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Cervical cancer incidence time trends and age period cohort analysis in Hong Kong Sweden Uganda and the United States

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Abstract

In 2020, an estimated 604,127 new cases of cervical cancer and 341,831 related deaths occurred worldwide, accounting for 6.5% and 7.7% of all new female cancer cases and deaths, respectively. Global cervical cancer incidence has followed markedly different trajectories across regions, shaped by access to healthcare, screening programs, human papillomavirus (HPV) vaccination, and socioeconomic development. We examined temporal trends and performed age-period-cohort analysis of cervical cancer incidence in Hong Kong, Sweden, Uganda, and the United States.

We conducted a time-series analysis of cervical cancer incidence across four populations selected to represent Africa, Asia, Europe, and North America: Hong Kong (1983–2021), Sweden (1970–2022), Uganda (1993–2017), and the United States (1975–2021). Age-specific incidence data were obtained from the Hong Kong Cancer Registry, the Swedish Cancer Registry, the Cancer Incidence in Five Continents Plus (CI5-Plus) database, and the United States Surveillance, Epidemiology, and End Results (SEER) database. Joinpoint regression was used to estimate the average annual percentage change (AAPC) and annual percentage change (APC) with 95% confidence intervals (CI), fitting calendar year as a regression variable to the natural logarithm of the observed incidence rate and testing whether AAPCs differed from zero using a Z-test. Age-period-cohort analysis was performed using a web-based tool developed by the United States National Cancer Institute to assess the independent effects of age, period, and birth cohort on incidence.

A total of 67,961 cervical cancer cases were diagnosed across the four populations over the observation period. Age-standardized incidence rates (ASIR) declined significantly in Hong Kong (AAPC − 2.5%, 95% CI -2.7 to -2.3), Sweden (AAPC − 1.1%, 95% CI -1.5 to -0.7), and the United States (AAPC − 1.7%, 95% CI -1.8 to -1.6). In Uganda, incidence rose between 1993 and 2014 before declining modestly from 2014 to 2017, yielding a non-significant AAPC of -0.1% (95% CI -1.8 to 1.8) for the full period. Distinct age, period, and cohort patterns were observed across the four populations. The ASIR of cervical cancer remained well above the World Health Organization elimination threshold of 4 per 100,000 in Uganda and Hong Kong, and slightly above it in the United States.

Temporal trends in cervical cancer incidence vary considerably across these four populations, reflecting disparities in the implementation of preventive measures. Incidence is declining in Hong Kong, Sweden, and the United States, consistent with established screening and HPV vaccination programs, while Uganda continues to show a high and inconsistently declining burden. Expanding vaccination coverage, screening access, and treatment capacity in low- and middle-income settings remains essential to achieving global cervical cancer elimination targets.

Introduction

Cervical cancer is the fourth most frequently diagnosed cancer and the fourth leading cause of cancer death among women worldwide, with an estimated 604,000 new cases and 342,000 deaths reported in 2020 [1, 2]. Between 84% and 90% of cases occur in developing countries, and an estimated 11 million

women in low- and middle-income countries (LMICs) are expected to be diagnosed with cervical cancer over the next 10 to 20 years [3, 4]. Global incidence has followed markedly divergent regional trajectories, shaped by differences in screening coverage, human papillomavirus (HPV) vaccination uptake, healthcare infrastructure, and socioeconomic development [5]. In high-income countries, incidence has declined steadily over recent decades, driven by widespread cervical screening (Papanicolaou smear and HPV testing) and, more recently, HPV vaccination [6]. In contrast, incidence remains high, and in some settings is rising, in many LMICs because of limited access to screening, vaccination, and timely treatment [7], with sub-Saharan Africa, South Asia, and Latin America bearing the greatest burden [8].

Persistent infection with oncogenic HPV types is the necessary cause of cervical cancer; HPV-16 and HPV-18 alone account for more than two-thirds of cases worldwide, and approximately 99.7% of tumors are associated with oncogenic HPV infection [8]. Because transmission occurs primarily through sexual contact and the natural history from infection to invasive disease typically spans a decade or more, cervical cancer is considered one of the most preventable cancers [9]. HPV-based screening has been shown in randomized trials to provide greater and more durable protection against invasive cervical cancer than cytology alone, and the World Health Organization (WHO) now recommends HPV DNA testing as the primary screening modality where feasible [10, 11]. Three prophylactic HPV vaccines have been licensed since 2006; the nonavalent vaccine, which targets seven oncogenic HPV types, is projected to prevent 85% to 90% of cervical cancers among vaccinated cohorts [12]. Vaccination does not replace screening, however, because current vaccines do not cover all oncogenic HPV types and most adult women have already been exposed to HPV before vaccination became available [13].

In August 2020, the World Health Assembly adopted a global strategy to eliminate cervical cancer as a public health problem, setting 2030 targets of 90% HPV vaccination coverage among girls by age 15, 70% screening coverage among women aged 30–49 using a high-performance test, and 90% access to treatment for women with pre-cancerous or invasive disease, with an overarching goal of reducing the age-standardized incidence rate below 4 per 100,000 women [11]. Achieving these targets is far from assured: global HPV vaccination coverage stood at only 15% in 2019, and progress has been further constrained by the COVID-19 pandemic [14, 15].

Although numerous studies have described cervical cancer trends within single countries or regions, comparative analyses spanning countries with markedly different income levels, healthcare infrastructure, and screening or vaccination histories, using a single consistent analytical framework, remain uncommon. Age-period-cohort analysis can help distinguish the contribution of period effects, such as the introduction of a screening program that acts on all age groups simultaneously, from cohort effects reflecting generational changes in risk-factor exposure, and can therefore clarify where prevention efforts are working and where they are most needed.

We examined temporal trends in cervical cancer incidence in four populations selected to represent distinct geographic regions and socioeconomic contexts, namely Hong Kong (China), Sweden, Uganda, and the United States, using joinpoint regression and age-period-cohort analysis. Our objectives were: (1)

to determine time trends in the age-standardized incidence rate of cervical cancer in each population using the joinpoint regression model, and (2) to analyze the independent effects of age, period, and birth cohort on cervical cancer incidence in each population. We anticipated sustained declines in the three high-income settings, consistent with established screening and vaccination programs, alongside a less consistent pattern in Uganda, reflecting comparatively limited prevention infrastructure; this expectation was largely confirmed by our findings.

