted via blood. After transmission has occurred, infection begins when the virus reaches the basal layer of the epithelium through microlesions in the skin or mucosa. The virus attaches to the receptors of

the basal cell and enters the host cell via endocytosis. The virus then travels to close proximity of the nuclear membrane, where it releases the viral genome which enters the nucleus. The viral DNA replicates as the basal cells differentiate and travel to the outermost layers of the epithelium. Here, the viral DNA is encapsidated with proteins and new virions are released, restarting the lifecycle. This cycle takes some three weeks, which is the time it takes the basal cell to differentiate and move up the epithelium. [15, 16, 10]

Most HPV infections are asymptomatic and present with no to minimal abnormal cytological development in the infected area (CIN1/LSIL). HPV infection and CIN1/LSIL are often resolved by the bodies immune system through the development of cell-mediated immunity (CMI). However, a small proportion do not make a successful CMI response and remain with persistent viral infection. In such cases, which are often associated with high-risk HPV types such as HPV16 and HPV18, the risk of developing high-grade CIN or HSIL increases. When infection is persistent, the viral genome integrates with the host genome and causes disruption of the E2 gene, responsible for the regulation of E6 and E7 genes. The over-expression of the E6 and E7 genes interferes with the transcription of tumor suppressor genes p53 and pRB, leading to unregulated growth of the epithelial cells and, in the most extreme cases, to cancer. [15, 16, 10]

Over 200 different types of HPV have been identified. These can broadly be categorized as high-risk HPVs and low-risk HPVs, with distinction made based on their oncogenic potential. It should be noted that HPV associated cancers and lesions encompass more than the cervix and affect both genders; high-risk HPVs such as 16, 18, 31, 33, and 35 are known to cause head, neck, anal, and genital malignancies. HPV 16 and 18 are commonly associated with cervical cancer and are responsible for over 70% of cancer cases, with HPV 16 also strongly associated with oropharyngeal malignancies. Low-risk HPVs such as HPV 6 and 11 may lead to the development of warts in the genitals, mouth, and throat. However, these usually do not lead to malignancies. Despite the vast amount of HPV types, identification of the types most frequently found in cancers have effectively informed the development of vaccines, which target the high-risk types responsible for the vast majority of HPV-related malignancies. [17]

2.2 HPV vaccination

The first HPV vaccine, GARDASIL, was approved in 2006. This vaccine is manufactured by Merck & Co and it is quadrivalent, meaning it protects against four types of HPV, namely HPV 6, 11, 16, and 18. GARDASIL was quickly followed by Cervarix in 2007, manufactured by GlaxoSmithKline, and it is a bivalent vaccine protecting against HPV 16 and 18. Since then, four other HPV vaccines have been introduced with one even being nonavalent, protecting against nine HPV types. Advancements aside, all introduced vaccines to date share a key component; they protect against the two most high-risk HPV types associated with cervical cancer, HPV16 and 18. [17]

The central functionality of all commercial HPV vaccines focuses on the HPV L1 protein. When the L1 protein is assembled into virus-like particles (VLPs), it induces

HPV type-specific neutralising antibodies. Initial proof-of-concept was demonstrated in animals. [17] The first proof-of-concept in humans was published in 2002 by Koutsky et al. This study randomly assigned 2392 young females into placebo and HPV16 vaccine groups, with routine check-ups performed regularly for a median duration of over 17 months. Importantly, analysis was limited to those females who were negative for HPV16 DNA and HPV16 antibodies at enrollment and HPV16 DNA still at month 7. Remarkably, all 41 cases of HPV16 infection presented in the placebo group, with 9 subjects developing CIN. As such, Koutsky et al demonstrated the effectiveness of the tested HPV16 vaccine in preventing infection and associated CIN development. [18] Subsequent larger-scale, phase III trials such as FUTURE I, FUTURE II, PATRICIA, and CVT extended these findings to the multivalent vaccines GARDASIL and Cervarix. These trials demonstrated the high efficacy of both vaccines for a range of cervical endpoints ranging from persistent infection to CIN3, leading to the widespread licensure and uptake of the vaccines. [19]

Today, 143 countries around the world have introduced HPV vaccination as part of national immunization programs. Originally, all HPV vaccines were administered in three doses; this still remains the recommendation of manufacturers for females aged 14/15 and above, depending on the vaccine. [20, 17] However, the implementation of three-dose schedules in young girls has proven challenging, and post hoc analysis of the original trials (where many received just one or two doses) suggested for the reduced doses' efficacy on immunogenicity and HPV protection. In 2022, the WHO concluded that there is enough evidence for a single-dose vaccine administration providing comparable effectiveness to two or three-dose schedules. [17] As a result, 53 countries to date have switched to single-dose schedules, while the rest remain using a two-dose schedule [20]. In Finland, those below the age of 15 are given two-doses while those 15 and above are given three-doses [21].

To date, the WHO maintains that there is no evidence to suggest the necessity of booster doses after initial vaccination, implying that the vaccines provide long-lasting effectiveness. However, given that HPV vaccines are still relatively new, further evaluation is required. Studies have shown that HPV antibody titres remain high for at least 12 years for both Cervarix and Gardasil, and for at least 6 years for the newer nonavalent vaccine. Continued protection against high-grade CIN (as well as vaginal and vulvar neoplasia) has been observed for at least 10 years following a three-dose vaccination. [22] A recent large-scale cohort study performed in Sweden concluded that the quadrivalent vaccine showed remarkable effectiveness in preventing high-grade CIN up to 17 years post-vaccination, with also support for one or two doses providing comparable protection to three doses in preventing high-grade CIN [20]. While there is strong evidence for the significant impact of HPV vaccines on reduced HPV infections and precancerous lesions, vaccination alone is unlikely to eliminate cervical cancer – vaccinations do not treat pre-existing infections and abnormal cervical developments, and thus cervical cancer screening remains necessary [23].

2.3 Cervical cancer screening

As vaccinations neither treat pre-existing infections nor cover every possible HPV type, screening continues to play a crucial role in curbing cervical cancer incidence globally. The goal in cervical cancer screening is to identify precancerous lesions and/or HPV infection, not just outright cancer [5]. Methods of screening include visual inspection, cytology, and HPV DNA testing.

Visual inspection is performed by the naked eye or, more recently, with camera-enhanced imaging. It is usually done using acetic acid (VIA, Visual Inspection with Acetic acid) or, alternatively, Lugol's iodine (VILI, Visual Inspection with Lugol's Iodine). In VIA, acetic acid is applied to the cervix, dehydrating the epithelial cells and reducing transparency. These changes are more pronounced in abnormal cells due to higher nuclear density. After applying the solution, the provider inspects the cervix through a speculum; distinct, well-defined acetowhite areas at or near the squamocolumnar junction that persist after one minute indicate a positive result. VILI follows a similar process, but color changes are different: normal epithelium becomes mahogany brown, while abnormal areas appear mustard or saffron yellow. VIA and VILI are common in low- and middle-income countries due to their low cost and low technological requirements. The test also provides immediate results. However, the methods have considerable limitations. Visual inspection is typically suitable only for younger women, usually under 50, with a clearly visible squamocolumnar junction, and test accuracy varies greatly depending on the provider. [24, 25]

Cytology, commonly known as the Pap test, is an established method for primary screening. It was developed by Papanicolaou and Babeș in the 1920s and became widely adopted in the 1960s. Today, it still remains particularly important in areas where HPV testing is not yet standard. In conventional cytology, a sample is collected from the squamocolumnar junction and endocervical canal using a swab, spatula, brush, or broom, then applied to a glass slide for microscopic examination. The method has been developed further with liquid-based cytology becoming the norm during the late 1990s. Liquid-based cytology refines the process by rinsing the sample cells into a preservative fluid before slide preparation, producing a better representation of the sample and reducing the rate of unsatisfactory slides. Additionally, liquid-based cytology enables testing for HPV or other biomarkers to be performed on the same sample, providing effective means for triage. Furthermore, computer-assisted systems for both conventional and liquid-based cytology have been around since the early 2000s. These systems enable rapid, automatic slide interpretation, improving efficiency and reducing the amount of professionals required for the process. [24, 26]

HPV testing is currently the WHOs recommended primary method of cervical cancer screening [5]. This method is relatively new, having been recognized by the FDA in 2014 as a suitable stand-alone primary cervical cancer screening method. As previously mentioned, the same sample taken for purposes of liquid-based cytology is suitable for HPV testing. HPV tests work by detecting DNA and RNA sequences of carcinogenic HPV types from the sample; these include but are not limited to HPV 16 and 18. The main test systems used include hybridization and polymerase chain reaction (PCR). Hybridization detects HPV by using labeled RNA probes

that bind to complementary HPV DNA in the sample; the resulting DNA/RNA hybrids are captured by specific antibodies, and an enzyme reaction ensues that yields a quantified light signal. PCR on the other hand, amplifies a defined HPV DNA region between two short primers through repeated heating–cooling cycles using Taq DNA polymerase, producing a large number of target copies for detection. The main advantage of HPV-based screening is its higher sensitivity in identifying severe precancerous lesions compared to cytology, with more reliable negative results. The higher sensitivity also enables increasing the screening interval, thereby providing an increased testing capacity. Limitations of HPV testing arise from its low specificity, resulting in a large amount of false positives. [24, 26, 27] In recent years, self-sampling for HPV tests has also gained attention. Studies show that self-collected samples provide comparable accuracy and can help reach women who might otherwise skip screening. Although it is still used in relatively few national programs, the WHO now recommends self-sampling as a safe and effective way to expand screening coverage, particularly after the COVID-19 pandemic accelerated adoption. [28]

The types of screening programs can generally be divided into two: (i) population-based organized screening programs and (ii) non-population based unorganized/ opportunistic screening programs. In opportunistic screening, women are primarily screened either out of their own desire or from having been referred for screening during a patient-practitioner interaction. In settings of opportunistic screening, participation is often highly polarized; participation is high with overly frequent screening performed in the higher socioeconomic group, while participation is low in the lower socioeconomic group. Opportunistic screening is also often associated to a screen-and-treat practice, whereby treatment of precancerous lesions is initiated immediately after a positive test result without confirmation via biopsy or colposcopy. In general, studies indicate that population-based organized screening is not only more effective, but also more cost effective and equitable. [24]

Since 2021, the WHO has suggested initiating screening by the age of 30, followed by a 5 to 10 year screening interval. It also suggest HPV testing as the primary screening method. [29] In practice, there is a wide array of different initiation ages, frequency, and screening methodology. Globally, 33% of countries recommend to start screening at 24 years or younger, 40% between 25 and 29 years of age, and 27% at 30 years or older. Cytology-based screening (whether alone or in combination with other tests) is still most common, with 78% of countries employing it as a primary method. Among countries utilizing cytology-based screening, the most common recommended screening frequency is every 3 years irregardless of age. For HPV testing, the recommended frequency is mainly every 5 years. [30]

The WHO cancer elimination guidelines include 70% of women being screened at least twice in a lifetime by a high-performance test by the year 2030; once by the age of 35 years, and again by age 45 [5]. Accurately assessing global progress toward this goal is challenging, as existing programs are not always properly documented or reported. Moreover, definitions of what qualifies as a screening program differ between countries, and the distinction between organized and unorganized screening can sometimes be unclear. Importantly, the existence of a screening program does not necessarily guarantee equitable access — programs may not be covered by health

insurance or accessible to all. [24] Nevertheless, studies have analyzed the progress through measures such as the existence of national screening programs as well as the reported number of women of specific age having been screened within a certain time frame. One such study found that, as of 2019, 133 of 194 (69%) countries had a national screening program in place; only 58 countries had more than 70% of women aged 30 to 49 screened within the past five years. The difference between high-income and middle- to low-income countries is drastic, with 36 of the 58 being high-income countries and 17 of 58 being low- to middle-income countries (with the remainder being unclassified). [31] Another study identified 139 of 202 (69%) countries having cervical cancer screening recommendations, including publicly funded primary screening tests. However, just 40 (29%) of these countries sent individual screening invitations to women. Globally, women aged 30 to 49 years screened ever in a lifetime stands at 36%, with 32% screened within the past five years; this too has considerable disparity between countries of different income-level, with high-income countries having an ever screened coverage of 84% while lower- to middle-income countries stand at just 27%. Screening within the past 5 years tells a similar story, with coverage in high-income countries standing at 77% and at just 24% for low- to middle-income countries. [30] The low uptake of cervical cancer screening in low- and middle-income countries is well documented, with barriers such as cost, lack of awareness, and cultural/traditional and religious beliefs being key contributors [7].

A wide array of studies confirm the effectiveness of screening in reducing incidence and mortality [24]. As vaccinations are further rolled out, we cannot forget the importance of screening; a significant disparity in screening coverage remains between high-income and low- to middle-income countries, with many still far from the WHO target [30]. Predictive studies indicate that vaccination coupled with organized screening accelerates incidence declines remarkably, offering the fastest path toward meeting elimination thresholds globally [32]. In lower income countries specifically, multi-model analyses show that achieving high screening uptake alongside scaled vaccination is necessary to reach elimination within a timely manner [33].

2.4 Cervical cancer screening in Finland

In Finland, organized cervical cancer screening began in the early 1960s with pilots in three municipalities. The program rapidly expanded nationwide and by 1970, invitation coverage already reached more than 80% of women in the target age group. From the early 1970s onwards, the registered coverage has encompassed nearly all of the target age groups. The effects of the screening program have had a considerable contribution to declined incidence and mortality rates in Finland; during 1955-1964, age-adjusted cervical cancer incidence was 15 per 100 000 woman-years, while during 1991-1995, incidence rate varied between 2.8 to 4.5 indicating a 70 to 80% decline. [34]

Today, the cervical cancer screening program invites women aged 30 to 65 years old to participate in screening every five years, at ages divisible by five. The inclusion of 65-year-olds started in 2022, with the previous upper-age being 60. [8]

The aforementioned details are stipulated by the Government Decree on Screenings (399/2011) and its amendments (752/2021, 1243/2022), with the latest amendment (622/2023) specifying that screening must also be carried out on those persons who have been in the target group by sex at birth but whose sex has been later confirmed as male [35]. Some WBSCs such as the Helsinki area also invite those aged 25 to participate in screening [36].

In 2023, healthcare reform in Finland resulted in the responsibility of screening organization being transferred from the municipalities to the WBSCs. At the beginning of each year, the FCR provides WBSCs with the personal identity codes of those to be invited, based on records from the Digital and Population Data Services Agency. Each WBSC then sends a personally addressed invitation letter containing information about the screening, along with a pre-arranged appointment time and location. A reminder letter is issued to non-participants within 4–8 weeks after invitation. [35]

The cervical screening test used in Finland has historically been cytology, or commonly the Pap test. Today, the Pap test as a stand-alone primary screening test is used only for those below 30 years of age. For those aged 30 or older, high-risk HPV (hrHPV) testing is the primary cervical screening method, with the Pap test used as a follow-up or triage test after hrHPV positive tests. Guidelines advise against the use of both Pap and hrHPV tests together as a primary test. [8, 35]

Historically in Finland, participation for those invited to screening has been roughly 70% since the 1990s, with the latest 2023 participation at 73%. There are considerable differences in participation rate between WBSCs, education level, and age groups. Attendance between WBSCs in 2023 ranged from 66% in North Karelia to 83% in South Savo. Those with just basic education level (or unknown) had a participation rate of 51%, while those with a higher level education had 80% participation. Those aged 25 to 34-years-old had a considerably lower participation rate compared to other age groups, 64% in 2023. [8] One contributing factor is likely testing outside of the screening program, with the practice more common in younger age groups [35]. This behavior has been observed in other countries too with well-established population-based cervical cancer screening programs [37].

