Affordability and Growth in HPV Vaccination Coverage: A Comparative Analysis of Gavi Vaccine Alliance Groups

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Abstract

HPV vaccination is a highly effective strategy for preventing cervical cancer but remains relatively expensive compared with other routine childhood vaccines especially in lower income countries, raising concerns about affordability and equitable access. This study examines whether access to subsidized HPV vaccines is associated with higher vaccination coverage, using country eligibility for support from Gavi, the Vaccine Alliance, as a proxy for affordability. Using country-level data from 161 countries observed from 2015 to 2024, we compare HPV first-dose vaccination coverage across Gavi-supported, transitioning, and non-Gavi countries. Descriptive analyses and growth-model estimates indicate that Gavi-supported countries exhibit higher coverage levels and steeper growth trajectories over time than comparable non-Gavi countries. While the analysis is descriptive and does not establish causality, the findings are consistent with an important role for vaccine affordability and institutional support in expanding HPV vaccination coverage.

1. Introduction

Cervical cancer remains a major cause of cancer-related mortality among women, with the burden disproportionately concentrated in low-income countries (LIC) and middle-income countries (MICs). Persistent infection with human papillomavirus (HPV) may lead to to cervical intraepithelial neoplasia (CIN) that, if untreated, can progress to invasive cervical cancer, and HPV vaccination is a highly effective preventive intervention (World Health Organization, 2017). However, HPV vaccines are substantially more expensive than many routine childhood immunizations, posing affordability and delivery challenges for countries with limited fiscal capacity(UNICEF Supply Division, 2026; 2025).

Gavi, the Vaccine Alliance, aims to address these constraints by providing subsidized vaccine prices and delivery support to eligible countries. Gavi support has traditionally focused on low-income and lower-middle-income countries, most of which progress through defined graduation stages as national income rises. More recently, Gavi has extended support to selected middle-income countries through the MICs approach, recognizing that affordability constraints may persist beyond low-income status. High-income countries (HICs), by contrast, are not eligible for Gavi support and typically finance HPV vaccination domestically.

This paper examines whether access to Gavi support is associated with higher HPV vaccination coverage and faster coverage growth. Using a country-year panel of 161 countries observed from 2015 to 2024, including 57 high-income countries and 104 non-high-income countries, we compare HPV first-dose vaccination coverage across countries with different Gavi support status, stratified by income group. For clarity, we use the term *Gavi status* to denote countries' time-varying eligibility and policy position with respect to Gavi support.

2. Data and Methods

2.1. Data

The analysis is based on a harmonized country-year panel dataset constructed from multiple publicly available sources. Annual HPV first-dose vaccination coverage data were obtained from WHO/UNICEF administrative estimates (World Health Organization & UNICEF, 2024), which report national-level coverage by antigen. These data were merged with time-varying country income classifications from the World Bank (World Bank, 2024) and detailed Gavi eligibility records, including information on countries supported through the classic Gavi mechanism and the MICs approach (Gavi, the Vaccine Alliance, 2024a;b).

World Bank income groups are defined using annually updated gross national income (GNI) per capita thresh-

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olds. Over the study period (2015-2024), LICs are characterized by GNI per capita of roughly USD 1,000 or less, lower-middle-income countries by approximately USD 1,0004,000, upper-middle-income countries by around USD 4,000-14,000, and high-income countries by levels exceeding roughly USD 12,000-14,000. Income classification is treated as time-varying throughout the analysis.

Observations with missing HPV vaccination coverage were excluded. Reported coverage values equal to zero were retained and interpreted as structural zero coverage, reflecting either pre-introduction years without vaccine availability or post-introduction years with no reported uptake. Countries were classified into high-income and non-high-income groups based on World Bank criteria. Non-HICs were further classified by time-varying Gavi policy status into four categories: Gavi-supported countries, which receive full Gavi support; former-Gavi MICs, which have transitioned out of Gavi support; new-Gavi MICs, which entered support under the MICs approach; and never-Gavi MICs, which have not received Gavi support. The resulting panel spans the period 2015-2024 and serves as the basis for all descriptive and growth-model analyses.

2.2. Empirical Model

Following Singer and Willett's (2003) multilevel model for change, we specify a linear growth model in which country-specific intercepts and time slopes characterize vaccination trajectories over time. Fixed effects are used to model how these growth parameters vary systematically with Gavi policy status, while random effects capture residual heterogeneity across countries (Singer & Willett, 2003).

Let y_{it} denote HPV first-dose vaccination coverage in country i observed in year t. Time is centered at the first year of observation, such that

$$\text{time}_{it} = \text{year}_{it} - 2015.$$

We estimate a linear growth model with random intercepts and random slopes:

$$\begin{aligned} y_{it} = \beta_0 + \beta_1 \,\text{time}_{it} + \boldsymbol{\gamma}^\top \mathbf{G}_i \\ + \boldsymbol{\delta}^\top (\text{time}_{it} \times \mathbf{G}_i) + b_{0i} + \varepsilon_{it}. \end{aligned} \tag{1}$$

where $\mathbf{G}_i$ is a vector of indicators for Gavi status (e.g., Gavi-supported, MICs approach, never Gavi), with the never-Gavi group (non-HIC) serving as the reference category.