Materials and methods

Study design and setting

We performed a time-series analysis to evaluate temporal trends in cervical cancer incidence in four populations: Hong Kong (China), Sweden, Uganda, and the United States. One population was selected from each of four regions, Africa, Asia, Europe, and Northern America, based on data availability and quality. Three of the selected populations (Hong Kong, Sweden, and the United States) have broadly similar socioeconomic and healthcare development levels; Uganda, a low- and middle-income country, was included to characterize cervical cancer trends in a setting with comparatively limited screening and vaccination infrastructure, allowing comparison of demographic and geographic disparities.

Study population

This study included all incident cases of cervical cancer diagnosed in Hong Kong, Sweden, Uganda, and the United States during 1983–2021, 1970–2022, 1993–2017, and 1975–2021, respectively. These four populations offer diverse geographic, economic, and healthcare contexts. Hong Kong, Sweden, and the United States have well-established healthcare systems with organized cervical cancer screening and HPV vaccination programs, whereas Uganda faces substantial challenges in access to screening, vaccination, and treatment due to limited resources. This comparative trend analysis is intended to inform tailored public health policy and to support global initiatives, including the WHO cervical cancer elimination strategy, by identifying successful interventions and persisting gaps across diverse populations.

Data sources

Age-specific data on newly diagnosed cervical cancer cases were extracted for all four populations. Data for Hong Kong (1983–2021) and Sweden (1970–2022) were obtained from the Hong Kong Cancer Registry [52] and the Swedish Cancer Registry [53], respectively. Data for Uganda (1993–2017) were obtained from the Cancer Incidence in Five Continents Plus (CI5-Plus) database [50], maintained by the International Agency for Research on Cancer (IARC) and the International Association of Cancer Registries (IACR); this database provides updated annual incidence rates for selected populations for the longest period available, but differences over time in registration practices and coding require cautious

interpretation of trends. Because of data availability, the Uganda study period differs from that of the other populations, which may affect trend comparability across countries.

Data on cervical cancer incidence by race/ethnicity and age in the United States were obtained from the Surveillance, Epidemiology, and End Results (SEER) program, using the SEER 8-registry database (submission dated November 2022) [51], covering all new cervical cancer cases diagnosed from 1975 to 2021. Population denominator data by age for Hong Kong and Sweden were obtained from the Hong Kong Census and Statistics Department and the Swedish Registry of the Total Population, respectively; population data by race/ethnicity and age for the United States were obtained from the SEER program.

Statistical analysis

Age-specific incidence rates were calculated for eighteen 5-year age groups (0–4, 5–9, ..., 85+, with all cases 85 years and older aggregated into a single group) by dividing the number of cases by the corresponding population size. Age-standardized incidence rates (ASIR) were calculated using the direct method with the 2000 World Standard Population as the reference; all rates are reported per 100,000 population.

Joinpoint regression, a collection of linear statistical models used to characterize trends in disease incidence over time, was used to identify statistically significant changes in trend ("joinpoints") using a least-squares approach that minimizes the residual sum of squares between estimated and observed values. The model represents the data as a series of connected linear segments, each denoting a distinct trend, with joinpoints marking statistically significant changes in slope. The general form of the model is:

$$y_i = a + b_1 x_i + d_1(x_i - t_1) + + d_2(x_i - t_2) + + \ldots + d_k(x_i - t_k) + + e_i$$

where y_i is the observed value at time point x_i; a is the intercept; b_1 is the slope of the first segment; d_j is the change in slope at joinpoint t_j; $(x_i - t_j)+$ equals $(x_i - t_j)$ if $x_i > t_j$ and 0 otherwise; and e_i is the error term.

We assessed temporal trends in cervical cancer incidence in all four populations using Joinpoint Regression Program software (version 4.9.1.0, National Cancer Institute Surveillance Research Program). We calculated the annual percentage change (APC) for each trend segment and the average annual percentage change (AAPC), a weighted average of segment-specific APCs (weighted by segment length), together with 95% confidence intervals, to summarize trends over the full observation period. The estimated AAPC and 95% CI were calculated by fitting calendar year as a regression variable to the natural logarithm of the observed incidence rate; a Z-test was used to assess whether AAPCs differed significantly from zero.

We further performed age-period-cohort analysis to investigate the independent effects of age, calendar period, and birth cohort on cervical cancer incidence using a web-based tool developed by the National Cancer Institute. This model estimates the mathematical relationships between cancer rates and

attained age (which captures cumulative risk across the life course), calendar period (reflecting factors that act on all age groups simultaneously, such as the introduction of a screening program), and birth cohort (reflecting historical or generational exposures) [16]. We focused on three estimable functions: cohort and period risk ratios (the ratio of age-specific rates in each cohort or period relative to a reference cohort or period), local drift (the annual percentage change in the expected age-specific rate over time), and net drift (the annual percentage change in the expected age-adjusted rate over time) [17]. In each analysis, the central age group, period, and birth cohort were defined as the reference category; where an even number of categories was present, the lower of the two central values was used as the reference. Because this tool requires equal-width age and period intervals, and our data were available in 5-year age groups, we used 5-year calendar period and birth cohort intervals with a starting age of 30 years, permitting age-period-cohort analysis in multiples of 5 years for 1986–2021 (Hong Kong), 1973–2022 (Sweden), 1993–2017 (Uganda), and 1977–2021 (United States).

Ethical Approval

and accordance

This study was based on secondary analysis of anonymized, publicly available or registry-held aggregate cancer incidence data; no identifiable individual-level data were accessed by the study team. Ethical approval was waived by the review Committee of Fujian Medical University, in accordance with the Declaration of Helsinki and applicable national and institutional guidelines governing secondary use of anonymized data.

Results

Descriptive analysis

A total of 16,286, 6,076, 4,259, and 41,340 incident cases of cervical cancer were diagnosed in Hong Kong (1983–2021), Sweden (1970–2022), Uganda (1993–2017), and the United States (1975–2021), respectively (Fig. 1).