3 Data analysis

3.1 Descriptive statistics

Cervical cancer incidence, mortality, and screening data were downloaded from the FCR, HPV vaccination coverage data from the Finnish Institute for Health and Welfare (THL), and processing/analysis/visualization was performed in Python. Figures related to incidence and mortality rates are presented in person years. The FCR defines person year as "the time accumulated by the population at risk of cancer, broken down by statistical year, gender and age" [38]. Person year is a unit of observation time reflecting the time that participants have been observed over a period prior to onset of disease, totaled for all participants. As an example, suppose the period of interest is two years and covers a sample of two people; the person who is disease-free for the whole period contributes two person years while the other who developed the disease midway through year two contributes 1.5 person years for a total of 3.5 person years or a rate of 1 per 3.5 person years. For a more intuitive understanding, one can think of person year as person per year - an incidence rate of 4 per 100 000 person years can be interpreted as 4 per 100 000 persons per year. [39]

Figures related to nation-wide incidence and mortality rates are also age standardized, allowing for better comparison over time. The selected standard population is that of Finland in 2014. Age standardization works by multiplying each age group specific incidence rate by the weight of the respective age group in the selected standard population. This results in a rate that corresponds to an unchanged population structure, negating for example the effects of an aging population. [38, 40]

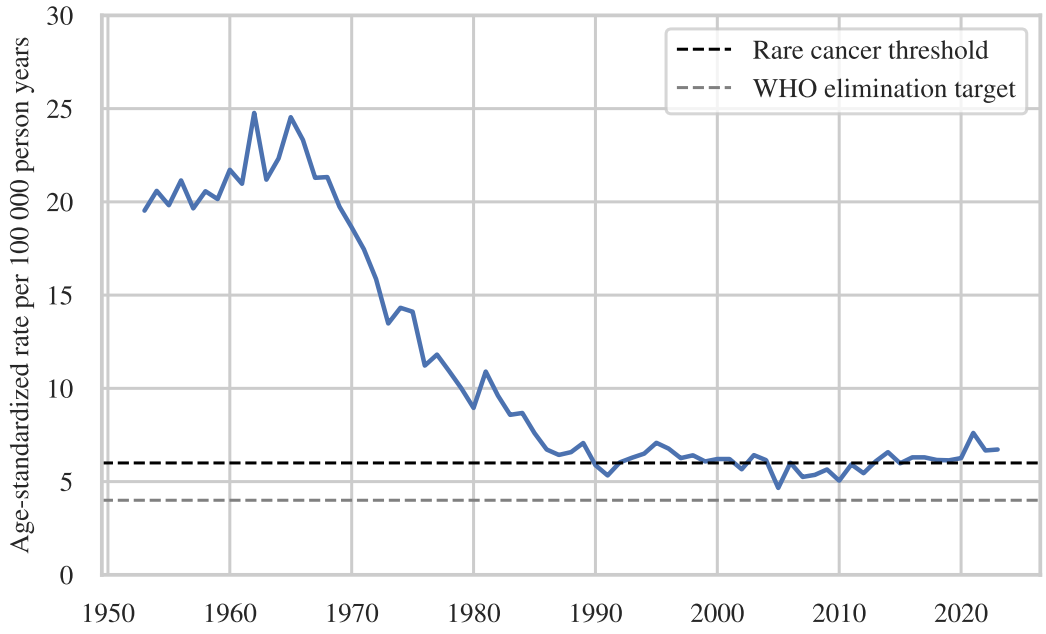


Figure 1: Cervical cancer incidence in Finland, 1953-2023

Figure 1 presents the cervical cancer incidence rate in Finland between 1953 and 2023. A significant drop in incidence can be observed starting from the late 1960s, coinciding with the start of nationwide screening in 1963. Since the 1990s, incidence rate has fluctuated at slightly above or below 6 per 100 000 person years, the rare cancer threshold within the European Union as defined by the RARECARE project [41]. The incidence rate reached its lowest point in 2005 at 4.7 per 100 000 person years and has been trending upwards since then, remaining above the rare cancer threshold for the past eight years. Noticeably, the incidence rate has never reached the WHOs targeted elimination threshold. Of course, no definitive conclusion should be made based on this regarding comparisons to the rare cancer threshold or the WHO target; different interpretations can be made depending on the chosen age standardization or based on crude rates, as presented in Appendix A1.

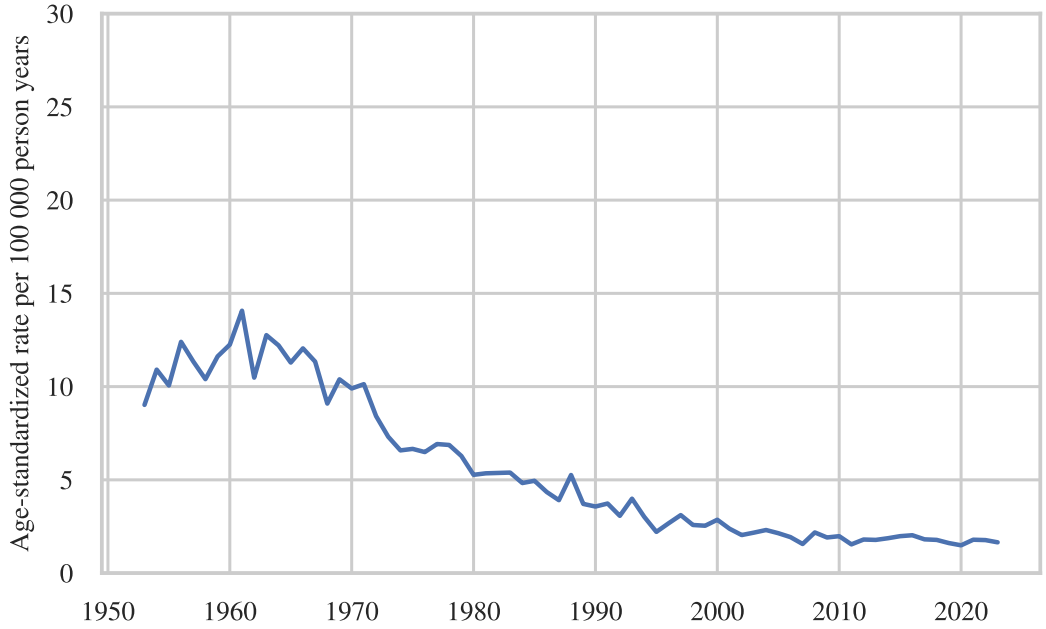


Figure 2: Cervical cancer mortality in Finland, 1953-2023

Figure 2 presents cervical cancer mortality in Finland between 1953 and 2023. Following the start of nationwide screening in 1963, mortality rates have significantly declined similar to incidence. The beginning of the sharpest decline seems slightly delayed compared to incidence, with a noticeable drop in the early 1970s. This is explainable by the delayed effect of the nationwide rollout of the screening program, whereby more and more precancerous findings can be identified and prevented from progressing to cancer. Contrary to incidence rates, mortality rates present a more continuous decline to date, with no discernible upward trend; for the last 10 years, mortality rate has remained rather stable between 1.5 and 2 per 100 000 person years. Alternate age standardizations and crude rates are presented in Appendix A2.

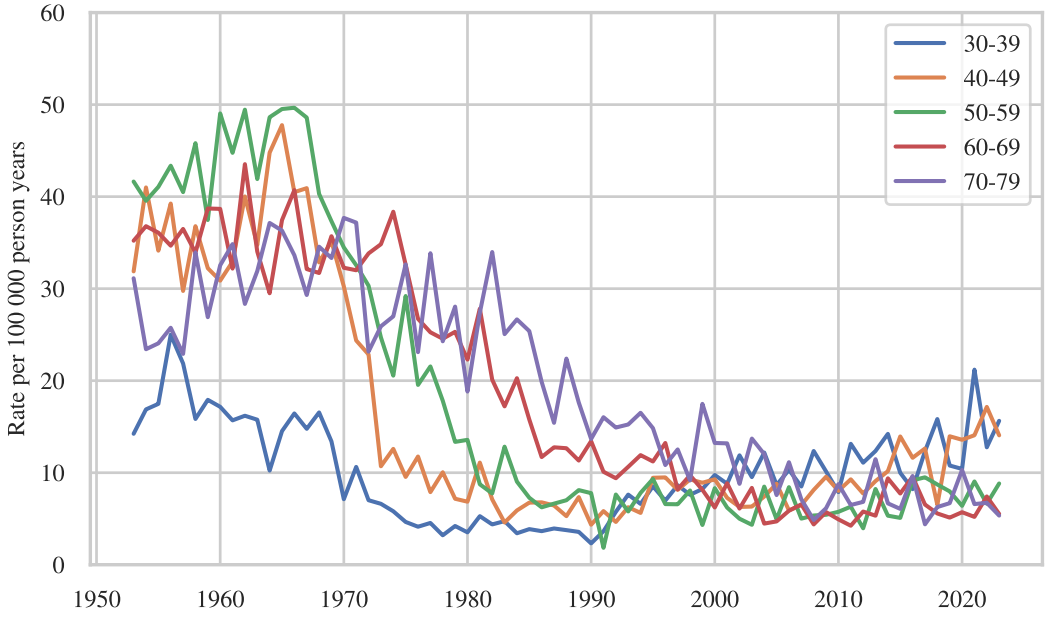


Figure 3: Cervical cancer incidence by age group in Finland, 1953-2023

Figure 3 above presents cervical cancer incidence by age group in Finland from 1953 to 2023. To aid visual clarity, the age groups below 30 have been excluded; among these groups, cervical cancer can be considered a very rare occurrence. Furthermore, considering the statutory screening program in Finland covers those aged 30 and above (with the exception of some WBSCs inviting also those aged 25), this better aligns the incidence statistics with the screening age cohorts. Also those aged 80 or above have been excluded as this age group is already far above the screening programs final invitation age of 65. Furthermore, the prevalence of having undergone hysterectomy increases by age, which could distort the figures in older age cohorts. Luoto et al estimated that in 1997, one fifth of those aged 45 to 64 years had undergone hysterectomy in Finland, with prevalence of approximately one in four for the 55 to 59 and 60 to 64 aged cohorts. [42] Given these older age groups are in or approaching the 80+ age range for more recent years, we deem it appropriate to exclude them. As a side note, a national register study indicates that hysterectomy rates in Finland have decreased substantially since the early 2000s, particularly among younger women, making hysterectomy related disturbances lesser in more recent cohorts [43]. For interested readers, Appendix A3 presents incidence rates for all age groups; the rates for those below 20 years old are basically zero let for a handful of years, while incidence among the 20 to 29 year olds has remained at a relatively low level since 1953.

Since 1953, incidence has generally declined among those aged 40 or above. For the cohorts of 50 to 59, 60 to 69, and 70 to 79, the incidence rate in 2023 was over 75% below the 1953 figure for each cohort. Again, the most dramatic decline begins in the late 1960s to early 1970s, coinciding with the start of nationwide screening. Rather worryingly, while the incidence rate among the 30 to 39 cohort declined from 1953 through to its lowest rate of 2.3 per 100 000 person years in 1990, it has steadily

increased since then; the latest 2023 incidence rate (15.6) is above that of 1953 (14.2). Likewise, the 40 to 49 year-old cohort reached its lowest incidence rate of 4.4 in 1990, but incidence has been growing since then. Currently, the latest 2023 incidence rate for the 40 to 49 year-olds was 14.1 per 100 000 person years.

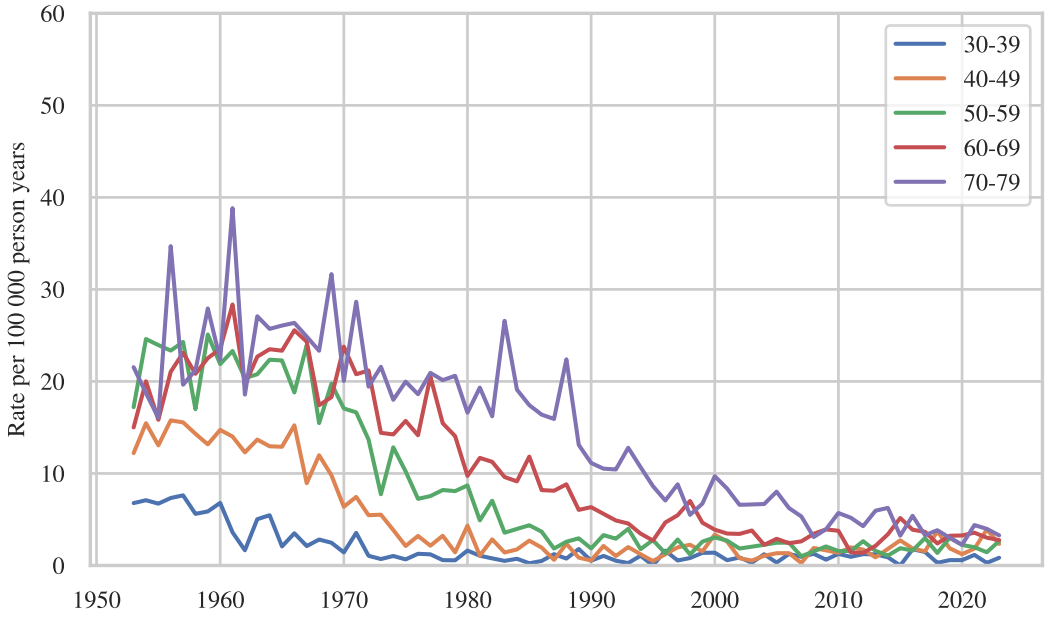


Figure 4: Cervical cancer mortality by age group in Finland, 1953-2023

Figure 4 presents the mortality rate by age group in Finland since 1953. As with the age group specific incidence rates, we omit those below the age of 30 and those 80 or above based on the same reasoning. Cervical cancer mortality for those below the age of 30 is basically zero throughout let for a few anomalies throughout the years, as demonstrated in Appendix A4. For all the age groups presented above, mortality has decreased by over 75% since 1953 and has been below 5 per 100 000 person years for the last seven years. The above figure demonstrates the delayed effect of the screening program, with mortality rates of older age groups dropping slower to below 5. This is explained by the older age group having increasingly more women who have been continuously screened throughout their life as time progresses, resulting in more detected precancerous lesions that can be prevented from ever progressing to cancer.

Invitation coverage and participation rates between 1991 and 2023 are presented in Figure 5. Ideally we would have screening data since the start of the nationwide program, but unfortunately 1991 is as far as data is openly available. In the invitation coverage and participation figure, each year only includes the statutory age groups. This means that 25 year olds are excluded from the data in full (screening of 25 year olds is not required and hence not all WBSCs include 25 year olds), while 65 year olds are included only as of 2022, the year when screening was extended to include said age group. Also, we should highlight that the participation rate is calculated as a percentage from those invited and not from the whole population. For interested readers, Appendix A5 presents the development of invitation coverage over time by

age. Furthermore, the above as well as all screening related data from here on only includes the broader age group screening cohort, and not the risk group screening cohort (a smaller group including, for example, those with a detected minor lesion requiring follow-up in less than five years). Finally, we should clarify that invitation coverage is calculated from the registered target population (population with confirmed contact details available) and not the whole target population, while the participation rate is calculated from those who have received an invitation and participated in the screening.

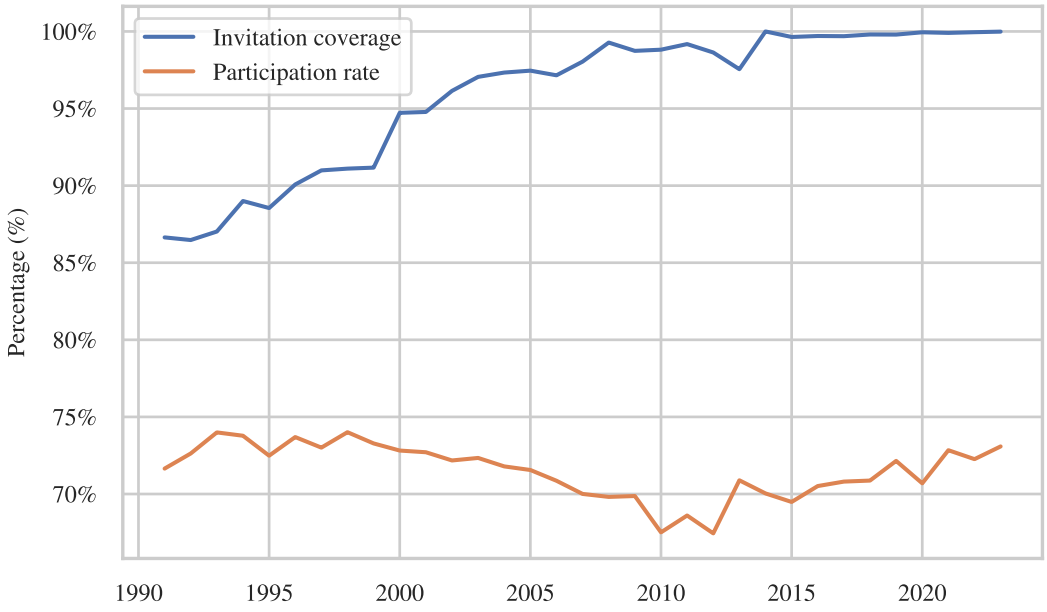


Figure 5: Invitation coverage and participation rates in Finland, 1991-2023

As Figure 5 demonstrates, invitation coverage has essentially reached 100% in Finland since 2014. Interestingly, participation has hardly changed since 1991; participation rate was 71.6% in 1991 and 73.1% in 2023. The average over the period has been 71.5%, with the lowest rate of 67.4% occurring in 2012 and the highest rate of 74.0% occurring in 1998. From the high point in 1998, participation declined for almost each year until the low point of 2012, after which participation rates have been trending upwards.

Figure 6 presents participation rates for different ages in Finland between 1991 and 2023. Interestingly, the drop observed in the nationwide participation rate in Figure 5 seems to be consistent for all ages between the later half of the 1990s and 2010, with all the ages either demonstrating an upward trend or plateauing since. For the past 4 years, those aged 50 have had the highest participation, with latest 2023 participation rate at 77%. Over the full period, consistently the most active participants seem to have been the 60 year olds, with the highest average participation rate of 77.2% for the whole period. In general, participation has been higher for more elderly people, with those of age 40 and above adhering to higher participation. However, the dispersion between those aged 40 and above has been very noticeable around the 2010s, with

the 40 and 45 year olds catching up to the more elderly population as of recent years. Consistently throughout the period, participation rates drop quite dramatically when inspecting the 35, 30, and 25 year olds. Since the lows of 2010, especially the 30 and 35 year olds seem to display a strong upward trend in participation, while participation among the 25 year olds seems even further apart from the other age groups than before.