The country-specific random intercept b_{0i} captures unobserved heterogeneity in baseline HPV vaccination coverage across countries and is assumed to follow:

$$b_{0i} \sim \mathcal{N}(0, \sigma_0^2), \qquad \varepsilon_{it} \sim \mathcal{N}(0, \sigma^2).$$

independently of the idiosyncratic error term

$$\varepsilon_{it} \sim \mathcal{N}(0, \sigma^2).$$

The coefficient β_0 represents average HPV vaccination coverage in 2015 for the reference group, while β_1 captures the average annual change over time. The vector $\boldsymbol{\gamma}$ measures differences in baseline coverage across Gavi status, and $\boldsymbol{\delta}$ captures differences in growth rates relative to the reference group.

3. Results

This section presents descriptive and model-based results on HPV first-dose vaccination coverage across country income groups and Gavi status.

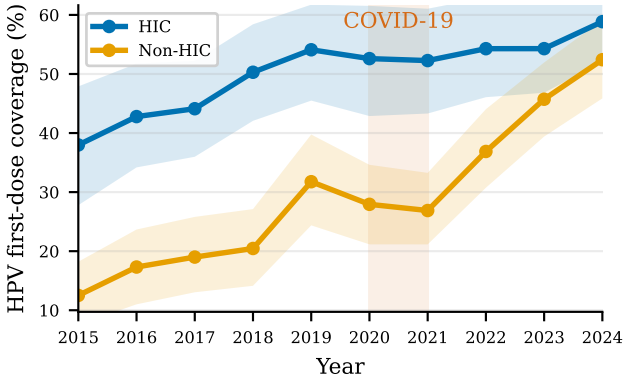

Figure 1. HPV first-dose vaccination coverage in HICs and non-HICs, from 2015 to 2024.

Figure 1 shows trends in HPV first-dose vaccination coverage between HICs and Non-HICs from 2015 to 2024. Coverage is consistently higher in HICs throughout the study period. Vaccination coverage increases over time in both HICs and non-HICs, with a temporary stagnation around 2020-2021 corresponding to the COVID-19 period. While a gap in coverage remains, the difference between the two groups narrows in the later years of the sample, reflecting a faster post-2021 increase in non-HICs that might also correspond with the launch of Gavi MIC approach.

We next examine heterogeneity within non-HICs by comparing HPV vaccination coverage across groups defined by Gavi status. Figure 2 shows that countries receiving Gavi support exhibit larger initial gaps but show pronounced convergence toward HICs coverage levels over time, particularly after 2020.

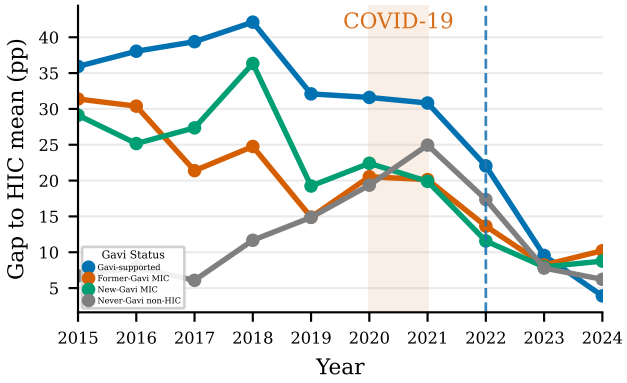

Figure 2. Gap (measured in percentage point) in HPV first-dose vaccination coverage relative to the HICs mean, by Gavi status among non-HICs.

Now we compare raw group means with growth-model-predicted trajectories for all non-HICs grouped by their Gavi status. The figure contrasts observed average coverage (dashed lines) with fitted growth-model predictions (solid lines), illustrating how vaccination trajectories differ by Gavi status over time.

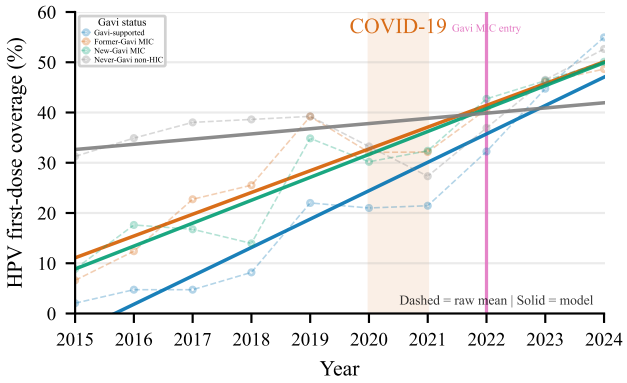

Figure 3. Model Predicted 2015–2024

Table 1. Growth model estimates of HPV first-dose coverage by Gavi status (non-HICs).