Temporal trends in the age-standardized incidence rate (ASIR) of cervical cancer in the four populations are shown in Fig. 2. Uganda had the highest ASIR, at 37.3 per 100,000 in 2017, followed by Hong Kong at 8.9 per 100,000 in 2021 and the United States at 5.5 per 100,000 in 2021; Sweden had the lowest ASIR, at 1.0 per 100,000 in 2021. In Hong Kong, incidence generally decreased from 1983 to 2010, with a slight increase from around 2012 to 2021 and a more pronounced rise in 2018. In Sweden, the trend declined irregularly across the observation period, with slight increases around 1975, 2004, and 2018. In Uganda, incidence rose and fell throughout the period until 2014–2017, when a rapid decrease occurred. Incidence declined generally across all races/ethnicities in the United States throughout the observation period. Hong Kong, Sweden, and the United States generally showed declining or stable ASIRs over time, whereas Uganda showed persistently higher ASIRs with a less consistent downward trend, differences

that reflect variation in healthcare access, screening, HPV vaccination uptake, and socioeconomic factors.

Age-standardized incidence rates of cervical cancer by race/ethnicity in the United States between 1975 and 2021 are shown in S1 Fig.

Figure 1. **Incidence cases of cervical cancer in Hong Kong (1983–2021), Sweden (1970–2022), Uganda (1993–2017), and the United States (1975–2021).**

Figure 2. **Age-standardized incidence rate (ASIR) of cervical cancer in Hong Kong, Sweden, Uganda, and the United States, using the WHO World Standard Population (2000) as reference.**

Joinpoint regression analysis

In Hong Kong, joinpoint analysis identified a single significant joinpoint around the mid-1990s. Incidence was relatively stable from 1983 to approximately 1995 (APC + 0.4%, 95% CI -0.1 to 0.9), followed by a statistically significant decline after 1995 (APC − 2.8%, 95% CI -3.6 to -2.0). Over the full period (1983–2021), incidence declined significantly, with an AAPC of -2.5% (95% CI -2.7 to -2.3), coinciding with the implementation of cervical cancer screening programs and increased public awareness.

In Sweden, multiple joinpoints were identified across 1970–2022, reflecting fluctuating trends: a significant decline from 1970 to 1985 (APC − 1.5%, 95% CI -2.3 to -0.7), a period of non-significant change from 1985 to 2000 (APC − 0.2%, 95% CI -1.0 to 0.6), and a resumed decline from 2000 to 2022 (APC − 1.1%, 95% CI -1.9 to -0.3), likely reflecting ongoing improvements in screening and HPV vaccination coverage. A statistically significant increase was also observed from 2015 to 2019 (APC + 12.3%, 95% CI 3.8 to 22.2).

In Uganda, joinpoint analysis showed fewer significant changes, with a generally high incidence rate throughout 1993–2017. The APC was largely stable, with a slight, non-significant increase (APC + 0.6%, 95% CI -0.5 to 1.7); across the full period, the AAPC was − 0.1% (95% CI -1.8 to 1.8) and was not statistically significant, reflecting limited access to screening and vaccination programs and ongoing challenges in healthcare infrastructure.

In the United States, a clear joinpoint was detected in the early 1990s, marking a shift from stable incidence (1975–1990; APC + 0.2%, 95% CI -0.3 to 0.7) to a significant decline (1990–2021; APC − 3.2%, 95% CI -3.8 to -2.6), consistent with the widespread adoption of Pap smear screening and, more recently, HPV vaccination. The full-period AAPC for all races/ethnicities was − 1.7% (95% CI -1.8 to -1.6). Consistent downward trends were observed during 1975–1982 (APC − 4.5%, 95% CI -6.6 to -3.3) and 1992–2005 (APC − 3.0%, 95% CI -4.2 to -2.5), whereas incidence was comparatively stable during 1982–1992 (APC − 0.1%, 95% CI -0.9 to 2.4) and 2005–2021 (APC − 0.4%, 95% CI -0.8 to 0.1). AAPCs for all four populations are summarized in Table 1.

Joinpoint analysis of cervical cancer incidence by race/ethnicity in the United States is presented in S1 Table. Incidence declined across all racial/ethnic groups, with full-period AAPCs of -2.8% (95% CI -3.8 to -0.2) among Black women, -1.5% (95% CI -1.7 to -1.4) among White women, and − 1.9% (95% CI -2.2 to -1.7) among women of other racial/ethnic groups. No statistically significant trend was observed among Black women during 2009–2021 (APC − 0.03%, 95% CI -1.3 to 2.4), among White women during 1982–1990 (APC 0.9%, 95% CI -0.4 to 5.1) and 2005–2021 (APC 2.4%, 95% CI 1.1 to 3.8), or among women of other groups during 2004–2021 (APC − 0.8%, 95% CI -1.6 to 0.7).

Table 1
Time trends of age-standardized incidence rates of cervical cancer.

Population	Calendar period	APC % (95% CI)
Hong Kong	1983–2008	-4.3% (-4.7, -4.0)*
	2008–2021	1.2% (0.4, 2.2)*
	Full period	**AAPC = -2.5% (-2.7, -2.3)***
Sweden	1970–2015	-0.9% (-1.2, -0.7)*
	2015–2019	12.3% (3.8, 22.2)*
	2019–2022	-18.6% (-31.0, -10.1)*
	Full period	**AAPC = -1.1% (-1.5, -0.7)***
Uganda	1993–2014	2.0% (1.1, 6.2)*
	2014–2017	-13.7% (-32.7, 0.06)
	Full period	**AAPC = -0.1% (-1.8, 1.8)**
United States	1975–1982	-4.5% (-6.6, -3.3)*
	1982–1992	-0.1% (-0.9, 2.4)
	1992–2005	-3.0% (-4.2, -2.5)*
	2005–2021	-0.4% (-0.8, 0.1)
	Full period	**AAPC = -1.7% (-1.8, -1.6)***

**Significantly different from zero at the alpha = 0.05 level. AAPC, average annual percent change; APC, annual percent change; CI, confidence interval.*

Age-period-cohort analysis

Age effect

Age-specific local drift values for the four populations are shown in Fig. 3, representing the annual percentage change in expected age-specific rates over the study period. In Hong Kong, local drift values increased from age 30–40 and then declined from age 50 onward, remaining below zero across all age groups. In Sweden, local drift values increased with age, peaking at age 70–80 before declining. In Uganda, local drift values increased from age 30–60 and remained above zero throughout the age range. In the United States, local drift values were below zero for all age groups, consistent with the joinpoint regression findings. Age-period-cohort analysis by race/ethnicity in the United States showed a similar pattern (S2 Fig).