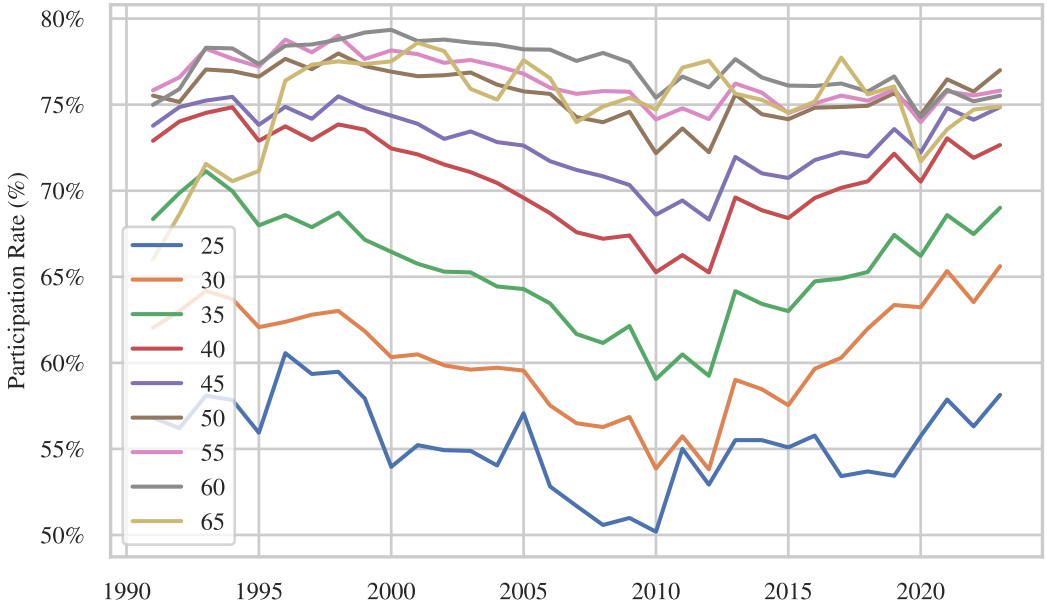
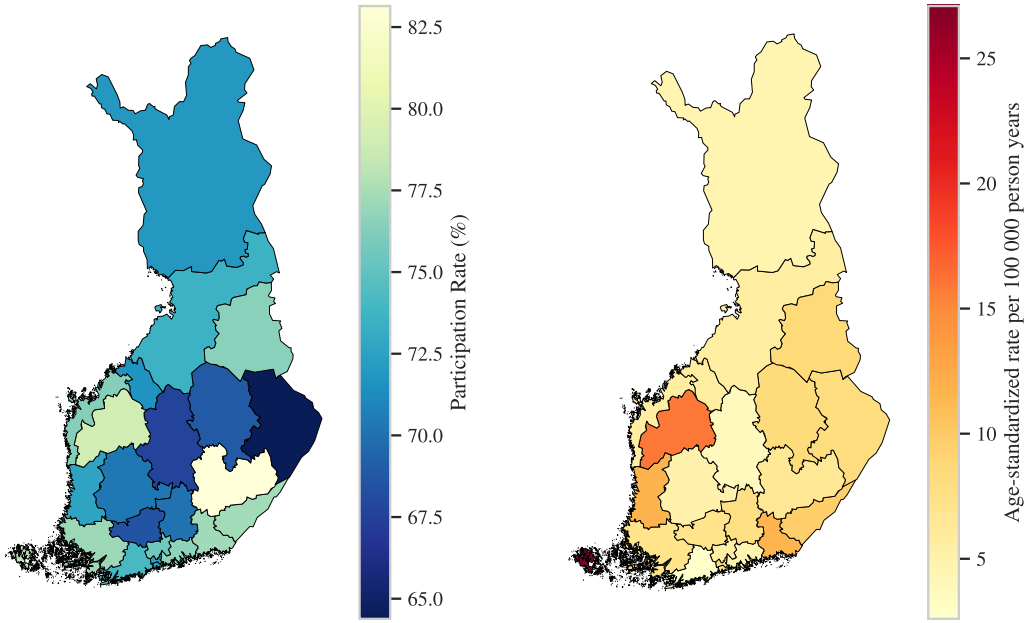


Figure 6: Participation rate in Finland by age, 1991-2023

Figure 7 presents screening participation and cervical cancer incidence by WBSC in Finland during 2023. Nationwide screening participation was 73.1% for the statutory population (30 to 65 year olds). The three lowest participation rate WBSCs were North Karelia, Central Finland, and Kanta-Häme with participation of 64.4%, 67.6%, and 68.5% respectively. Interestingly, all three of these WBSCs had participation rates above the national average in 1991 and roughly in line with the average in 2007, indicating a consistent declining trend. The top three highest participation rate WBSCs were South Savo, South Ostrobothnia, and Åland with participation rates of 83.1%, 79.0%, and 78.1% respectively. Of these, South Savo and South Ostrobothnia have consistently had participation rates above the national average in 1991 and 2007. Helsinki, where most of the population is concentrated, had a participation rate of 72.4%, which is relatively close to the nationwide average. From 1991 to 2007, Helsinki and nearby Central and West Uusimaa WBSCs increased markedly. As illustrated in Figure 7a, WBSCs near the coast, particularly in the South, have quite high participation rates including the WBSC of South Savo. There seems to be a pronounced cluster or ”belt” of WBSCs in the center of Finland where participation rates are low, before they again increase in the Northern parts. Table 1 presents detailed participation rates for WBSCs for the years 1991, 2007, and 2023. Note that Table 1 reports statutory participation only: 25-year-olds are excluded throughout and 65-year-olds included only in 2023.



(a) Screening participation rate **(b)** Cervical cancer incidence rate

Figure 7: Screening participation and cervical cancer incidence by WBSC, 2023

Table 1: Invitation coverage and participation rate by WBSC 1991, 2007, 2023

	1991			2007			2023		
Area	Registered target pop.	Invitation coverage, %	Particip. rate, %	Registered target pop.	Invitation coverage, %	Particip. rate, %	Registered target pop.	Invitation coverage, %	Particip. rate, %
Central Finland	11 862	78.9	73.8	12 335	89.0	73.2	12 888	99.8	67.6
Central Ostrobothnia	3 101	80.0	78.3	3 159	100.0	78.5	2 998	99.9	71.6
Central Uusimaa	7 238	80.9	65.1	9 032	97.5	62.0	10 672	99.5	75.5
City of Helsinki	27 262	99.0	60.3	30 494	100.0	62.5	37 641	100.0	72.4
East Uusimaa	4 116	87.4	65.6	4 741	99.7	64.7	5 050	99.7	76.6
Kainuu	4 328	64.4	73.2	3 713	99.7	71.2	3 222	100.0	76.5
Kanta-Häme	7 985	85.0	74.6	8 133	99.6	69.7	8 284	100.0	68.5
Kymenlaakso	8 993	89.3	79.8	8 553	99.6	77.5	7 692	100.0	77.2
Lapland	9 592	81.3	72.4	8 598	97.7	72.8	8 619	100.0	71.9
North Karelia	8 551	86.5	75.8	7 825	99.9	71.4	7 646	100.0	64.4
North Ostrobothnia	14 367	84.9	71.4	17 419	92.0	70.4	19 150	100.0	73.5
North Savo	11 892	79.2	74.3	11 923	99.4	65.7	11 933	100.0	68.9
Ostrobothnia	7 738	87.6	83.6	7 433	99.7	80.0	8 152	100.0	76.3
Pirkanmaa	12 467	82.2	75.2	5 217	83.4	73.2	26 434	100.0	70.3
Päijät-Häme	9 543	96.5	74.2	10 052	99.7	74.0	10 073	100.0	70.0
Satakunta	11 042	87.5	79.3	10 605	100.0	77.0	10 080	100.0	72.6
South Karelia	1 070	99.9	80.0	6 201	99.7	74.3	5 933	99.8	77.2
South Ostrobothnia	9 305	85.4	83.6	8 704	99.8	82.4	8 915	99.9	79.0
South Savo	3 224	90.7	77.7	7 103	100.0	77.9	6 044	100.0	83.1
Southwest Finland	19 710	79.1	79.1	22 373	99.1	71.8	24 134	100.0	77.0
Vantaa and Kerava	10 083	99.1	63.1	11 770	99.2	62.0	14 733	99.7	72.4
West Uusimaa	16 976	87.8	59.3	21 277	99.3	64.4	25 324	99.8	74.0
Åland	–	–	–	1 374	99.9	61.2	1 574	100.0	78.1
Total	220 445	86.6	71.6	238 034	98.0	70.0	277 191	100.0	73.1

Figure 7b presents cervical cancer incidence rates across WBSCs. In general, incidence rates are uniformly quite low let for a few hot spots, namely Åland, South Ostrobothnia, Satakunta, and Kymenlaakso. The incidence rates in these WBSCs were 27.1, 15.9, 11.6, and 11.5 per 100 000 person years respectively, while all other WBSCs had incidence rates clearly below 10. In Åland, the result is likely a one-off, as the reported crude number of diagnosed cases is not available, indicating that there have been between 1 and 4 cases, which is high in relation to the small permanent population of Åland. The WBSCs with the lowest incidence were West Uusimaa, Central Finland, and Lapland having rates of 2.6, 3.6, and 4.6 per 100 000 person years respectively. Table 2 presents incidence rates by WBSC for the years 1991, 2007, and 2023.

Table 2: Cervical cancer incidence rates by WBSC 1991, 2007, 2023

	1991			2007			2023		
Area	Diagnosed cases*	Rate per 100 000†	Age stand. Rate per 100 000‡	Diagnosed cases*	Rate per 100 000†	Age stand. Rate per 100 000‡	Diagnosed cases*	Rate per 100 000†	Age stand. Rate per 100 000‡
Central Finland	7	5.4	5.4	–	2.2	2.2	–	2.9	3.6
Central Ostrobothnia	–	5.8	4.1	–	8.8	10.5	–	5.9	5.7
Central Uusimaa	–	4.0	5.7	–	3.3	3.9	6	5.8	5.5
City of Helsinki	25	9.2	9.1	20	6.6	6.1	23	6.6	6.7
East Uusimaa	–	2.3	1.5	–	4.2	4.8	–	6.0	4.6
Kainuu	–	4.3	4.6	–	7.5	7.8	–	8.7	8.6
Kanta-Häme	–	1.2	1.5	–	4.6	4.1	6	7.0	7.1
Kymenlaakso	10	10.5	10.5	5	5.6	5.3	10	12.5	11.5
Lapland	5	5.0	6.1	6	6.5	5.8	–	4.5	4.5
North Karelia	–	2.2	2.1	–	3.5	3.2	6	7.4	8.2
North Ostrobothnia	–	2.3	2.5	10	5.2	5.4	12	5.8	5.6
North Savo	–	3.0	3.5	9	7.0	6.2	10	8.0	8.4
Ostrobothnia	–	3.5	3.8	6	7.1	7.0	5	5.7	5.6
Pirkanmaa	13	5.8	6.2	11	4.5	4.6	14	5.2	5.0
Päijät-Häme	5	4.7	4.9	5	4.7	4.6	8	7.7	7.8
Satakunta	7	5.7	5.9	12	10.3	10.4	13	12.2	11.6
South Karelia	–	2.8	3.6	5	7.4	7.9	7	11.2	9.7
South Ostrobothnia	–	1.9	2.0	–	2.0	1.4	13	13.6	15.9
South Savo	5	6.0	6.1	5	6.5	6.0	5	7.6	6.5
Southwest Finland	9	4.1	4.0	11	4.7	4.4	17	6.8	7.2
Vantaa and Kerava	–	4.3	2.9	–	2.6	3.0	11	7.8	7.6
West Uusimaa	9	5.3	8.1	11	5.3	5.5	7	2.8	2.6
Åland	–	15.9	15.3	0	0.0	0.0	–	26.1	27.1
Total	127	4.9	5.3	142	5.3	5.3	193	6.8	6.7

* Cases between 1 and 4 are censored from the data, indicated by "-"

†Rate per 100 000 person years

‡Rate per 100 000 person years, age standardized by Finland 2014 population

Analyzing HPV vaccination coverage in Finland is not straightforward. Data on vaccination coverage of the full population is not openly available. However, THL does provide the latest vaccination data as of August 2025 for persons born between 2005 and 2012 [44]. In Finland, HPV vaccination has been included in the national immunization program since 2013. The vaccine of choice is CERVARIX, which is a two-dose HPV vaccine. Usually, the first dose is administered during fifth grade (at age 11) and the second dose during sixth grade (at age 12). However, those who have not received the HPV vaccination during the aforementioned period can still receive it free of charge until the age of 19. [45] As such, the data available, which represents those aged 13 (born in 2012) to 20 years old (born in 2005), misses a considerable

relevant population of those aged 21 (born in 2004) to 30 years old (born in 1995), who have potentially had the opportunity to receive the vaccination free of charge as part of the national immunization program since its launch in 2013. Furthermore, data on those vaccinated outside the program is not openly available; the GARDASIL 9 vaccine can be purchased from pharmacies by prescription and administered by a healthcare professional [46].

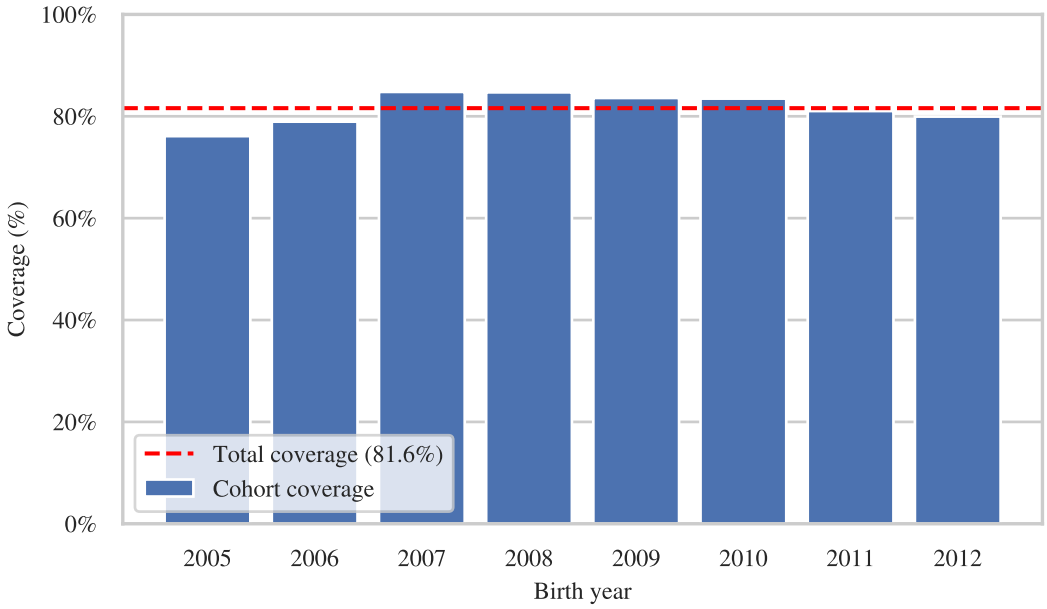


Figure 8: Girls with at least one dose of vaccine by birth cohort, as of August 2025

Figure 8 presents vaccination coverage as of August 2025 for girls born between 2005 and 2012, corresponding to those aged 13 to 20 years old. This data includes those who have received at least one dose of the vaccine. The coverage for the whole cohort is 81.6%. The highest coverage occurs for those born between 2007 and 2010, while coverage is lower for those born between 2005 and 2006, as well as between 2011 and 2012. The slightly lower coverage for the youngest cohort is not too alarming, as this cohort still has ample time to be vaccinated under the national immunization program. However, the lower coverage among the two oldest cohorts is worrying, as most are soon outside the national immunization program. Furthermore, Finland seems to be considerably behind its Nordic peers. According to one study, the estimated one-dose vaccination coverage by age 15 in 2023 was 90% in Sweden, 94% in Norway, and 92% in Denmark [47]. The same study estimated Finland at 84% in 2023, while our data indicates the coverage at 83.5% as of August 2025 (2010 born cohort), indicating flat development.

Figure 9 presents vaccination coverage as of August 2025 for girls born between 2005 and 2012 having received two doses of the vaccine. The total coverage for this cohort is 73.8%, approximately 8 percentage points below those who have received at least 1 dose. The overall trend is the same as in Figure 8, with those born between 2007 and 2010 having the highest coverage. The lower coverage among the youngest cohort

is far more pronounced, with those born in 2012 having only a 64.8% vaccination coverage. When considering the WHO's target of 90% of girls vaccinated by age 15, the statistics are slightly worrying. While the cohort born in 2011-2012 still have time to rectify this, they are still approximately 19 and 25 percentage points respectively below the WHO's target. Coverage for those who are born in 2010 (aged 15) is 75.7%, which is approximately 14 percentage points below the WHO target. In terms of full-dose coverage, Finland is again considerably below its Nordic peers; the estimated full-dose vaccination coverage by age 15 in 2023 was 85% in Sweden, 93% in Norway, and 83% in Denmark [47], with Finland estimated at 76% which is similar to our latest 2025 figure.