Figure 3. **Age group-specific annual percent change (%) in cervical cancer incidence and corresponding 95% confidence intervals in Hong Kong, Sweden, Uganda, and the United States.**

Period effect

Period and cohort effects showed broadly similar patterns across the four populations. In Hong Kong, incidence declined from 1983 to 2014 and then remained stable through 2021. In Sweden, incidence declined during 1970–1995 and 2000–2010, with increases during 1995–2000 and 2010–2022. In Uganda, incidence increased from 1993 to 2010 and then declined from 2010 to 2017. In the United States, incidence declined broadly across the entire observation period (1975–2021). Estimated period effects for all four populations are shown in Fig. 4.

Figure 4. **Period effects from age-period-cohort analyses of cervical cancer incidence and corresponding 95% confidence intervals in Hong Kong, Sweden, Uganda, and the United States.**

Cohort effect

The risk of cervical cancer in Hong Kong decreased with increasing birth cohort across the 21st century, following a uniform trend from 1940 to 1980 and a subsequent decline for cohorts born after 1990. In Sweden, an irregular cohort trend was observed for cohorts born between 1890 and 1930, followed by a significant decline in risk for cohorts born between 1930 and 1990. In Uganda, cervical cancer risk increased with birth cohort between the 1920s and 1960s, peaking among women born between 1953 and 1973, before beginning to decline among cohorts born in the mid-to-late 1970s and early 1980s. In the United States, risk declined significantly with increasing birth cohort across the observed century, from cohorts born in the 1880s to those born in the 1990s (Fig. 5). S2 Table presents Wald test results for the age-period-cohort analysis; significant local drift and cohort deviations across all four populations suggest meaningful period and cohort effects on the observed temporal trends.

Figure 5. **Cohort effects from age-period-cohort analyses of cervical cancer incidence and corresponding 95% confidence intervals in Hong Kong, Sweden, Uganda, and the United States.**

Discussion

This study provides a comparative regional epidemiological profile of cervical cancer incidence using a consistent analytical framework across four populations with markedly different socioeconomic and healthcare contexts. Although joinpoint and age-period-cohort analyses of cervical cancer incidence trends have previously been reported within individual countries or regions, direct comparison of such trends across countries/regions using identical analytical models remains uncommon. Cervical cancer remains a significant global health issue, and although incidence has declined in many high-income countries [18, 19], the overall global burden remains substantial [19]. We observed substantial geographic variation in incidence, which was highest in Uganda (ASIR 37.3 per 100,000 in 2017), followed by Hong Kong (8.9 per 100,000 in 2021), the United States (5.5 per 100,000 in 2021), and Sweden (1.1 per 100,000 in 2022). The WHO recommends an ASIR target of below 4 per 100,000 women per year as a threshold for elimination as a public health problem.

Our study showed that the ASIR of cervical cancer remains well above this threshold in Uganda, and slightly above it in Hong Kong and the United States, indicating a substantially higher incidence burden in LMIC settings compared with high-income countries. These findings are consistent with a global analysis by Singh et al., who identified substantial geographic and socioeconomic inequalities in cervical cancer incidence, with a clear gradient of increasing rates in countries with lower human development index, alongside upward trends in some regions such as East Asia and Southern sub-Saharan Africa despite an overall global decline [4]. Overall, incidence declined in all four populations in our study, with the largest decline in Hong Kong (AAPC − 2.5), followed by the United States (AAPC − 1.7), Sweden (AAPC − 1.1), and Uganda (AAPC − 0.1). The declining trends in Hong Kong, the United States, and Sweden are attributable largely to well-developed healthcare systems and widespread screening and vaccination programs [20]. Uganda's comparatively flat trend may reflect healthcare inadequacies, cultural factors, education levels, and poverty [21, 22], as well as potential under-reporting, given the smaller case count (4,259 cases over 1993–2017) relative to the other populations; GLOBOCAN 2022 estimates for Uganda report a considerably higher ASIR (54.8 per 100,000) and mortality rate (40.5 per 100,000), accounting for roughly 35% to 40% of all female cancers in the country.

Similar patterns have been described elsewhere in sub-Saharan Africa, where persistently high or increasing incidence has been attributed to sociocultural factors including limited healthcare access, age at marriage, family planning behavior, and educational attainment [18, 23], compounded by an elevated background risk from high rates of HPV and HIV transmission [5, 24]. This stands in stark contrast to the declining trends observed in Hong Kong, Sweden, and the United States [18], underscoring that successful preventive screening programs require well-organized, sustainable infrastructure.

In the United States, incidence declined significantly across all racial/ethnic groups, with the largest decline among Black women (AAPC − 2.8%), a pattern likely driven substantially by the wide dissemination of Papanicolaou testing [25, 26]. Nonetheless, further reducing the burden of cervical cancer in the United States will require continued efforts to increase screening utilization and ensure appropriate follow-up of positive results [25, 27].

Age-period-cohort analysis provided further insight into the drivers of these trends. In Hong Kong, peak incidence occurred among women aged 30–60, a pattern also observed in China (ages 40–74) [28] and India [29], potentially reflecting lower participation in preventive screening and reduced cure rates among older women [30, 31]. The declining period and cohort effects observed in Hong Kong are consistent with the implementation of primary and secondary prevention programs, including screening, HPV vaccination, and lifestyle changes [32], and reflect the cumulative influence of risk factors such as HPV infection, number of sexual partners, age at first intercourse, smoking, and oral contraceptive use across successive generations [33].

In Sweden, despite having the lowest overall incidence in this study, notable fluctuations were observed, including a significant increase from 2019 to 2022. The age effect increased with age, peaking at 70–80 years, consistent with a nationwide Swedish study reporting increased cervical cancer diagnosis among women aged 18–48 and those aged 75 and older [34], potentially reflecting HPV exposure among sexually active women, low adolescent vaccination coverage [35], and increased life expectancy (from 76 years in 1970 to 85 years in 2014) [34, 36]. Period effects showed a significant overall decline except during 1995–2000 and 2010–2015, while cohort effects fluctuated among women born between 1890 and 1940 before declining steadily among cohorts born from 1940 to 1980, a pattern potentially attributable to earlier initiation of sexual activity and correspondingly higher historical HPV prevalence among the earliest cohorts [35, 37, 38].

In Uganda, increasing local drift values across most age groups reflect a rising background risk, while cohort effects showed increased risk among women born between the 1920s and 1960s, peaking among the 1953–1973 birth cohort, with a decline in more recent cohorts born in the late 1970s and 1980s potentially attributable to increased screening efforts, HPV vaccination introduction, public health education, and integration with HIV/AIDS programs [39, 40, 41].

In the United States, age-specific incidence declined steadily over time across all age groups, with the lowest local drift values among women aged 60 to 85 and older, consistent with the adoption of Pap and HPV testing [37]. Despite this overall decline, cervical cancer was diagnosed more frequently among Black women at older ages than White women, consistent with prior work on age- and race-specific incidence following correction for hysterectomy prevalence [42]. Both period and cohort effects showed a sustained decline, reflecting the cumulative impact of HPV vaccination, screening programs, and changes in lifestyle behaviors [25], although continued efforts to improve screening utilization and follow-up remain necessary [25, 27].

Cervical cancer control illustrates the essential differences between LMIC and high-income country contexts in public health priority-setting, healthcare resources and infrastructure, cultural barriers, and capacity for prevention and treatment. A comprehensive control strategy requires all three prevention tiers: primary prevention through HPV vaccination [43], secondary prevention through screening [44], and tertiary prevention through treatment of pre-cancerous lesions [45]. The global decline in cervical cancer incidence is closely tied to HPV vaccination program implementation, and high-income countries with

robust vaccination programs, including Hong Kong, Sweden, and the United States, have seen substantial reductions in HPV-related cancers. The WHO elimination strategy targets a 90% reduction in global cervical cancer incidence by 2030 through 90% vaccination coverage among girls by age 15, 70% screening coverage among women aged 35–45, and treatment access for 90% of women with cervical cancer [46]. However, screening coverage varies widely: as of 2019, only 36% of women aged 30–49 worldwide had ever been screened, ranging from over 80% in high-income countries to below 10% in lower-middle-income countries [47], and even within high-income countries such as the United States, screening coverage is markedly lower among uninsured women and those in remote or rural areas [48, 49]. Globally, two-thirds of cervical cancer cases occur among women who were never screened or were not screened regularly [47].

Public health implications

Our findings underscore several public health priorities. First, scaling up HPV vaccination and regular screening remains essential, particularly in LMICs such as Uganda, where HPV infection is the leading cause of cervical cancer and where expanding vaccine access could substantially reduce future incidence. Second, addressing the socioeconomic and healthcare infrastructure disparities that underlie persistently high incidence in LMICs will require strengthened health systems, improved access to screening services, and community-level education about prevention. Third, further research is needed to characterize the specific drivers of regional disparities, including HPV vaccination coverage, screening adherence, and potential biological differences between populations, in order to inform more tailored interventions. Finally, governments and international organizations should prioritize resource allocation toward prevention, detection, and treatment in underserved regions, ensuring that programs are culturally sensitive, economically accessible, and integrated within primary healthcare systems, particularly in rural areas.

Limitations

This study has several limitations. First, the observation periods differed across countries, with Uganda's data ending in 2017 while other populations extended to 2021–2022, which may limit direct comparability of recent trends. Second, data quality and completeness for trend analysis are more limited in LMIC settings such as Uganda than in the other study populations. Third, we could not assess deeper causal inferences due to the unavailability of individual-level data on HPV vaccination coverage, screening adherence, and other risk factors. Finally, because each population represents a single country or administrative region, our findings cannot be generalized to entire continents.

Conclusions

This study identifies significant geographic variation in the age-standardized incidence rate of cervical cancer across four populations: Uganda had the highest ASIR (37.3 per 100,000 in 2017) and Sweden the lowest (1.1 per 100,000 in 2022), differences that reflect disparities in healthcare access, preventive programs, and public health systems between low-income and high-income regions.

In Hong Kong, Sweden, and the United States, cervical cancer incidence declined over time, particularly in more recent birth cohorts, consistent with successful screening programs, early detection, and widespread HPV vaccination; the declining period and cohort effects suggest that lifestyle changes and early interventions have meaningfully reduced cervical cancer risk. In contrast, Uganda showed more erratic patterns, with certain cohorts and age groups experiencing increased risk, pointing to gaps in healthcare infrastructure, limited HPV vaccination coverage, and restricted access to screening and treatment.

These findings highlight persistent disparities in cervical cancer incidence trends between high-income and low-income countries and underline the critical role of healthcare infrastructure, screening programs, and vaccination in reducing disease burden. While substantial progress has been made in high-income countries, LMICs continue to face significant challenges in cervical cancer prevention and treatment. Sustained global efforts to expand screening and vaccination coverage, particularly in underserved regions, remain essential to achieving the World Health Organization's goal of eliminating cervical cancer as a public health problem by 2030.

Declarations

Clinical trial number

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Author Contribution

Conceptualization: O.F. and J.W.J. Data curation: O.F. Formal analysis: O.F. and J.W.J. Methodology: O.F. and J.W.J. Writing – original draft: J.W.J. Writing – review and editing: O.F., T.-W.C., and M.A.M. Supervision: J.W.J. and H.T.B. All authors read and approved the final manuscript.

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Data Availability

No new primary data were generated during this study. The findings are based on secondary data obtained from the Hong Kong Cancer Registry, the Swedish Cancer Registry, the International Agency for Research on Cancer's Cancer Incidence in Five Continents Plus (CI5plus) database, and the United States National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program. The CI5plus data are publicly available at https://ci5.iarc.who.int/, and the SEER data are available to registered users at https://seer.cancer.gov/data/. Restrictions apply to the availability of data from the Hong Kong Cancer Registry and the Swedish Cancer Registry, which are not publicly available for unrestricted redistribution. These data may be available from the respective registries, subject to their access requirements and permission. All publicly available datasets used in this study are cited in the reference list.