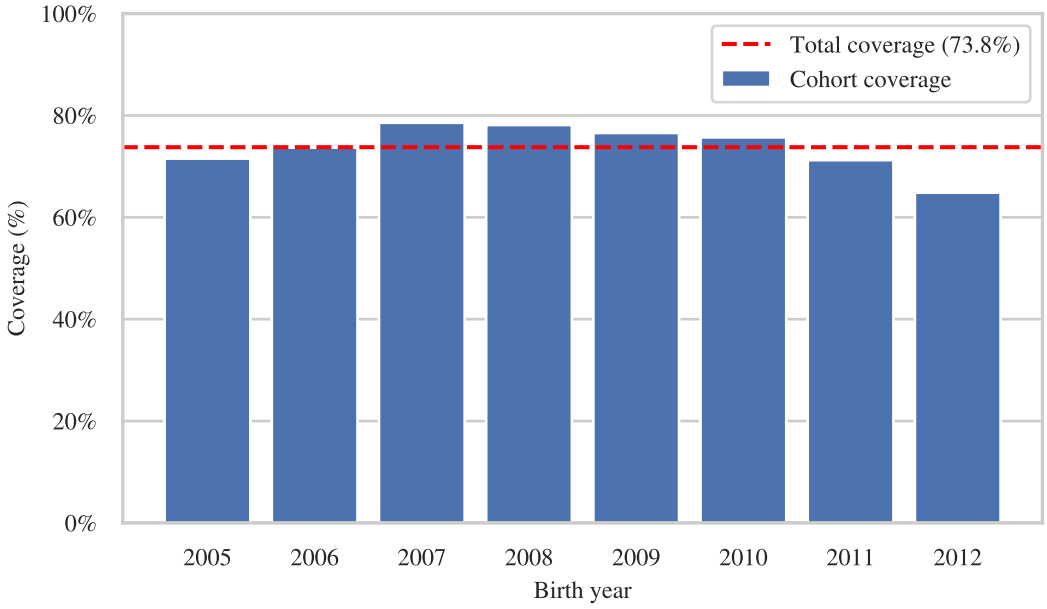
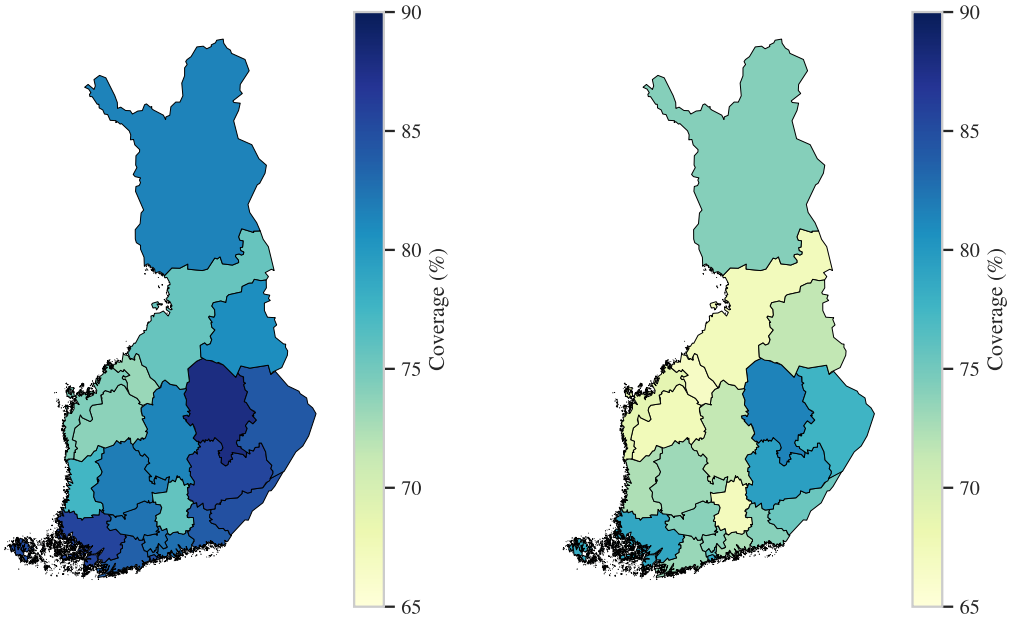


Figure 9: Girls with two doses of vaccine by birth cohort, as of August 2025

Figure 10 presents vaccination coverage by WBSC as of August 2025 for girls born between 2005 and 2012. Figure 10a presents coverage for those having received at least one dose, while Figure 10b presents coverage for those having received two doses. In both cases, vaccination coverage seems to be lower along the west coast of Finland, beginning from the WBSC of Satakunta and reaching all the way to North Ostrobothnia. In addition, Päijät-Häme is another noteable WBSC with low coverage, while Central Finland and Kainuu have relatively low two dose coverage. The three lowest one dose coverage WBSCs are Central Ostrobothnia (73.3%), South Ostrobothnia (73.9%), and Ostrobothnia (74.3%). The three lowest two dose coverage WBSCs are Central Ostrobothnia (66.6%), Päijät-Häme (67.2%), and North Ostrobothnia (67.3%). Within both one dose and two dose coverage, the three WBSCs with the highest coverage are North Savo, South Savo, and Southwest Finland having one and two dose coverages of 87.8% and 81.4%, 85.6% and 79.4%, 85.6% and 78.8%, respectively. Interestingly, North Savo is the only WBSC with a two dose vaccination coverage exceeding 80%. For interested readers, Appendix A1 and A2 present detailed tabular data on WBSC

vaccination coverages.

Low vaccination coverage in the Ostrobothnia regions has been recognised for many years, not only for HPV but also for several other childhood vaccines. In 2018, THL Chief Physician Hanna Nohynek noted in connection with measles outbreaks that vaccination coverage in Ostrobothnia has been low for the past decade. According to her, vaccination hesitance in the region is affected by differing world views as well as various beliefs and notions related to vaccinations that spread through social media. [48, 49] An article published in early 2025 reiterates the persisting vaccination hesitance, with THL Lead Specialist Mia Kontio and Central Ostrobothnia WBSC's Chief Infectious Diseases Physician Marko Rahkonen identifying several region-specific factors. According to them, vaccine refusal in the Ostrobothnia region is influenced by long-standing cultural ties to Sweden, where vaccine-critical attitudes have historically been more prominent, as well as by general vaccine fatigue and increased skepticism toward health authorities in the aftermath of the COVID-19 pandemic. They also emphasize the role of misinformation concerning vaccines and their side effects, which circulate widely on social media, and note that many younger parents lack personal experience with the infectious diseases targeted by childhood vaccines, reducing their perception of the severity of these illnesses. [50]



(a) Coverage for at least one dose

(b) Coverage for two doses

Figure 10: Vaccination coverage by WBSC as of August 2025, ages 13-20

3.2 Statistical tests

In this subsection, select statistical tests are conducted on the data. We begin by simply investigating whether participation rate has significantly changed between certain periods of interest within WBSCs and age groups. To compare screening participation between two years, the two-sample proportion test is utilized.

We wish to test whether there is a difference in proportions for two populations at different points in time. Let p_1 and p_2 denote the two population proportions. As such, the null hypothesis is defined $H_0 : p_1 = p_2$, and the alternate hypothesis is defined $H_a : p_1 \neq p_2$ (two-tailed test). Suppose we have the sample proportions $\hat{p_1}$ and $\hat{p_2}$ both corresponding to the number of successes, x_1 and x_2, and sample sizes of n_1 and n_2, respectively. Assuming independent sampling and sufficiently large samples, the sample proportions are approximately normally distributed and permit the use of the z-statistic, defined:

$$z = \frac{\hat{p_1} - \hat{p_2}}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}},$$

where $\hat{p}$ is the pooled proportion estimate calculated as

$$\hat{p} = \frac{x_1 + x_2}{n_1 + n_2}.$$

The computed z-statistic is then compared against the standard normal distribution to calculate the p-value. In addition, the confidence interval for the difference in population proportions, $(p_1 - p_2)$, at a level $(1 - \alpha)$ is

$$(\hat{p_1} - \hat{p_2}) \pm z_{\alpha/2}\sqrt{\frac{\hat{p_1}(1-\hat{p_1})}{n_1} + \frac{\hat{p_2}(1-\hat{p_2})}{n_2}},$$

where $z_{\alpha/2}$ is the critical value from the standard normal distribution such that a proportion α of the total area lies between $-z_{\alpha/2}$ and $z_{\alpha/2}$. We should also note that the proportion test assumes that the samples $\hat{p_1}$ and $\hat{p_2}$ are binomial samples, which is exactly the case for our data; we have the underlying number of persons screened, x, and the number of invitations sent, n. [51, 52] This data can be considered to be a sample of n successive Bernoulli trials with a binary outcome of "participated" or "did not participate", with those participating totaling to x.

Due to the considerable number of tests performed, we have also utilized Bonferroni correction to avoid the multiple-testing problem. When running many statistical tests, even in the case that all null hypotheses are actually true, some may conclude as significant just by chance. For example, with a significance level of 0.05, each test has a 5% chance of producing a false positive if the null hypothesis is true. So, suppose we run 100 independent tests and all null hypotheses are true, we would expect about 5 "significant" results purely by luck. [53]

The Bonferroni correction proceeds as follows. Suppose we want an overall significance level α for a family of m hypothesis tests. Instead of testing each

hypothesis at level α, we test each one at level α/m. An equivalent approach is to multiply each individual p-value by m and compare the adjusted p-values to α. This procedure ensures that the probability of making at least one false rejection among the m tests is no greater than α. This approach can also be applied to confidence intervals. Suppose we want to compute m confidence intervals at an overall level $(1 - \alpha)$, the Bonferroni method replaces the usual $(1 - \alpha)$ intervals with wider intervals at a level of $(1 - \alpha/m)$. [54] In the result tables, we present both the standard p-values and confidence intervals as well as the Bonferroni corrected p-values (denoted p_B) and Bonferroni corrected confidence intervals (denoted CI_B).

Proportion tests were performed for three pairs of different time periods. For each pair of time periods, we compared the participation rate within each age group, as well as within each WBSC. The first pair of years compares participation in 1991 (earliest available data) to 2023 (latest available data) to test whether participation rate has changed significantly over an extended period within age groups and WBSCs. The second and third pairs test whether participation changes significantly around the COVID-19 pandemic. For this, we compare the year 2019 to 2020 and the year 2020 to 2023, where 2019 represents normal conditions, 2020 is the year of COVID-onset, and 2023 again represents normalized conditions.

Considering we have nine age groups (25, 30, ... , 65) of screening participants, 23 different WBSCs (Åland does not have data to test for 1991), and 3 pairs of time periods, this results in $3 \times 9 + 2 \times 23 + 22 = 95$ separate tests. As such, it could be argued that the strictest adoption of Bonferroni correction would be to test each hypothesis at a level of $\alpha/95$. However, we consider only the tests performed on the same pair of years to be a family, while also making a distinction between the age and WBSC tests. As such, the proportion tests for participation by age have been adjusted with $m = 9$. The proportion tests for WBSCs have been adjusted with $m = 22$ for comparing 1991 and 2023 (since Åland has no data), and by $m = 23$ for the tests concerning COVID-19.

Results for the age group proportion tests are presented in Tables 3–5. We consider tests with $p_B < 0.05$ significant. When comparing the long term change from 1991 to 2023, only those aged 30, 45, 50, and 65 are deemed to demonstrate a significant change in participation. These aforementioned cohorts had an increase in participation rate ranging from 1.1 to 8.9 percentage points. It should be noted that 65 year-olds were not part of the statutory screening program in 1991, which may explain the drastic increase of 8.9 percentage points. However, some WBSCs did include 65 year-olds already in 1991 and we have used the raw figures for invitations and attendance, meaning the participation rate should not be twisted by e.g. including 65 year-olds in the invitation count who resided in WBSCs that did not screen the age cohort back then. When comparing participation from 2019 to 2020, all except 30 year-olds demonstrate a significant change in participation. Interestingly, all the age groups besides 25 year-olds showed a decrease in participation, with 25 year-olds participation increasing by 2.3 percentage points from 2019 to 2020. Finally, comparing participation in 2020 to 2023 indicates that all ages have had a significant change in participation rates, with all age groups also showing a noticeable increase.

Table 3: Proportion tests for participation by age group, 1991 versus 2023.

Age	Δ (pp)	95% CI	p-value	95% CI$_B$	p_B-value
25	+1.3	[0.2, 2.4]	0.021*	[−0.3, 2.9]	0.187
30	+3.6	[2.8, 4.4]	< 0.001***	[2.5, 4.7]	< 0.001***
35	+0.7	[−0.0, 1.4]	0.062	[−0.3, 1.6]	0.559
40	−0.2	[−0.9, 0.4]	0.465	[−1.2, 0.7]	1.000
45	+1.1	[0.5, 1.7]	< 0.001***	[0.2, 2.0]	0.008**
50	+1.5	[0.8, 2.2]	< 0.001***	[0.5, 2.4]	< 0.001***
55	−0.0	[−0.8, 0.8]	0.961	[−1.1, 1.1]	1.000
60	+0.5	[−0.4, 1.5]	0.259	[−0.8, 1.8]	1.000
65	+8.9	[7.1, 10.6]	< 0.001***	[6.4, 11.4]	< 0.001***

Table 4: Proportion tests for participation by age group, 2019 versus 2020.

Age	Δ (pp)	95% CI	p-value	95% CI$_B$	p_B-value
25	+2.3	[1.2, 3.5]	< 0.001***	[0.7, 3.9]	< 0.001***
30	−0.1	[−0.9, 0.6]	0.718	[−1.2, 0.9]	1.000
35	−1.2	[−1.9, −0.5]	< 0.001***	[−2.2, −0.2]	0.006**
40	−1.6	[−2.3, −0.9]	< 0.001***	[−2.6, −0.7]	< 0.001***
45	−1.4	[−2.1, −0.7]	< 0.001***	[−2.3, −0.4]	< 0.001***
50	−1.3	[−1.9, −0.6]	< 0.001***	[−2.2, −0.3]	0.002**
55	−1.9	[−2.5, −1.3]	< 0.001***	[−2.8, −1.0]	< 0.001***
60	−2.4	[−3.0, −1.8]	< 0.001***	[−3.3, −1.5]	< 0.001***
65	−4.4	[−5.4, −3.4]	< 0.001***	[−5.8, −2.9]	< 0.001***

Table 5: Proportion tests for participation by age group, 2020 versus 2023.

Age	Δ (pp)	95% CI	p-value	95% CI$_B$	p_B-value
25	+2.4	[1.2, 3.5]	< 0.001***	[0.8, 4.0]	< 0.001***
30	+2.4	[1.7, 3.1]	< 0.001***	[1.4, 3.4]	< 0.001***
35	+2.8	[2.1, 3.5]	< 0.001***	[1.8, 3.8]	< 0.001***
40	+2.1	[1.5, 2.8]	< 0.001***	[1.2, 3.1]	< 0.001***
45	+2.6	[2.0, 3.3]	< 0.001***	[1.7, 3.6]	< 0.001***
50	+2.6	[1.9, 3.3]	< 0.001***	[1.6, 3.6]	< 0.001***
55	+1.8	[1.2, 2.5]	< 0.001***	[0.9, 2.7]	< 0.001***
60	+1.3	[0.6, 1.9]	< 0.001***	[0.4, 2.1]	< 0.001***
65	+3.2	[2.4, 4.0]	< 0.001***	[2.0, 4.4]	< 0.001***

Results for the WBSC-specific proportion tests are presented in Tables 6–8. When comparing the year 1991 to 2023, almost all WBSCs show significant change in participation rates. Only 3/22 WBSCs had no significant change, namely Kainuu, Lapland, and South Karelia. The majority of WBSCs with a significant change showed a decline in participation rate (12/19), with only 7/19 of the WBSCs with a significant change showing an increase over the 33 year period. The largest significant changes were seen in West Uusimaa (+14.8 pp), the City of Helsinki (+12.1 pp), and East Uusimaa (+11.0 pp). Conversely, the largest significant decreases were seen in North Karelia (-11.4 pp), Ostrobothnia (-7.3 pp), and Central Ostrobothnia (-6.7 pp). Considering the four regions of Ostrobothnia which, as previously discussed, are generally also vaccine hesitant, the results are slightly worrying. Only North Ostrobothnia showed an increase (+2.1 pp) in participation, while all other Ostrobothnia WBSCs showed significant decreases in participation.

When comparing participation between 2019 and 2020, the results are not as pronounced. In fact, only 11 of the 23 WBSCs showed a significant change in participation. Of these 11 WBSCs, all but Kymenlaakso (+7.4 pp) showed a decrease in participation rate. Of the 10 WBSCs with a significant decrease (Central Finland, Helsinki, Kanta-Häme, Pirkanmaa, Päijät-Häme, Satakunta, South Savo, Southwest Finland, Vantaa and Kerava, West Uusimaa), all but perhaps Central Finland could be considered relatively Southern WBSCs. Furthermore, these 10 WBSCs feature some of the most highly populated ones such as Helsinki and its surrounding areas, Pirkanmaa, and Southwest Finland. As such, the results make sense intuitively, with likely the most noticeable COVID effects taking place sooner or at an accelerated rate compared to less populated regions with lesser foreign traffic.

The comparisons between 2020 and 2023 also showed 11 of 23 WBSCs having a significant change in participation. Of these, only a single region had a negative change, namely North Karelia with a considerable decrease in participation of -10.4 pp. One explanation for this could be a change in the screening process; instead of the invited persons being assigned a pre-determined screening time (as done for example in Helsinki), they are now instead given instruction for how to book a time themselves [55]. This additional "nuisance" could potentially deter some of those invited. Nevertheless, the change is so drastic that it is difficult to believe this to be the sole reason. Of the WBSCs with a significant positive change in participation, the top three were South Savo (+7.2 pp), North Savo (+6.1 pp), and South Karelia (+5.6 pp).

Finally, analysis was performed to investigate whether there is correlation between incidence rates and preceding participation rates. The approach for this was to perform simple Spearman and Pearson tests on data comparing incidence rates with 10-year lagged screening participation rates. In practice, our analysis compares the incidence rate during year t to the screening participation rate in year $t - 10$. For example, the incidence rate in year 2021 is compared to the participation rate in year 2011 i.e., lagged by 10 years. Since our participation data spans 1991 to 2023, the analysis is restricted to covering 23 data points. Furthermore, an approach comparing e.g. the averages over 3 year intervals could be more suitable to smooth out single-year variations, but this would further restrict the data points to just 8 (assuming first or last interval is a shortened 2-year interval), which would reduce the explanatory power.

Table 6: Proportion tests for participation by WBSC, 1991 versus 2023.

Area	**Δ (pp)**	**95% CI**	***p*-value**	**95% CI$_B$**	**p_B-value**
Central Finland	−6.2	[−7.4, −5.0]	< 0.001***	[−8.1, −4.3]	< 0.001***
Central Ostrobothnia	−6.7	[−9.0, −4.4]	< 0.001***	[−10.2, −3.1]	< 0.001***
Central Uusimaa	+10.4	[8.9, 11.8]	< 0.001***	[8.1, 12.7]	< 0.001***
City of Helsinki	+12.1	[11.4, 12.9]	< 0.001***	[11.0, 13.3]	< 0.001***
East Uusimaa	+11.0	[9.1, 12.9]	< 0.001***	[8.0, 14.0]	< 0.001***
Kainuu	+3.3	[1.1, 5.5]	0.004**	[−0.2, 6.7]	0.078
Kanta-Häme	−6.1	[−7.5, −4.6]	< 0.001***	[−8.3, −3.8]	< 0.001***
Kymenlaakso	−2.6	[−3.9, −1.3]	< 0.001***	[−4.6, −0.6]	0.002**
Lapland	−0.5	[−1.9, 0.9]	0.477	[−2.6, 1.6]	1.000
North Karelia	−11.4	[−12.8, −9.9]	< 0.001***	[−13.7, −9.1]	< 0.001***
North Ostrobothnia	+2.1	[1.1, 3.1]	< 0.001***	[0.5, 3.7]	0.001**
North Savo	−5.4	[−6.6, −4.2]	< 0.001***	[−7.3, −3.5]	< 0.001***
Ostrobothnia	−7.3	[−8.6, −6.0]	< 0.001***	[−9.3, −5.3]	< 0.001***
Pirkanmaa	−4.9	[−5.9, −3.9]	< 0.001***	[−6.5, −3.3]	< 0.001***
Päijät-Häme	−4.2	[−5.5, −3.0]	< 0.001***	[−6.2, −2.3]	< 0.001***
Satakunta	−6.7	[−7.9, −5.6]	< 0.001***	[−8.6, −4.9]	< 0.001***
South Karelia	−2.8	[−5.4, −0.1]	0.046*	[−6.9, 1.3]	1.000
South Ostrobothnia	−4.6	[−5.8, −3.4]	< 0.001***	[−6.4, −2.8]	< 0.001***
South Savo	+5.4	[3.6, 7.2]	< 0.001***	[2.6, 8.2]	< 0.001***
Southwest Finland	−2.0	[−2.9, −1.2]	< 0.001***	[−3.3, −0.7]	< 0.001***
Vantaa and Kerava	+9.3	[8.1, 10.5]	< 0.001***	[7.4, 11.2]	< 0.001***
West Uusimaa	+14.8	[13.8, 15.7]	< 0.001***	[13.3, 16.3]	< 0.001***
Åland					

Table 7: Proportion tests for participation by WBSC, 2019 versus 2020.

Area	**Δ (pp)**	**95% CI**	***p*-value**	**95% CI$_B$**	**p_B-value**
Central Finland	−5.0	[−6.2, −3.8]	< 0.001***	[−6.9, −3.2]	< 0.001***
Central Ostrobothnia	+1.7	[−0.6, 4.1]	0.152	[−2.0, 5.4]	1.000
Central Uusimaa	−0.6	[−1.9, 0.7]	0.360	[−2.6, 1.4]	1.000
City of Helsinki	−1.5	[−2.2, −0.8]	< 0.001***	[−2.6, −0.4]	< 0.001***
East Uusimaa	−1.0	[−2.8, 0.9]	0.296	[−3.9, 1.9]	1.000
Kainuu	+1.0	[−1.2, 3.3]	0.362	[−2.5, 4.5]	1.000
Kanta-Häme	−4.4	[−5.9, −2.9]	< 0.001***	[−6.8, −2.0]	< 0.001***
Kymenlaakso	+7.4	[5.9, 9.0]	< 0.001***	[5.1, 9.8]	< 0.001***
Lapland	+0.9	[−0.5, 2.4]	0.218	[−1.4, 3.2]	1.000
North Karelia	+2.2	[0.7, 3.7]	0.004**	[−0.2, 4.5]	0.102
North Ostrobothnia	−1.2	[−2.2, −0.3]	0.012*	[−2.7, 0.3]	0.277
North Savo	+1.1	[−0.2, 2.4]	0.099	[−1.0, 3.2]	1.000
Ostrobothnia	+1.1	[−0.3, 2.6]	0.129	[−1.1, 3.4]	1.000
Pirkanmaa	−3.8	[−4.6, −2.9]	< 0.001***	[−5.1, −2.5]	< 0.001***
Päijät-Häme	−3.4	[−4.8, −2.0]	< 0.001***	[−5.6, −1.3]	< 0.001***
Satakunta	−2.8	[−4.2, −1.5]	< 0.001***	[−4.9, −0.8]	< 0.001***
South Karelia	+1.3	[−0.5, 3.0]	0.150	[−1.4, 4.0]	1.000
South Ostrobothnia	+1.8	[0.5, 3.1]	0.008**	[−0.3, 3.8]	0.183
South Savo	−2.5	[−4.1, −0.9]	0.002**	[−4.9, 0.0]	0.049*
Southwest Finland	−4.5	[−5.3, −3.7]	< 0.001***	[−5.8, −3.2]	< 0.001***
Vantaa and Kerava	−1.8	[−2.9, −0.7]	0.001**	[−3.5, −0.1]	0.032*
West Uusimaa	−1.4	[−2.2, −0.5]	0.002**	[−2.7, 0.0]	0.040*
Åland	−1.2	[−4.3, 1.8]	0.434	[−6.0, 3.5]	1.000

Table 8: Proportion tests for participation by WBSC, 2020 versus 2023.

Area	**Δ (pp)**	**95% CI**	p**-value**	**95% CI**$_B$	p_B**-value**
Central Finland	−0.0	[−1.2, 1.2]	0.967	[−1.9, 1.8]	1.000
Central Ostrobothnia	−1.9	[−4.3, 0.4]	0.100	[−5.6, 1.7]	1.000
Central Uusimaa	+1.2	[−0.0, 2.4]	0.052	[−0.7, 3.1]	1.000
City of Helsinki	+4.7	[4.1, 5.4]	$< 0.001^{***}$	[3.7, 5.8]	$< 0.001^{***}$
East Uusimaa	+3.4	[1.7, 5.2]	$< 0.001^{***}$	[0.7, 6.2]	0.003^{**}
Kainuu	+0.9	[−1.3, 3.0]	0.424	[−2.5, 4.2]	1.000
Kanta-Häme	+2.2	[0.8, 3.7]	0.003^{**}	[−0.1, 4.5]	0.071
Kymenlaakso	+2.5	[1.1, 3.9]	$< 0.001^{***}$	[0.3, 4.6]	0.012^{*}
Lapland	−0.8	[−2.2, 0.6]	0.288	[−2.9, 1.4]	1.000
North Karelia	−10.4	[−11.9, −8.9]	$< 0.001^{***}$	[−12.8, −8.1]	$< 0.001^{***}$
North Ostrobothnia	+1.5	[0.6, 2.4]	0.001^{**}	[0.1, 3.0]	0.028^{*}
North Savo	+6.1	[4.9, 7.4]	$< 0.001^{***}$	[4.2, 8.1]	$< 0.001^{***}$
Ostrobothnia	+1.0	[−0.4, 2.3]	0.170	[−1.2, 3.1]	1.000
Pirkanmaa	+1.0	[0.2, 1.8]	0.015^{*}	[−0.3, 2.3]	0.337
Päijät-Häme	+2.6	[1.3, 3.9]	$< 0.001^{***}$	[0.5, 4.7]	0.003^{**}
Satakunta	+1.7	[0.4, 3.0]	0.011^{*}	[−0.3, 3.7]	0.244
South Karelia	+5.6	[4.0, 7.3]	$< 0.001^{***}$	[3.1, 8.2]	$< 0.001^{***}$
South Ostrobothnia	+1.2	[−0.1, 2.4]	0.068	[−0.8, 3.1]	1.000
South Savo	+7.2	[5.7, 8.6]	$< 0.001^{***}$	[4.9, 9.5]	$< 0.001^{***}$
Southwest Finland	+5.0	[4.3, 5.9]	$< 0.001^{***}$	[3.8, 6.3]	$< 0.001^{***}$
Vantaa and Kerava	+1.0	[−0.1, 2.0]	0.082	[−0.7, 2.6]	1.000
West Uusimaa	+4.2	[3.4, 5.1]	$< 0.001^{***}$	[3.0, 5.5]	$< 0.001^{***}$
Åland	−1.2	[−4.1, 1.8]	0.433	[−5.8, 3.4]	1.000

We briefly outline the Pearson and Spearman correlation. The Pearson correlation coefficient provides a numerical measure of the linear relationship between two random variables. Its value lies between –1 and 1, taking the extreme values ±1 exactly when the variables are related by an equation of the form $y = ax + b$ for some real numbers $a, b \in \mathbb{R}$, $a \neq 0$. If the variables x and y are independent, then the Pearson correlation coefficient $r(x, y) = 0$. The Pearson correlation coefficient for data pairs (x_i, y_i), $i = 1, ..., n$ is defined

$$r(x, y) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}.$$

A flexible form of dependency can be measured with the Spearman correlation, which measures monotonic dependence between random variables. The Spearman coefficient lies between -1 and 1 and (assuming no repeated data values) attains the extreme vales ±1 if and only if $y = g(x)$ for some monotonic function g. The first step is to compute ranks for each observation within its sample. Spearman correlation coefficient $\rho(x, y)$ is the Pearson coefficient calculated from the ranks. We use Spearman correlation as the primary measure since it does not assume linearity. [56, 57]

The p-values for both coefficients were computed using Python's default implementations. For the Pearson correlation, the test of the null hypothesis that the distributions underlying the samples are uncorrelated utilizes the exact density function $f(r)$ for a case where the correlation coefficient $r(x, y) = 0$:

$$f(r) = \frac{(1 - r^2)^{n/2-2}}{B(\frac{1}{2}, \frac{n}{2} - 1)},$$

where B is the Beta function and n is the sample sizes. This approach assumes normality. [58] However, normality tests were not performed in this study.

For the Spearman correlation, the null hypothesis of having uncorrelated samples is tested by first computing the test statistic t, defined:

$$t = r\sqrt{\frac{n - 2}{1 - r^2}},$$

where r is the observed correlation coefficient and n is the sample size. This is compared against the Student's t-distribution with $n - 2$ degrees of freedom to compute the p-value. It should be noted that this test does not assume normality of the underlying data, but a larger sample than our 23 observations is generally required for high accuracy. [59]

Figure 11 presents a scatter plot of pair-wise data points where y-axis is the incidence rate and x-axis is the 10-year lagged screening participation rate. The annotations of the data points refer to the year where the incidence rate is measured from. For example, the upper-left data point labeled 2021 indicates that incidence rate in 2021 was slightly above 7.5 per 100 000 person years, whereas screening participation rate was roughly 0.685 in 2011. Visually, there seems to be a trend of lower participation in prior years being associated with increased incidence rates. The

Spearman correlation coefficient is -0.578, indicating negative correlation, while the p-value of 0.004 indicates a statistically significant result. The Pearson correlation coefficient, deemed less suitable here, indicates a correlation of -0.564 with also a p-value indicative of significance.

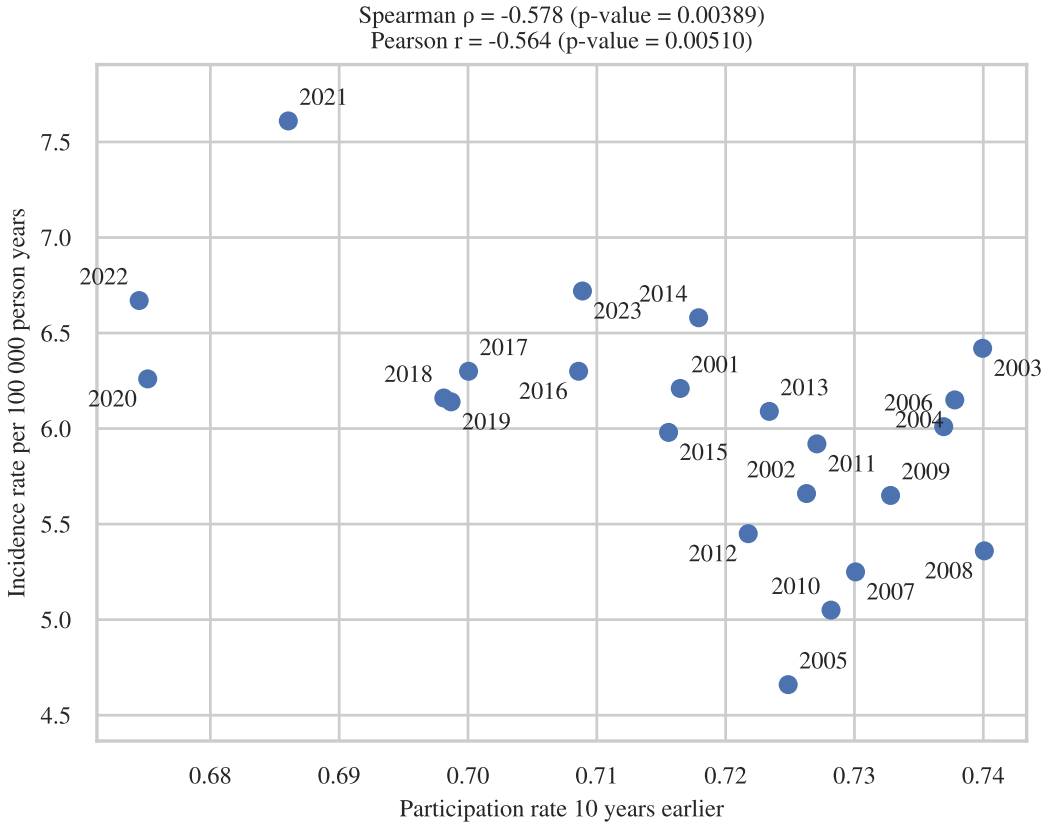


Figure 11: Incidence versus 10-year lagged screening participation

To further segment the analysis, the same tests were performed for different age groups. When testing for ages, we have compared the same screening participant cohorts to their incidence rates 10 years later. This means that the screening participation rate among the cohort of age k in year t is compared to the incidence rate among the cohort of age $k + 10$ in year $t + 10$. The results are displayed in Figures 12–15.

When comparing the incidence rates among 40-49 year-olds to their 10-year lagged screening participation rates (screened at age 30-39), their is visually a very clear trend of decreasing incidence as participation increases. This is supported by very strong Spearman coefficient of -0.780 and Pearson coefficient of -0.786, with both deemed significant. Within those aged 50-59, the visual trend is not as clear but both coefficients support some degree of negative correlation while still being significant. Moving to the older ages of 60-69, there seems to be no visually discernible association and neither correlation coefficient supports any conclusions on dependence. Finally among the oldest group of 70-79 year-olds, neither visualizations nor correlation coefficients and their respective p-values support any significant dependency.