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Figures

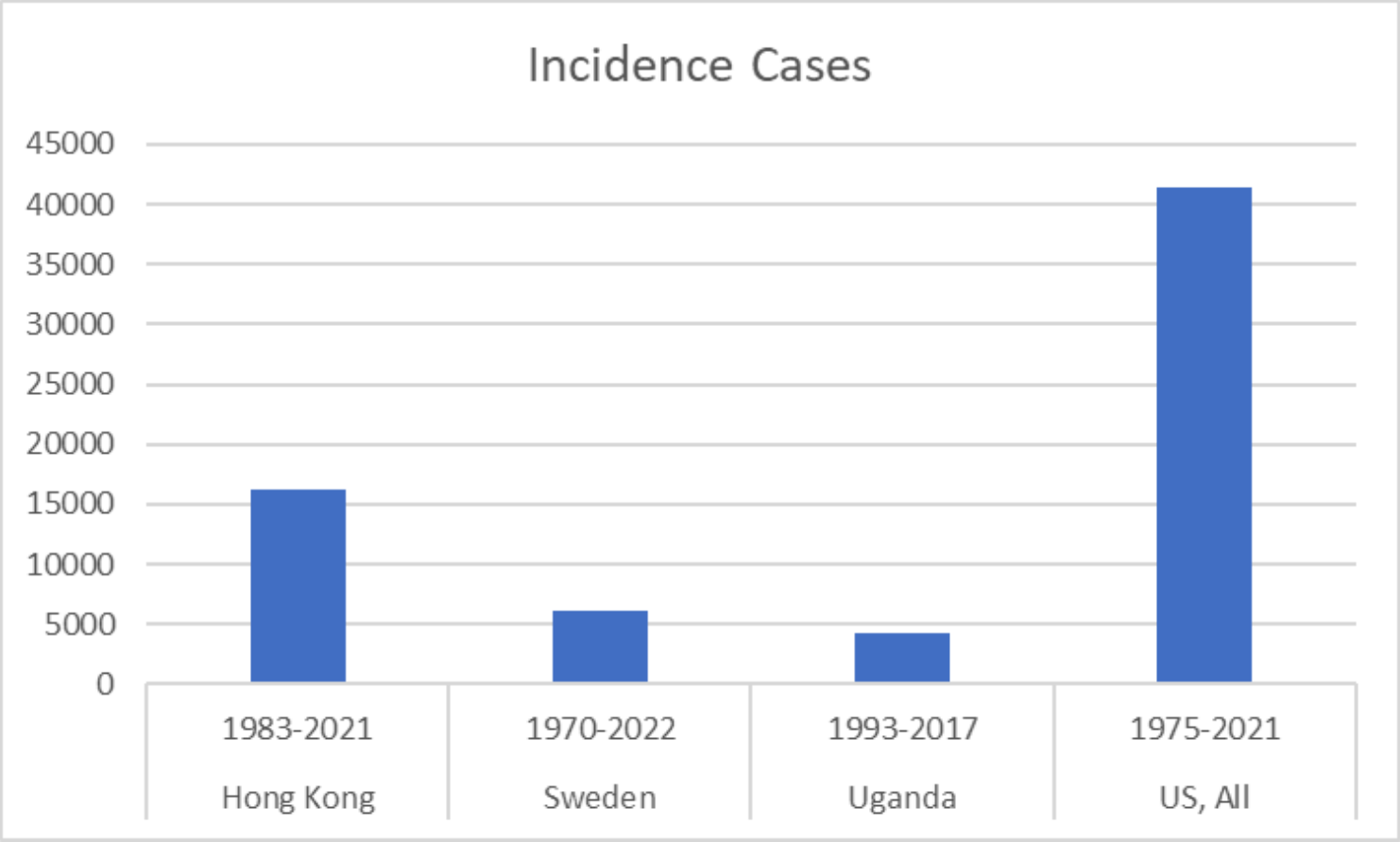


Figure 1

Incidence cases of cervical cancer in Hong Kong (1983-2021), Sweden (1970-2022), Uganda (1993-2017), and the United States (1975-2021).

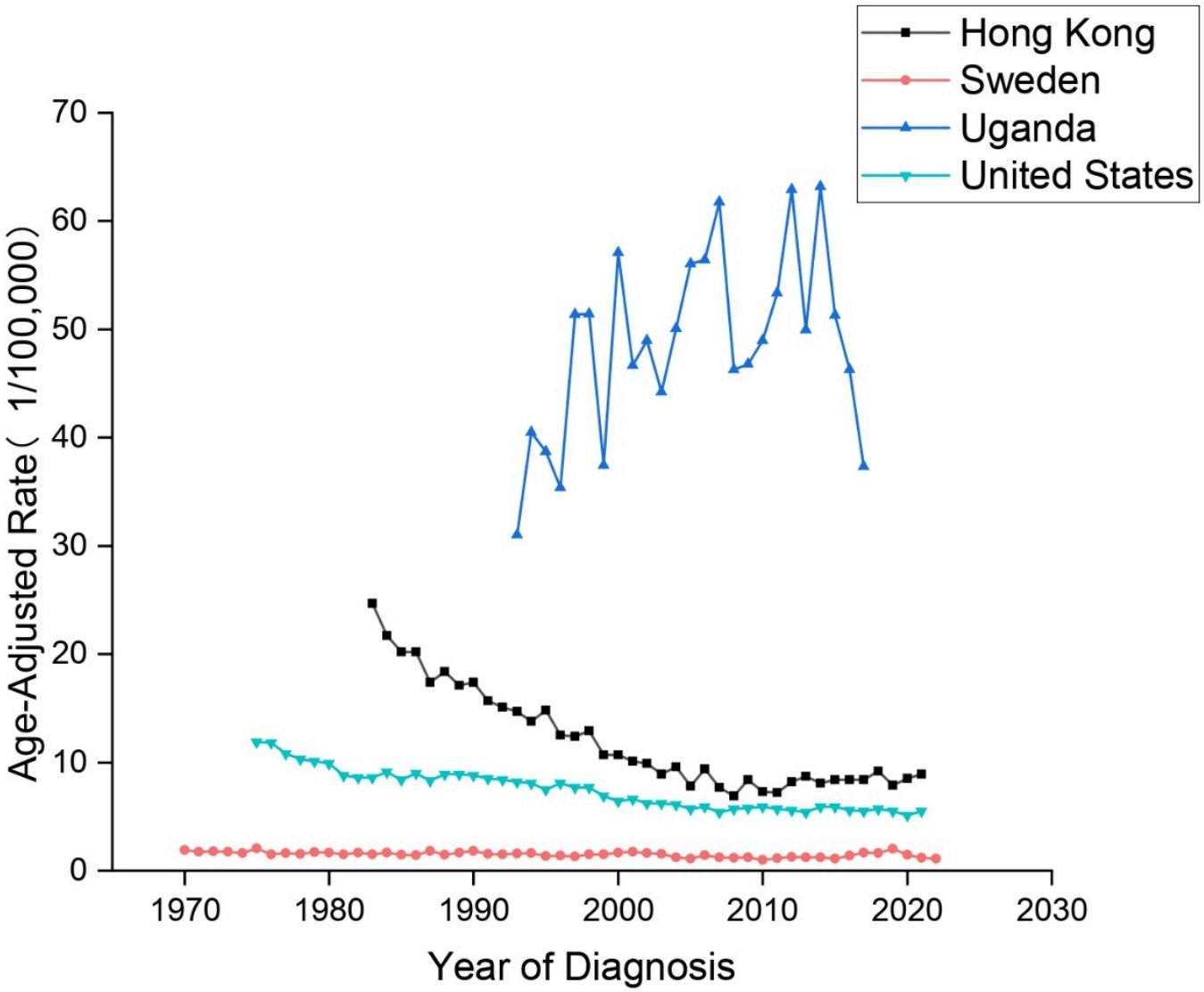


Figure 2

Age-standardized incidence rate (ASIR) of cervical cancer in Hong Kong, Sweden, Uganda, and the United States, using the WHO World Standard Population (2000) as reference.