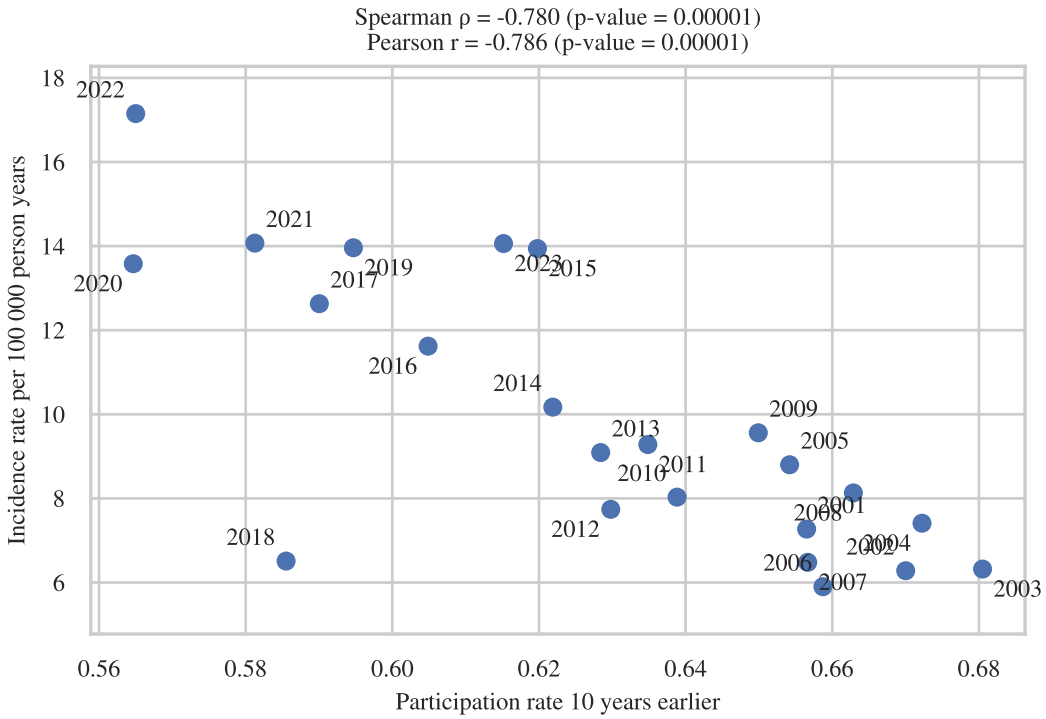


Figure 12: Incidence (ages 40-49) versus 10-year lagged screening participation

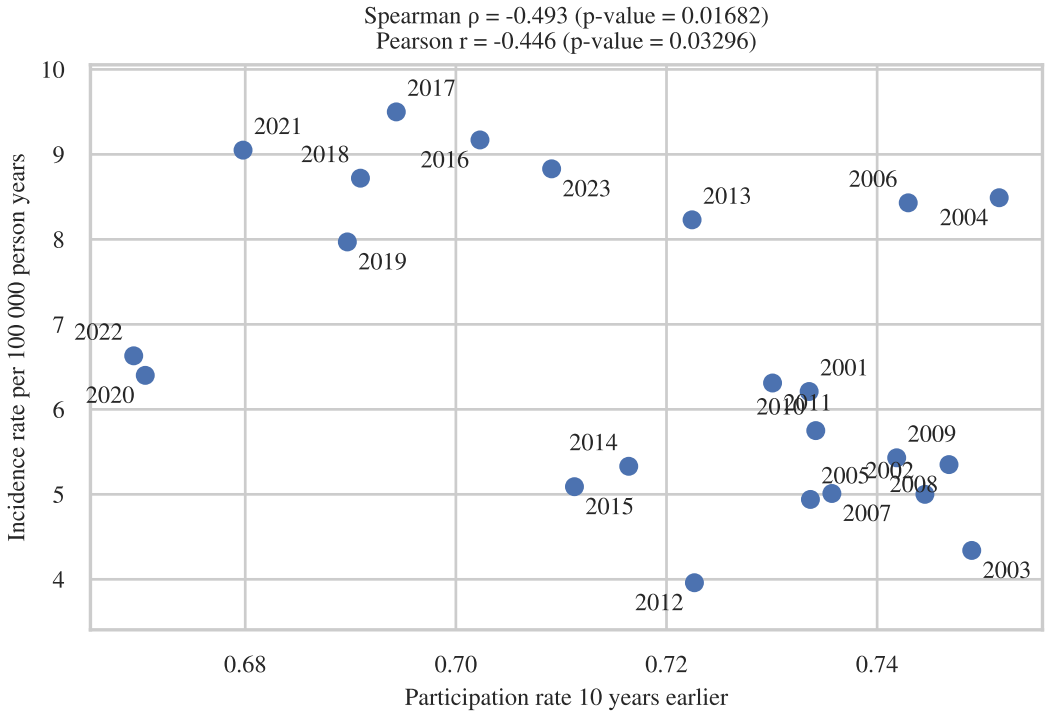


Figure 13: Incidence (ages 50-59) versus 10-year lagged screening participation

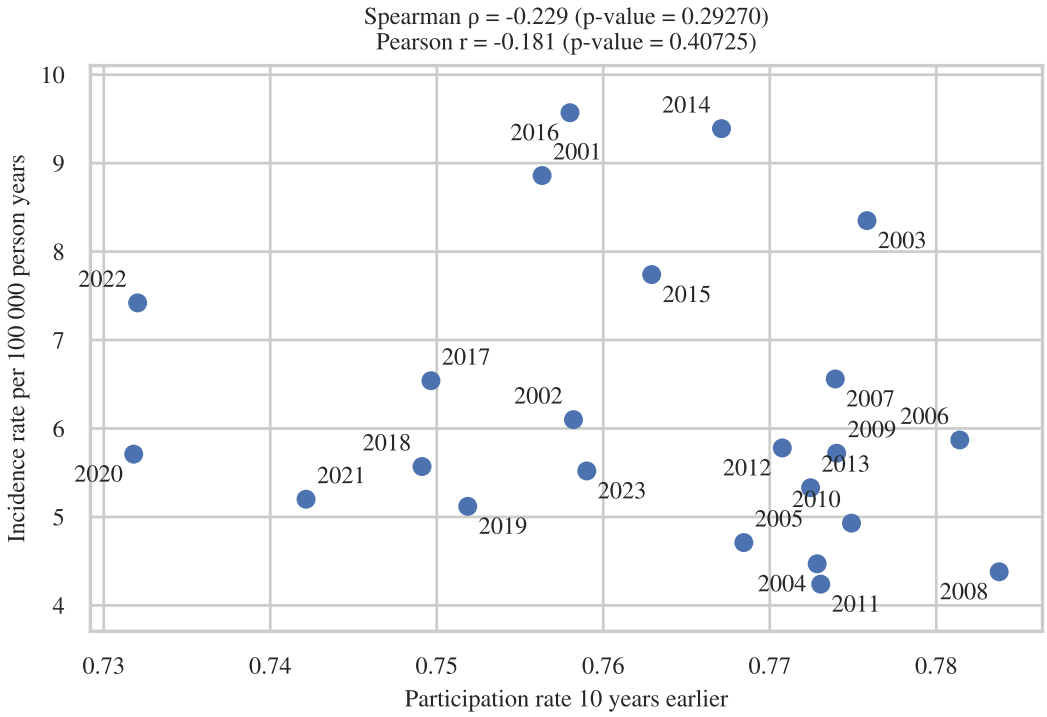


Figure 14: Incidence (ages 60-69) versus 10-year lagged screening participation

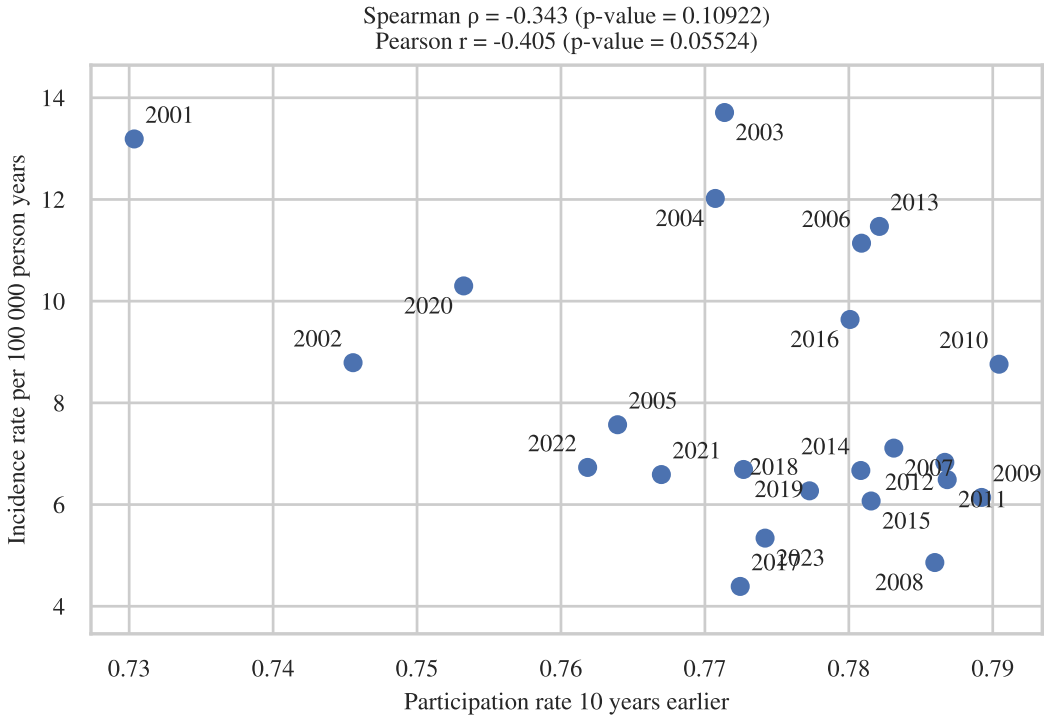


Figure 15: Incidence (ages 70-79) versus 10-year lagged screening participation

3.3 Forecast

As depicted by historical figures, the incidence of cervical cancer has been on an upward trend in the last 10 to 15 years. During this same period, HPV vaccination of the Finnish youth has been rolled out as part of the national immunization program. While the incidence trend is worrying, we can expect that as time progresses, the effects of vaccination will be visible in national incidence statistics. However, most of the vaccinated youth are still very young and the true impact is likely years away. In order to gain some perspective into what the future may behold, we have performed a simple forecast of cervical cancer incidence in Finland under varying vaccination coverage scenarios. The underlying population forecast is downloaded from the Statistics Finland website. While the forecasting method makes many simplifications, it illustrates that relying on vaccination alone will not provide a rapid solution to the increasing incidence rates.

One of the core assumptions of the forecast is that fully vaccinated (two doses) women will attain 100% immunity to HPV and hence are not subject to developing cervical cancer. Of course, no current vaccine provides protection against all possible HPV types, but they do provide protection against the ones most often associated with cervical cancer (such as HPV 16 and 18). Furthermore, while it is possible that those who have received just one dose have similar protection as those with two, we have taken the approach of considering only two doses to be sufficient; the main vaccine in Finland is CERVARIX and the manufacturer recommends two doses, which is also the recommendation in the Finnish immunization program.

The forecast also assumes that vaccination coverage is the only independent variable, and all else remains as is. As such, we make no assumptions on the impact of increasing or decreasing screening participation upon vaccination uptake. This naturally implies an assumption of vaccination status and screening participation being independent of each other, which is supported by a recent Finnish study published in early 2025 [60]. This study found that people who had positive vaccination status showed no statistically significant change in the likelihood to participate in organized screening compared to unvaccinated people.

As the forecast assumes those who are vaccinated to be immune, cervical cancer develops only in the unvaccinated population. The incidence rate among the unvaccinated population is assumed to be the last five years average (2020 to 2024) for the respective age groups throughout the forecast period. The 2024 figure is a preliminary statistic provided by the FCR. The FCR mentions that historically, roughly 6% of cases are not included in the preliminary figure [61]. In the forecast, incidence for each year is calculated within five year age groups (20-24, 25-29, ... , 80-84, 85+), with those below 20 years of age assumed to have zero incidence. The forecasted cases within each age group is then totaled and a nationwide incidence rate is calculated for each future year.

With regards to the vaccinated base, we take the 2025 starting figure to be the current number of 20 year olds vaccinated in Finland, which is approximately 21 thousand or 71.5% of the cohort. In the base case, we assume each successive cohort reaching age 20 to attain a 73.8% coverage, which is the current total coverage among

those aged 13 to 20 years old. We then roll-over to next year the raw number of vaccinated women. We roll-over the raw number as opposed to keeping a fixed percentage since the Statistics Finland population forecast also includes immigration, and we assume immigrated people over the age of 20 to be unvaccinated. Furthermore, we make no assumption on the currently vaccinated population over the age of 20, since no reliable data is available. While there certainly are a considerable number of people aged 21 to 30 who have been vaccinated, we assume the starting figure to be zero in the forecast.

The alternate scenarios assume reaching 80% and 90% vaccination coverage in women aged 20 years old. In both cases, we take the 2025 coverage to be the current figure of 71.5%. The target level in both scenarios is reached in the year 2029, with a gradual increase between the years.

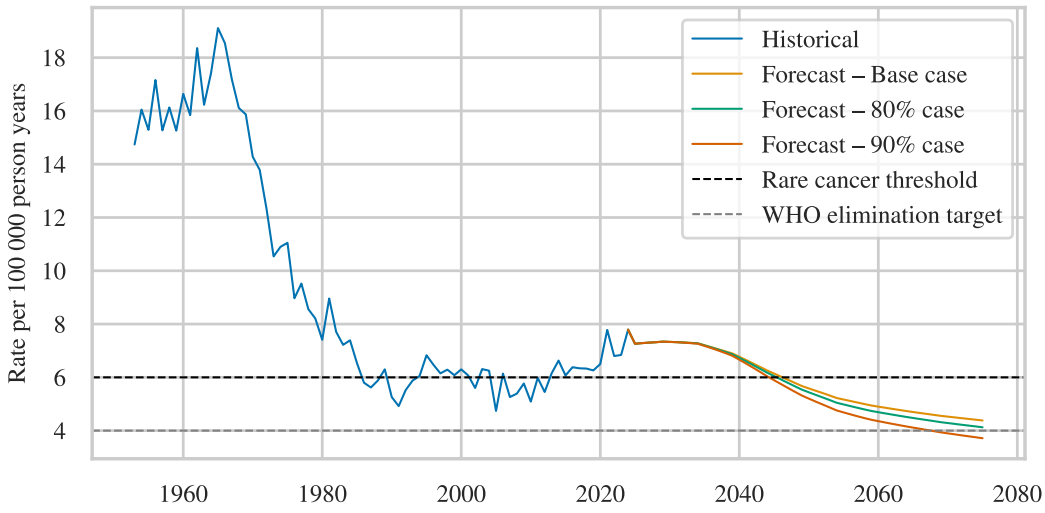


Figure 16: Forecast under varying vaccination scenarios, crude rate

Figure 16 presents the forecasted crude cervical cancer incidence rate. Note that the 2024 figure is not a forecast, but rather based on the FCR's preliminary reported figure. In all scenarios, the steepest decline in incidence begins around 2035 when the vaccinated population begins to reach the age groups where cervical cancer is more prevalent. Some plateuing effect can be seen from approximately 2050 onward, when a significant portion of the population begins to be vaccinated. In all scenarios, incidence is forecasted to return back to historical lows only around 2050. Notably, only the 90% vaccination coverage scenario will reach the WHO elimination target in the forecast time frame, surpassing the threshold of 4 per 100 000 in the year 2068. In the final forecast year of 2075, the incidence rates are 4.4, 4.1, and 3.7 per 100 000 for the base case, 80% case, and 90% case respectively.

The decline seen in Figure 16 is also facilitated by a considerable aging of the Finnish population. Based on the last five year averages, the rate of incidence per 100 000 is the highest in those between 30 and 49 years-old, being 12.8, 18.7, 17.1, and 13.8 within the 30-34, 35-39, 40-44, and 45-49 age groups respectively. For those

aged 50 and above, incidence rates drop to below 9 for all age groups. In 2024, those aged 50 or over made up 44% of the Finnish population, while their share increases already to 48% in 2050 and eventually to 53% in 2075. As such, the forecasted decline is facilitated by not just the increasing number of vaccinated persons, but also by a significant demographic transition. Furthermore, the gradual plateauing is also impacted by a decreasing amount of young people entering the population in addition to reaching high vaccination coverage among the risk group; in 2024, the share of those below the age of 20 was 20%, which decreases to 16% by 2050 and 15% by 2075. Interested readers can find detailed illustrations of the Finnish population distributions over time in Appendix B1.

Since the demographic transition is very noticeable in the Finnish population, using age-standardized incidence rates provides a more comparable analysis between the years. As such, Figure 17 presents the age-standardized incidence rates, with the Finnish population in 2014 considered the standard population. Historical figures have been age-standardized by the FCR, while the forecast has been manually standardized. For this, the Finnish population breakdown in 2014 was downloaded from Statistics Finland. The age-standardized incidence rate (ASIR) for each forecast year was calculated via

$$\text{ASIR} = \sum_i (r_i w_i), \tag{1}$$

where r_i is the crude cervical cancer incidence rate per 100 000 among age group i, and w_i is the proportion of age group i among the 2014 Finnish population (the standard population). It should be noted that there is the possibility of a small deviation in standardization between the described approach and that of the FCR; the FCR does not detail whether standardization has been done for each specific age, or using certain age groups. Nevertheless, this approach should closely align the forecasted standardized figures with the historically standardized figures of the FCR.

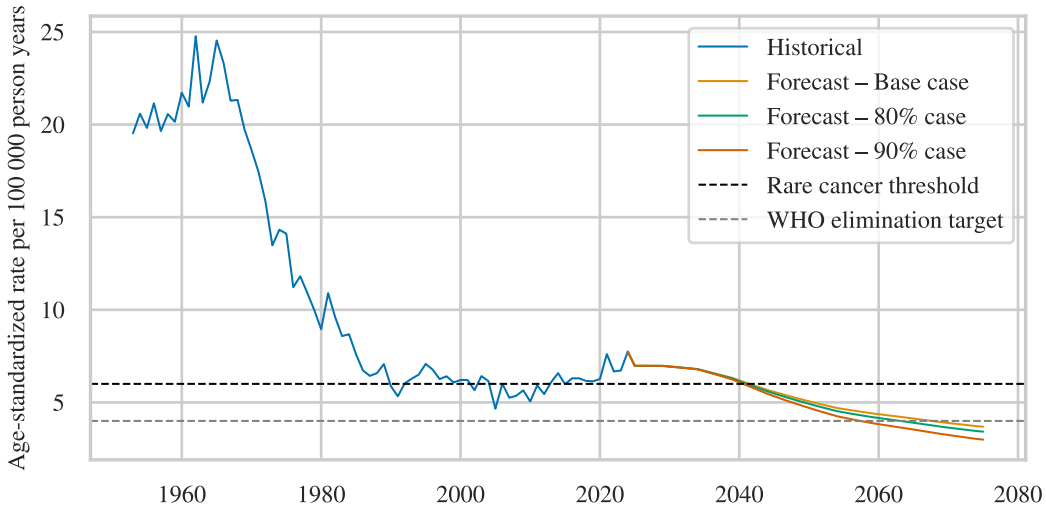


Figure 17: Forecast under varying vaccination scenarios, age-standardized (Finland)

As Figure 17 demonstrates, when the effects of aging are eliminated, the impact of vaccination becomes more visible earlier in the forecast period. In contrast to the crude rates, which initially even increase during the period between 2025 and 2029, the age-standardized incidence begins to gradually fall right away. This standardized measure better isolates the effect of removing HPV in younger cohorts and hence provides a valuable perspective of the considerable effect vaccination also also has on the younger cohorts, which is partially masked by an aging population in the crude rates for an extended period of time. In age-standardized terms, all cases would reach the rare cancer threshold in roughly 2040, while each case would also surpass the WHO elimination target during the forecast period. The base case surpasses the WHO target in 2068, the 80% case in 2064, and the 90% case already in 2058. In the final forecast year of 2075, the age-standardized incidence rates are 3.7, 3.4, and 3.0 per 100 000 for the base case, 80% case, and 90% case respectively.

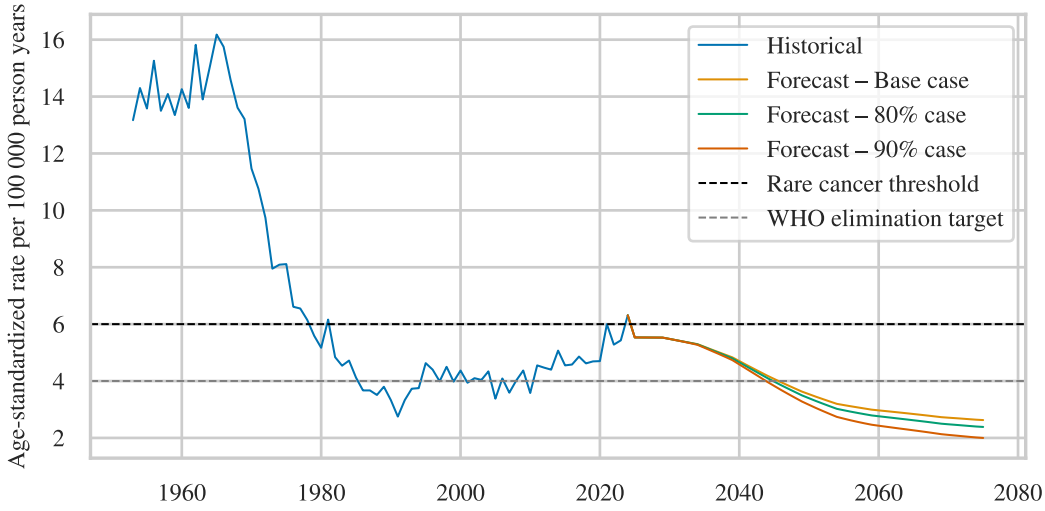


Figure 18: Forecast under varying vaccination scenarios, age-standardized (world)

Finally, Figure 18 presents age-standardized incidence forecasts based on the world standard population. The chosen world standard population reflects the world population distribution during the 1950s as defined by Segi and Doll et al, which is the convention used by the FCR [62, 63]. The calculation method is exactly as presented in Equation (1), except the weight w_i is the proportion of age group i within the world standard population as opposed to the Finnish population in 2014.

On a world-standardized basis, the outcome is a drastic decrease not just in forecasted incidence rates but also in the near-term historical rates. Effectively, the starting point is already at the rare cancer threshold, while all the cases surpass the WHO elimination target at the latest by 2046. A noticeable decrease in incidence also begins much sooner, which is due to the significant weight the world standard population places on younger cohorts, while considerably discounting the weight of older cohorts. For example, in Finland during 2024 the share of those below 30 years old was approximately 30%, while the world standard population assumes approximately 60%. Those between 30 and 49 represented also approximately 30%

in Finland during 2024, while the world standard population assumes approximately 20%. For those 50 and above, the share was approximately 40% in Finland during 2024 whereas the world population assumes just 20%. This deviation is understandable as the world standard population was constructed in the 1950s when life expectancy was substantially lower and age structures were far younger than today (see Appendix B1 for details on world standard population). As such, we may argue that it is not representative of current populations, particularly for ageing, high-income countries such as Finland where life expectancy has increased. Furthermore, the relevance of the world standard population can be considered to diminish even further when applied to a far-reaching forecast; in our forecast, the standard population is applied to situations that exceed 100 years since its inception. Nevertheless, standardizing by the world standard population still aligns the analysis with the convention used by the FCR and many other studies, while providing a perspective on the impact vaccinations would have in a far younger population.

4 Results and discussion

The descriptive results highlight a long term decrease in cervical cancer incidence, paired with a more recent and concerning reversal in incidence trends. National incidence rates declined sharply after the start of nationwide screening in the 1960s, reached a low of 4.7 per 100 000 person-years in 2005, and has trended upward since then, remaining above the EU ”rare cancer” threshold (6 per 100 000) for the past eight years. Importantly, Finland has not reached the WHO elimination target of 4 per 100 000 in the historical series under the national age-standardization (population of Finland in 2014) used by the FCR.

Age-specific incidence trends suggests that the recent increase is driven primarily by younger aged cohorts. The 30–39 cohort reached its lowest incidence in 1990 (2.3 per 100 000) but has increased steadily since; by 2023 it was 15.6 per 100,000, exceeding even the 1953 level (14.2). Those ages 40–49 display a similar pattern, with a low of 4.4 per 100 000 in 1990 and an increase to 14.1 in 2023. In contrast, incidence has generally declined since 1953 among those aged 50 or above.

Mortality trends are more encouraging and show a continued decline without a recent upward trend. Mortality dropped markedly after the screening program's introduction and has remained roughly stable at 1.5–2 per 100 000 person-years over the last decade; across age groups above 30, mortality has decreased by over 75% since 1953 and has been below 5 per 100 000 for the last seven years. So far, mortality rates seem to not display any near-term upward trends as opposed to incidence rates. However, the impact of increasing cancer diagnoses could have a lagged effect on mortality statistics and developments should be carefully monitored.

While screening shows practically a 100% invitation coverage, there has only been a modest improvement in participation (measured as a percentage of those invited, not the whole population) since 1991: 71.6% in 1991 versus 73.1% in 2023, with a low point in 2012 (67.4%) and a gradual recovery since. Participation is consistently higher in older ages; in recent years, those aged 50 have been the most active participants, while participation among the youngest invited cohorts (especially those in the age 25 cohort, where invited) is substantially lower. This low participation in the younger cohorts is particularly relevant given the observed rise in incidence at ages 30–49.

Regional variation between WBSCs is substantial. In 2023, participation ranged from 64.4% (North Karelia) to 83.1% (South Savo), with a visible ”belt” of lower participation in central Finland. Over the longer horizon (1991 to 2023), most WBSCs experienced statistically significant change; notably, more WBSCs saw significant declines than increases, with large decreases in North Karelia (-11.4 pp), Ostrobothnia (-7.3 pp), and Central Ostrobothnia (-6.7 pp), while major population hubs of West Uusimaa (+14.8 pp) and Helsinki (+12.1 pp) increased noticeably. Considering the wide spread of participation rates between WBSCs and very differing changes over time, the findings may indicate that the most effective method for increasing national participation rates would be to have regionally differing approaches and program specifications.

The proportion tests reinforce that participation changes are not uniform across ages or time periods. Over the long term (1991 vs 2023), only a subset of ages (30,

45, 50, and 65) showed statistically significant increases in participation, with changes ranging from 1.1 to 8.9 percentage points. Around COVID-19, participation decreased broadly from 2019 to 2020 (all ages except 30 showed significant change; most ages decreased, while 25 increased), and then rebounded strongly from 2020 to 2023 with significant increases across all ages. Regionally, the early COVID effects seemed concentrated in more populous/southern WBSCs from 2019 to 2020, while the 2020 to 2023 recovery was positive in most WBSCs—except for a notable decline in North Karelia (-10.4 pp), potentially linked to process changes that shift more responsibility to invitees to book their own appointment.

An interesting result of this thesis is the observed association between incidence and prior screening participation. Nationally, incidence plotted against participation 10 years earlier shows a statistically significant negative Spearman correlation ($\rho = -0.578$, p = 0.00389). While this is based on only 23 yearly data points, the result is consistent with the expected lag from screening attendance to prevention of invasive cancer, and supports the plausibility that declines in participation in some periods/regions contribute to later increases in cancer incidence. The age-segmented analyses strengthen this interpretation: for incidence among ages 40–49 versus participation of the same group of people at ages 30–39 ten years earlier, the Spearman correlation is very strong (ρ = -0.780, p = 0.00001). For incidence among ages 50–59 versus participation at 40–49 ten years earlier, the association remains significantly negative (ρ = -0.493, p = 0.01682). In older ages (60–69 and 70–79), the correlations are weaker and not statistically significant, which may reflect smaller marginal benefit of incremental participation changes once accumulated lifetime screening history is likely higher, and other competing health risks are elevated.

HPV vaccination trends provide a partial warning as to why near-term incidence increases may persist. As of August 2025, coverage among girls aged 13–20 is 81.6% for at least one dose, but only 73.8% for two doses; for the 2010 birth cohort (age 15), full-dose coverage is 75.7%, which is around 14 percentage points below the WHO target of 90% vaccinated by age 15. Finland also appears behind its Nordic peers on comparable metrics. In addition, vaccination coverage varies by WBSC, and persisting hesitancy has been highlighted especially in the Ostrobothnia area, with proposed drivers including cultural influences, persisting post-COVID vaccine skepticism, and social media misinformation. Taken together, these data imply that vaccination alone is unlikely to rapidly counteract rising incidence in cohorts currently at highest risk (30–49), because many of these cohorts were never eligible for routine vaccination and because vaccinated cohorts are only now beginning to enter into screening and cancer-risk ages.

The forecast results make this point explicit. Under the base-case assumption (73.8% full-dose coverage among cohorts entering adulthood), crude incidence declines most steeply only from roughly 2035 onward when vaccinated cohorts enter the higher-risk ages; incidence returns to ”historical lows” only around 2050, and only the 90% scenario reaches the WHO elimination target (crude incidence below 4 per 100 000) within the forecast horizon, specifically in 2068. By 2075, crude incidence is 4.4 (base case), 4.1 (80% case), and 3.7 (90% case) per 100 000. These patterns are shaped not only by vaccination coverage but also by demographic aging

(a rising share of the population aged 50 and above), which affects crude rates and can mask early benefits of vaccinating younger cohorts. When standardized to Finland's 2014 population, vaccination effects appear earlier: all scenarios cross the rare cancer threshold (by approximately 2040), and all pass the WHO elimination target during the forecast period (base case in 2068, 80% case in 2064, and 90% case in 2058), with age-standardized rates in 2075 of 3.7, 3.4, and 3.0 respectively.

Overall, the results suggest two key complementary implications for prevention policy in Finland. First, sustaining and improving screening participation remains essential, because incidence increases are statistically associated with lesser participation particularly in the age groups at highest risk, and screening has historically strongly coincided with reduced incidence rates. Furthermore, there is clearly lesser screening participation among younger women with also high deviation between WBSCs, indicating that improving participation rates requires age and region specific targeted responses. Second, vaccination coverage – especially full-dose coverage by age 15 – needs to rise meaningfully toward 90% to not only reach elimination thresholds on a reasonable timescale, but also to catch up to our Nordic peers. In addition, regional hesitancy patterns particularly in the Ostrobothnia regions deserve targeted actions.

5 Summary and future prospects

This thesis examined Finnish cervical cancer trends and through (i) descriptive analyses of long term incidence, mortality, screening participation, and vaccination coverage; (ii) statistical testing of participation changes across age groups and WBSCs, including COVID-era comparisons; (iii) exploratory correlation analysis between cervical cancer incidence and 10-year lagged screening participation; and (iv) a simplified scenario-based forecast of future incidence under differing HPV vaccination coverage assumptions.

Finland's organized screening program has historically reduced the cervical cancer burden substantially, but incidence has increased since the mid-2000s after reaching its lowest level in 2005 (4.7 per 100 000, age-standardized). The increase is concentrated in screening-age cohorts, especially ages 30–49, where incidence in 2023 exceeded the lows observed around 1990. Mortality, however, has continued to decline and remained low and stable in the last decade.

Screening data shows that invitation coverage is essentially maximized nationally, while participation has remained around the low 70% range and varies substantially by age and region. Participation is higher at older ages and notably lower among younger invitees, while WBSC level participation ranges widely (mid-60% to low-80% in 2023). Statistical comparisons indicate that long-term participation changes by age were modest, but regional changes were more pronounced and more often negative than positive over 1991 to 2023; participation also dipped in 2020 during COVID onset and recovered by 2023, with some WBSC-specific exceptions.

A central analytical finding is a negative association between cervical cancer incidence and screening participation ten years earlier: this is evident nationally (Spearman $\rho = -0.578$) and particularly for ages 40–49 versus participation ten years prior at age of 30–39 (Spearman $\rho = -0.780$). While this does not establish a causal relationship, these results are consistent with the expected lagged preventative effect of screening and support the interpretation that participation declines can contribute to higher later incidence.

Vaccination coverage supports long-term progress but implies a slow timeline to elimination at current levels. Full-dose coverage among girls remains below the WHO target (e.g., 73.8% for ages 13–20; 75.7% in the 2010 cohort). In the forecast, crude incidence declines meaningfully only after vaccinated cohorts enter into higher-risk groups; only the 90% scenario reaches the WHO elimination threshold (below 4 per 100 000 crude rate) within the projection period.

Future prospects and potential improvements follow three key priorities:

1. Increase HPV vaccine uptake, especially full-dose coverage by age 15. Finland is noticeably lagging compared to Nordic peers and, as the forecast demonstrates, current levels are unlikely to deliver elimination quickly.

2. Improve screening participation where it is lowest, particularly among younger invitees and low-participation WBSCs. As of 2023, there was considerable variation in participation between WBSCs, with a nearly 20 percentage point difference between the highest and lowest. We also demonstrated that their seems

to be a significant association between participation and incidence, particularly among high-risk cohorts, which supports screening as a central tool in the battle to eliminate cervical cancer.

3. Improve the evidence base with richer data and modeling. The correlation analysis is simple and limited by data availability. A clear improvement would be to gather data covering a longer timeline and consider other confounders such as migration, testing outside the program, and prior screening histories. Similarly, a more advanced forecasting model could incorporate details such as partial vaccination effects, herd effects, impact of boys vaccination, and screening changes over time.

In summary, this thesis indicates that Finland's cervical cancer situation is at somewhat of a crossroads: historical prevention has been highly effective in reducing incidence, mortality remains low, and the forecast indicates that vaccination offers a path toward eventual elimination. However, rising incidence among those aged 30 to 49, noticeable differences in participation and vaccination uptake between WBSCs and age groups, and long timelines to elimination under current vaccination coverage levels imply that improvements in both screening and vaccination are needed to reverse the slightly worrying near-term trend and accelerate progress toward the WHO elimination target.