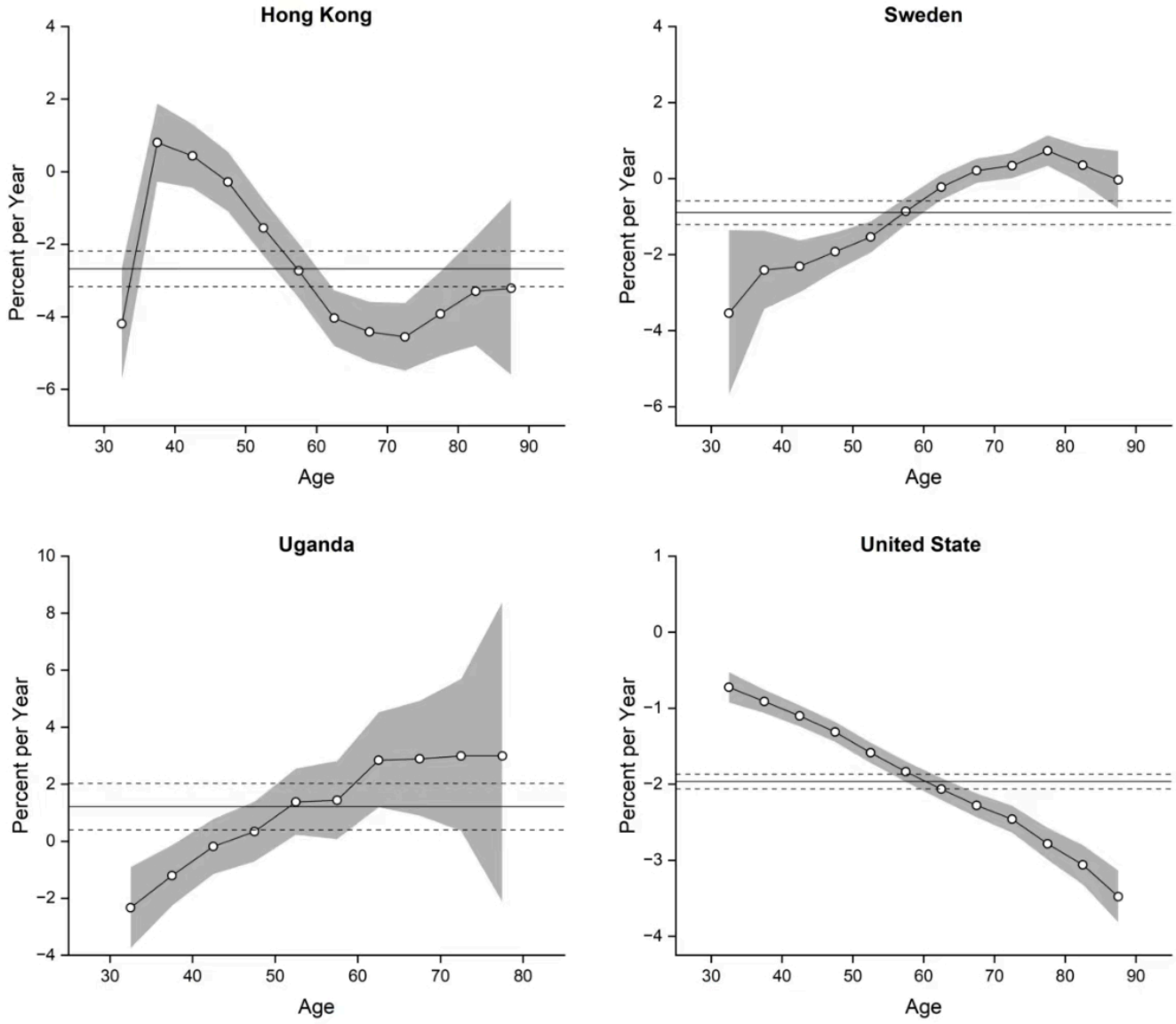


Figure 3

Age group-specific annual percent change (%) in cervical cancer incidence and corresponding 95% confidence intervals in Hong Kong, Sweden, Uganda, and the United States.