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A Additional descriptive statistics

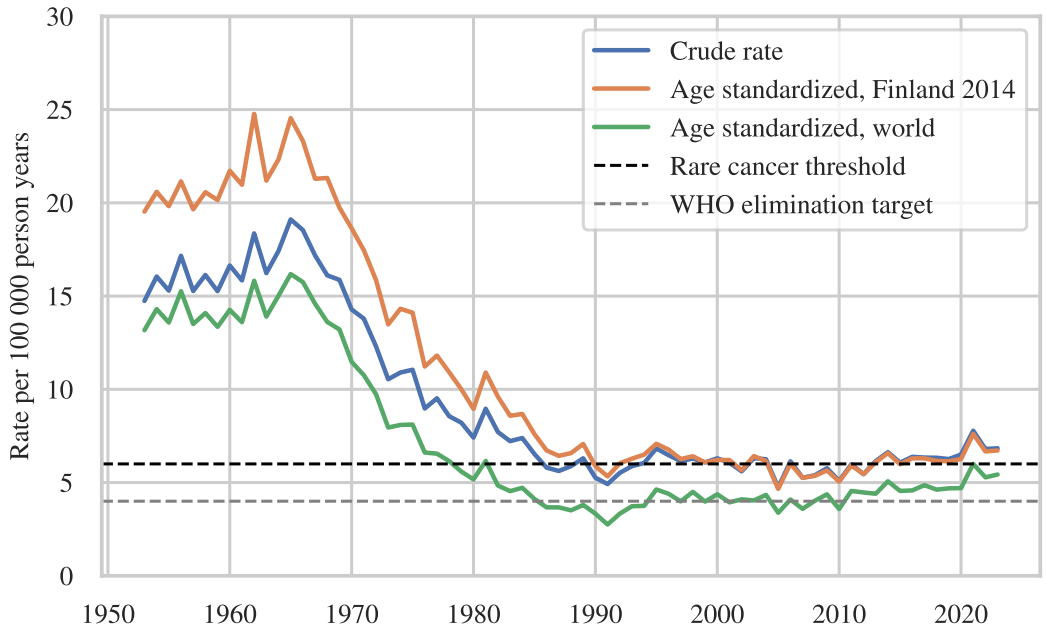


Figure A1: Cervical cancer incidence in Finland, 1953-2023

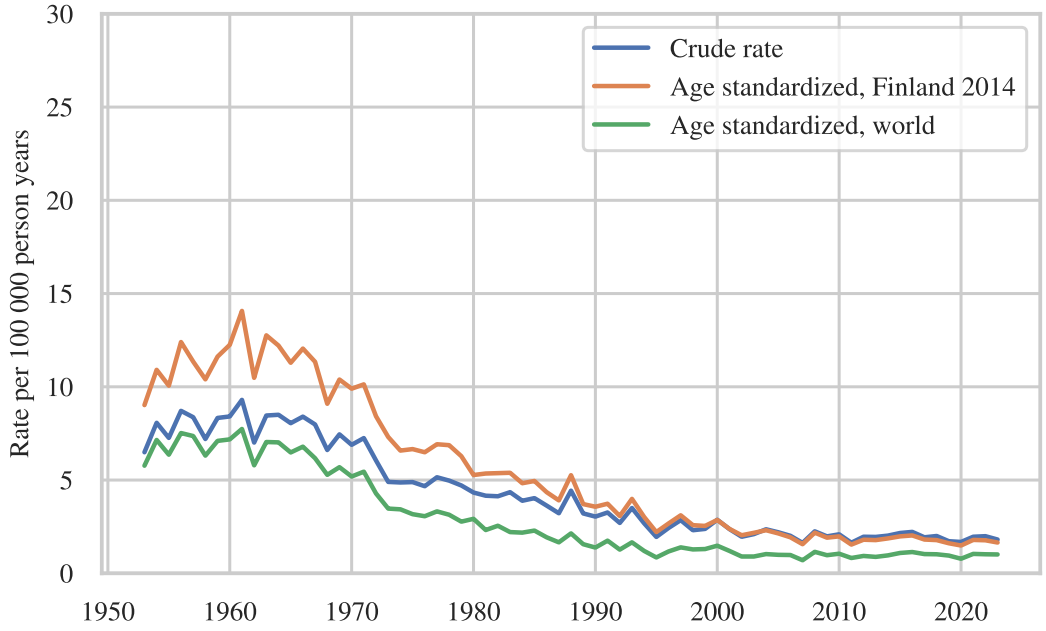


Figure A2: Cervical cancer mortality in Finland, 1953-2023

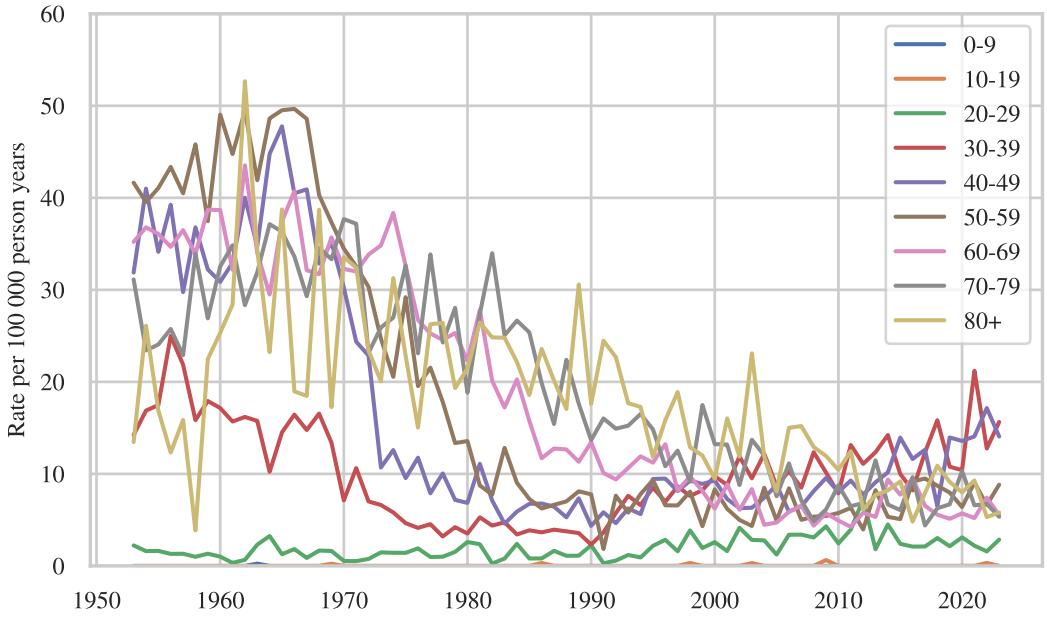


Figure A3: Cervical cancer incidence by all age groups in Finland, 1953-2023

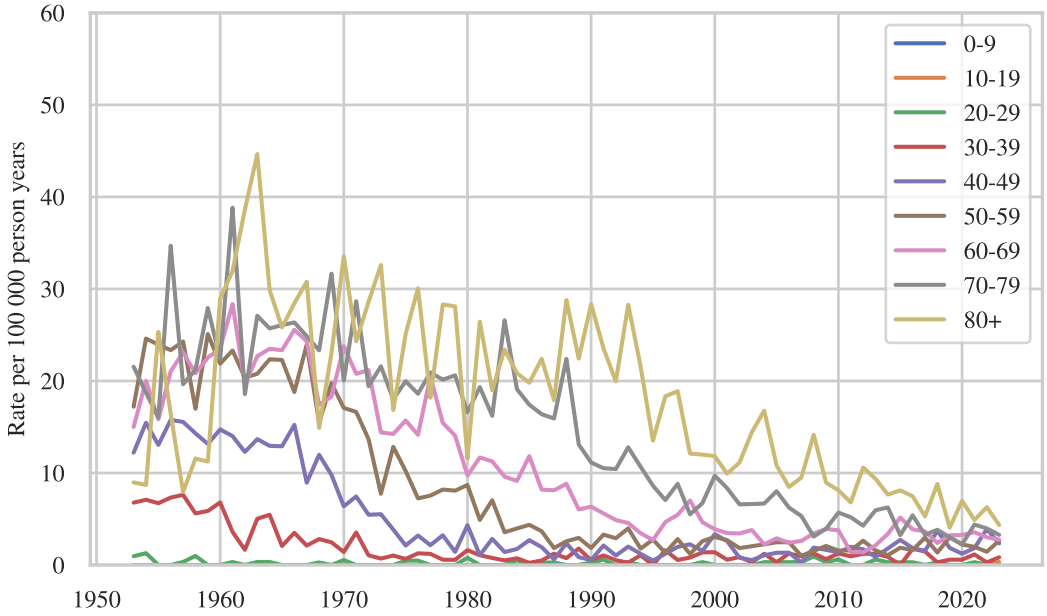


Figure A4: Cervical cancer mortality by all age groups in Finland, 1953-2023

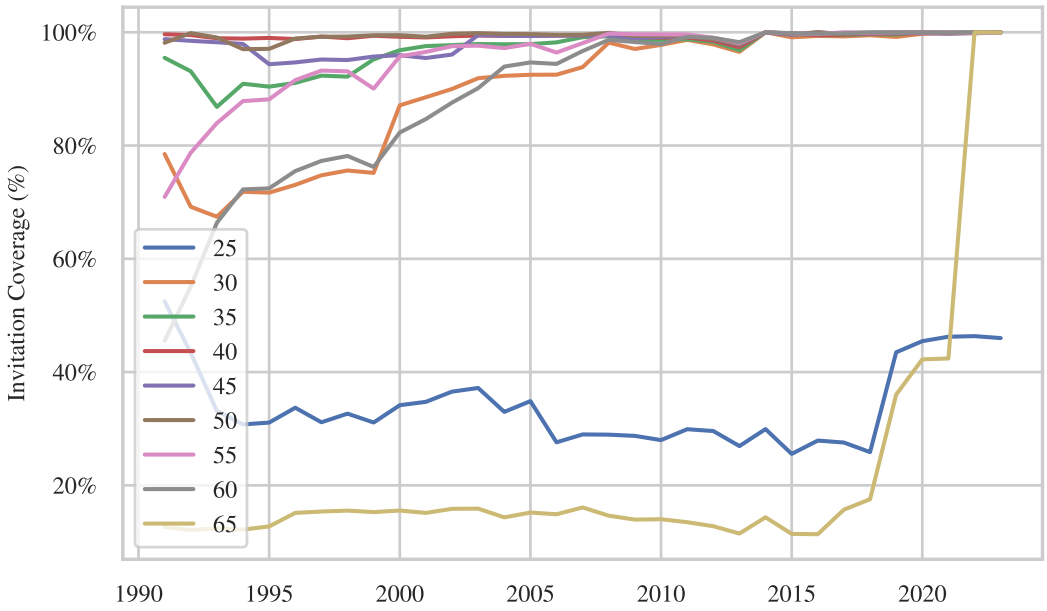


Figure A5: Invitation coverage in Finland by age, 1991-2023

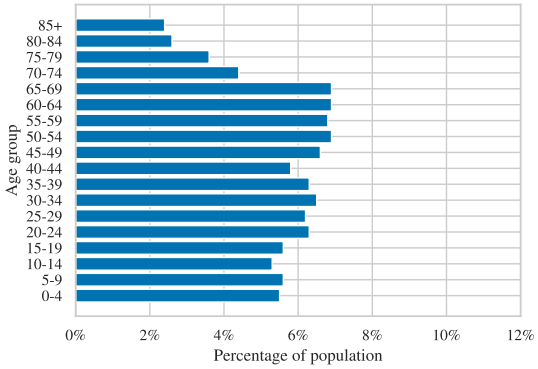
Table A1: At least one dose vaccination coverage-% by WBSC and birth Year

	Birth year								
Area	2005	2006	2007	2008	2009	2010	2011	2012	Total
Central Finland	78.1	78.7	85.8	82.3	83.4	82.1	80.4	80.3	81.4
Central Ostrobothnia	61.9	71.1	76.7	77.0	77.2	72.2	74.9	72.6	73.3
Central Uusimaa	77.1	78.0	87.6	87.4	82.7	85.2	82.8	78.0	82.5
City of Helsinki	81.3	83.3	87.4	87.4	86.8	87.4	83.3	82.2	84.8
East Uusimaa	77.3	81.5	84.8	84.1	84.7	83.3	81.5	81.8	82.6
Kainuu	75.3	79.7	81.9	84.8	84.8	83.2	79.0	76.2	80.8
Kanta-Häme	74.0	77.0	87.2	87.4	84.1	85.4	82.6	79.5	82.4
Kymenlaakso	76.0	81.3	87.1	86.6	88.2	86.9	82.8	80.0	83.9
Lapland	75.4	75.1	84.6	83.6	83.8	85.5	80.8	81.6	81.4
North Karelia	79.0	83.3	87.7	88.4	84.3	86.6	83.7	81.2	84.1
North Ostrobothnia	68.1	70.7	79.5	80.7	76.8	76.7	76.5	75.2	75.6
North Savo	81.1	87.7	91.5	90.1	90.4	87.9	87.4	86.8	87.8
Ostrobothnia	68.9	67.1	77.2	76.8	76.7	77.8	74.2	74.4	74.3
Pirkanmaa	75.1	80.2	84.9	85.0	83.9	83.3	82.1	81.3	81.9
Päijät-Häme	68.4	75.6	78.7	80.0	78.2	76.2	72.1	75.3	75.7
Satakunta	67.3	70.5	80.2	79.7	80.3	80.3	80.1	79.3	77.4
South Karelia	81.6	81.8	88.4	89.0	85.8	87.2	81.0	83.8	84.8
South Ostrobothnia	68.9	68.1	74.0	76.7	76.8	77.6	74.2	73.4	73.9
South Savo	83.8	84.3	88.0	89.7	86.8	88.1	82.5	80.9	85.6
Southwest Finland	78.8	83.0	87.3	87.7	87.9	88.0	86.5	86.9	85.6
Vantaa and Kerava	77.2	81.1	85.5	85.3	85.6	84.5	82.2	81.4	82.9
West Uusimaa	80.5	83.4	88.2	86.7	85.7	84.8	81.0	77.8	83.6
Åland	86.9	85.2	87.7	89.0	83.0	82.2	84.8	81.5	85.0
Total	76.1	78.9	84.8	84.7	83.6	83.5	81.0	79.9	81.6

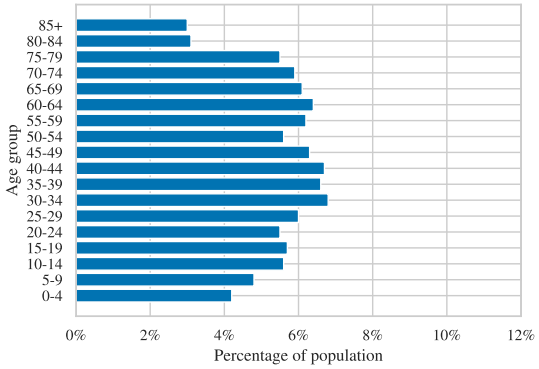
Table A2: Two dose vaccination coverage-% by WBSC and birth Year

	Birth year								
Area	2005	2006	2007	2008	2009	2010	2011	2012	Total
Central Finland	75.1	75.5	73.2	70.8	68.9	72.9	70.1	64.5	71.4
Central Ostrobothnia	59.2	66.4	73.8	71.3	71.6	63.9	68.2	56.3	66.6
Central Uusimaa	73.9	75.1	71.0	81.5	74.6	74.1	74.4	64.8	73.7
City of Helsinki	78.0	79.0	82.5	82.3	81.8	81.7	76.2	68.3	78.6
East Uusimaa	71.9	72.8	79.4	78.2	79.0	73.1	69.9	57.1	72.5
Kainuu	63.5	60.6	79.9	79.2	79.3	77.7	68.8	60.8	71.5
Kanta-Häme	68.8	72.6	79.9	78.5	75.5	75.6	72.4	66.5	73.9
Kymenlaakso	73.0	76.3	81.8	80.4	79.1	76.1	65.5	59.7	74.0
Lapland	71.2	68.5	80.4	78.6	78.5	77.8	71.1	66.7	74.2
North Karelia	73.8	78.9	81.7	82.5	78.0	80.1	76.0	71.7	77.7
North Ostrobothnia	60.4	59.9	75.4	75.6	71.4	69.4	65.6	59.8	67.3
North Savo	76.9	84.3	86.9	79.5	84.0	83.6	81.3	75.4	81.4
Ostrobothnia	66.0	61.3	73.0	73.2	71.5	73.0	67.4	65.2	68.9
Pirkanmaa	70.1	74.8	76.9	77.9	75.5	74.2	72.5	63.4	73.1
Päijät-Häme	62.9	70.6	73.7	72.2	70.9	66.0	59.6	60.7	67.2
Satakunta	64.6	68.7	74.7	75.0	76.3	74.4	73.7	70.3	72.4
South Karelia	77.7	80.4	85.0	79.8	76.1	76.9	64.7	63.6	75.4
South Ostrobothnia	64.8	65.3	70.5	71.1	70.9	72.7	65.2	59.4	67.5
South Savo	76.6	83.5	85.0	85.3	81.3	82.6	74.5	65.5	79.4
Southwest Finland	74.1	78.8	82.0	81.8	81.1	79.8	78.3	75.4	78.8
Vantaa and Kerava	73.8	75.3	77.4	78.9	81.6	79.9	75.1	65.4	76.0
West Uusimaa	75.5	76.7	82.7	79.0	76.0	74.7	65.2	57.1	73.3
Åland	81.5	81.9	75.5	82.8	79.3	75.1	77.0	75.0	78.3
Total	71.5	73.7	78.6	78.1	76.6	75.7	71.2	64.8	73.8

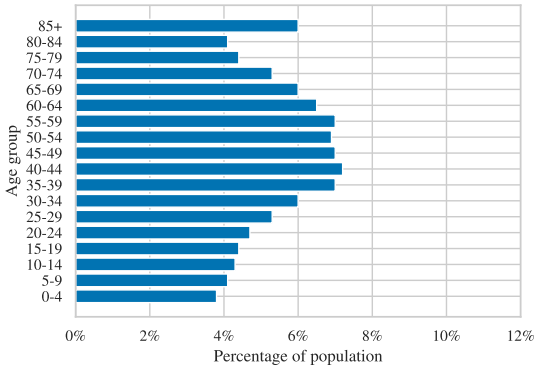
B Population distributions



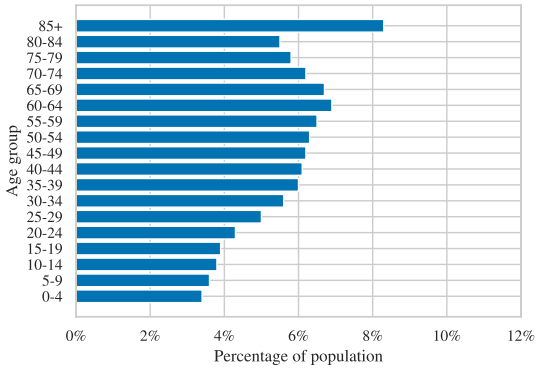
(a) Finnish population, 2014



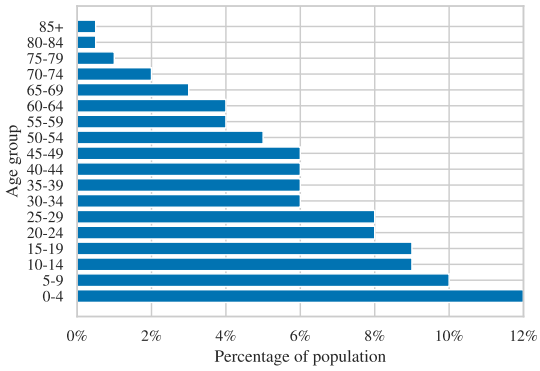
(b) Finnish population, 2024



(c) Finnish population, 2050 forecast



(d) Finnish population, 2075 forecast



(e) World standard population (1950s)

Figure B1: Finnish population distribution over time and world standard population