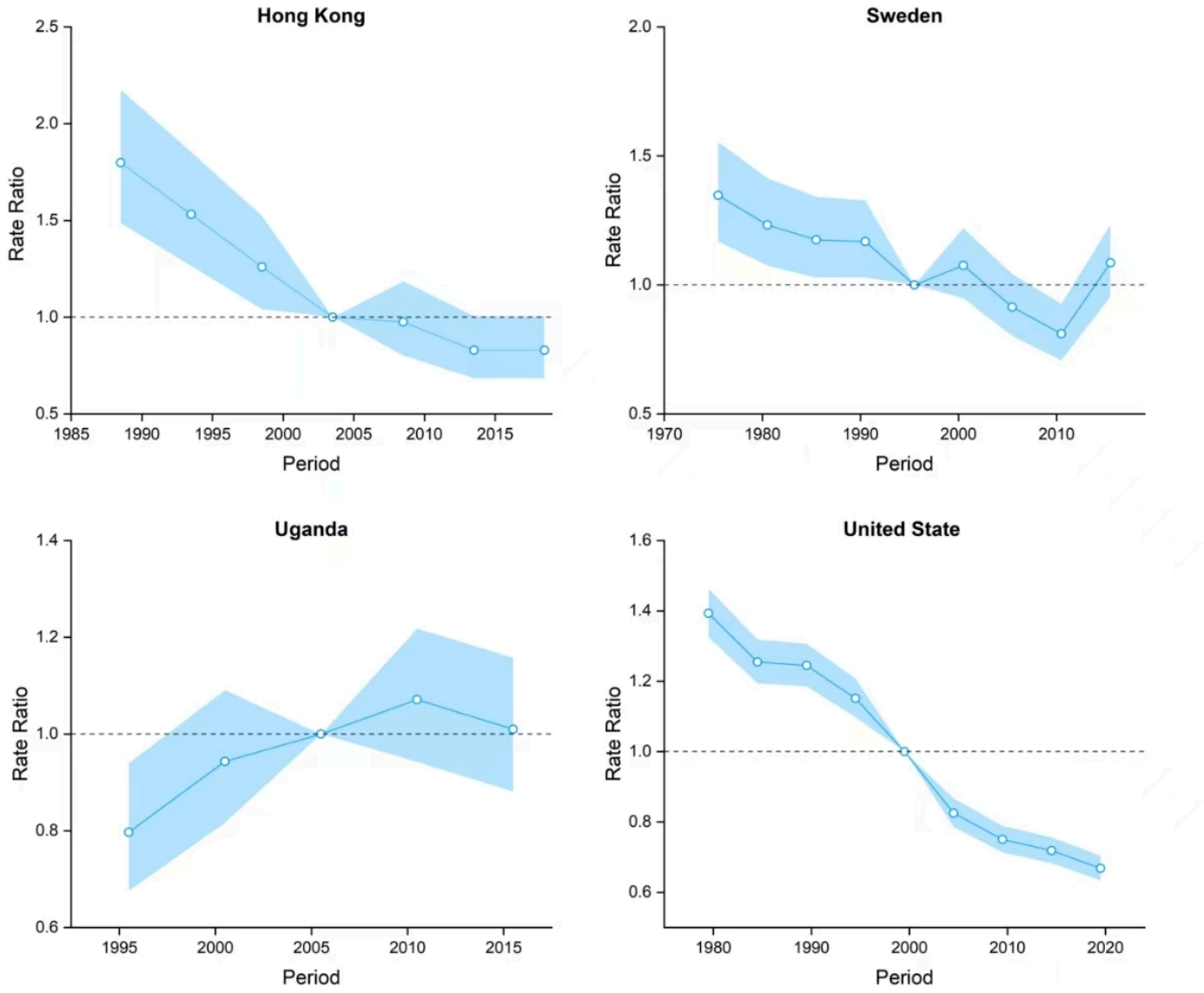


Figure 4

Period effects from age-period-cohort analyses of cervical cancer incidence and corresponding 95% confidence intervals in Hong Kong, Sweden, Uganda, and the United States.

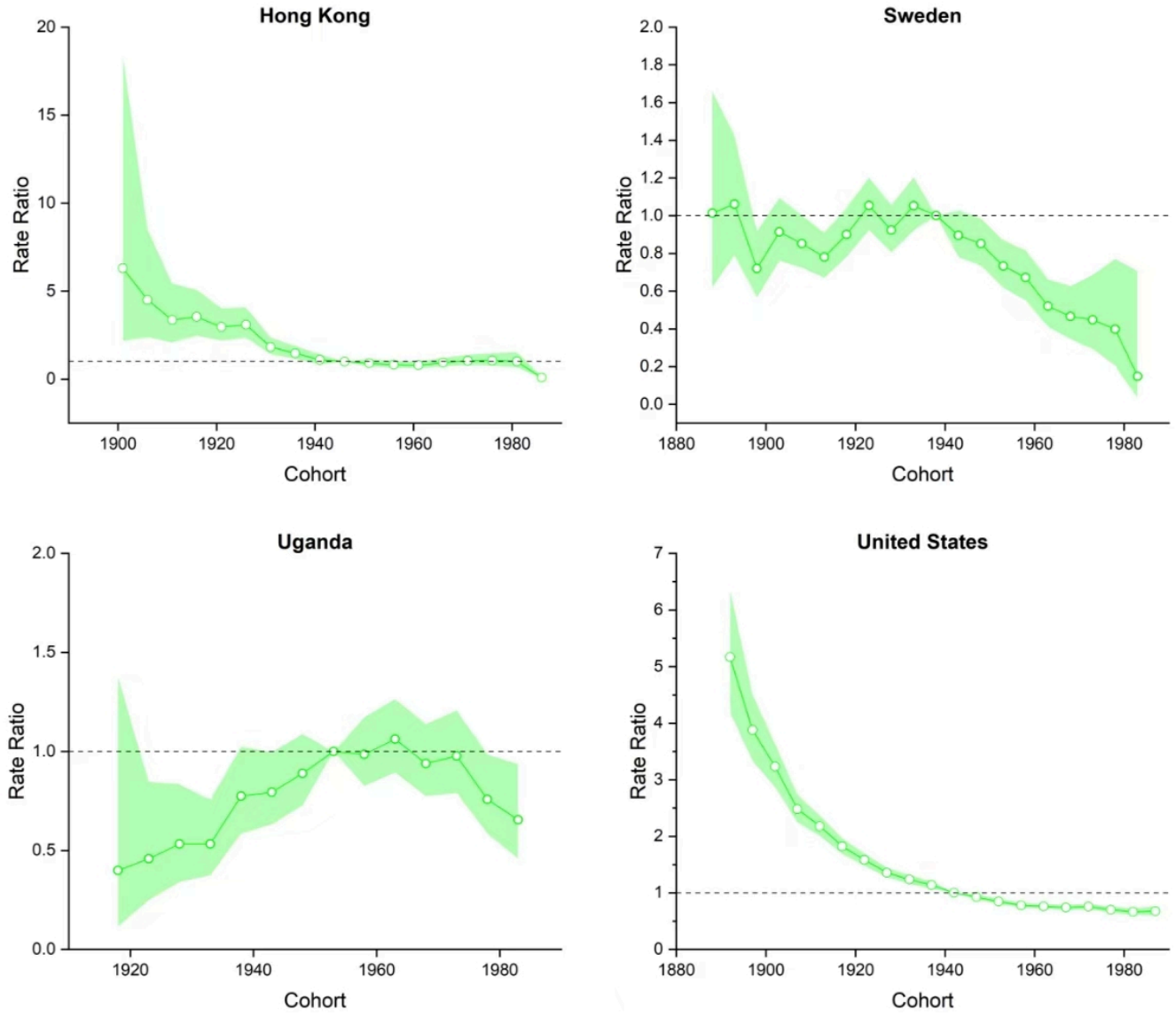


Figure 5

Cohort effects from age-period-cohort analyses of cervical cancer incidence and corresponding 95% confidence intervals in Hong Kong, Sweden, Uganda, and the United States.

Supplementary Files

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- S1Fig.jpeg