Term	Estimate	SE	z	p
Intercept	32.64	4.93	6.62	< 0.001
Gavi Supported	-36.46	6.65	-5.48	< 0.001
Former-Gavi MIC	-21.55	8.65	-2.49	0.013
New-Gavi MIC	-23.78	7.76	-3.06	0.002
Time (years since 2015)	1.03	0.47	2.21	0.027
Time × Gavi Supported	4.62	0.61	7.56	< 0.001
Time × Former-Gavi MIC	3.30	0.79	4.16	< 0.001
Time × New-Gavi MIC	3.53	0.71	5.00	< 0.001

Figures 3 show rising HPV vaccination coverage across all non-HIC groups, with consistently steeper growth among Gavi-supported countries. Differences between Gavi and non-Gavi groups widen over time, particularly in later years.

Table 1 reports the corresponding growth-model estimates, quantifying differences in baseline coverage and growth rates across Gavi status. Several coefficients in the growth model stand out. The baseline level differences for Gavi-supported countries and new-Gavi MIC countries are large and statistically significant, indicating substantially lower initial HPV first-dose coverage relative to never-Gavi countries. The time by Gavi interaction terms for Gavi-supported, former-Gavi MIC, and new-Gavi MIC countries, are all positive and highly significant, indicating faster growth in vaccination coverage over time in these groups. By contrast, the main effect of time for never-Gavi countries (our reference, Time (years since 2015)) is positive but estimated with less precision, suggesting slower and more heterogeneous growth in this group.

Table 1 reports the estimated coefficients from the growth model, which quantify differences in baseline HPV first-dose coverage and changes in coverage over time across Gavi policy groups. The Intercept represents the average HPV first-dose coverage in 2015 for the reference group, never-Gavi non-HICs. The coefficient indicates that this group starts the period with a moderate baseline level of coverage. The coefficients for Gavi-supported, former-Gavi MICs, and new-Gavi MICs capture differences in baseline coverage relative to the never-Gavi non-HICs. All three estimates are negative and statistically significant, indicating that these countries begin the period with substantially lower average coverage than never-Gavi non-HICs. The magnitude of these coefficients suggests particularly large baseline gaps for countries receiving Gavi support and those newly entering under the MICs approach. The coefficient on Time (years since 2015) reflects the average annual change in coverage for never-Gavi non-HICs. This estimate is positive, indicating gradual increases in coverage over time for the reference group, though it is estimated with less precision than several other terms. The time-by-Gavi interaction terms indicate how growth rates differ for Gavi-supported and transitioning countries relative to never-Gavi non-HICs. All three interaction terms are positive and highly statistically significant, indicating that HPV vaccination coverage increases more rapidly over time in Gavi-supported, former-Gavi MICs, and new-Gavi MIC countries. Together, these estimates show that although Gavi-supported and transitioning countries start from lower baseline coverage, they experience faster subsequent growth, consistent with the narrowing coverage gaps observed in the figures.

Delivery modality as a potential mechanism

A mediation analysis was further conducted to examine whether delivery strategy mediates the relationship between Gavi support and HPV vaccination coverage. Delivery modality was dichotomized into school-based versus non-school-based strategies, and the analysis was restricted to the

year 2024. Both traditional mediation tests and a nonparametric bootstrapping approach implemented in `pingouin` were applied.

As shown in Figure 4, Gavi-supported countries are significantly associated with the adoption of school-based delivery strategies. However, neither the direct effect of Gavi support on HPV coverage nor the association between delivery modality and coverage is statistically significant. The bootstrapped mediation estimates similarly indicate no significant indirect effect, yielding conclusions consistent with the traditional analysis. These results suggest that while Gavi support influences program delivery modality, the delivery strategy alone did not statistically explain the coverage differences observed in the previous section.

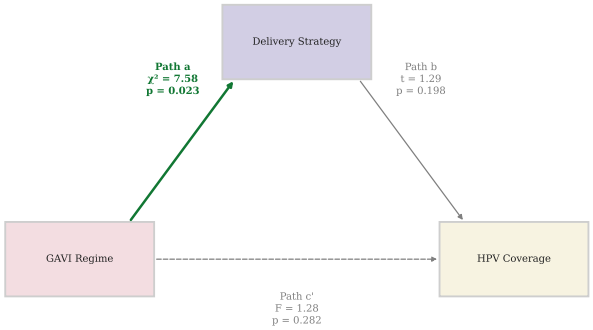

Figure 4. Mediation analysis for 2024

4. Discussion & Conclusion

This study describes population-level patterns in HPV first-dose vaccination coverage across countries with different income levels and Gavi status between 2015 and 2024. Descriptive trends show systematically higher coverage in high-income countries (HICs) and substantial heterogeneity among non high-income countries (non-HICs) by Gavi status. These patterns are mirrored in the growth-model estimates, which indicate lower average baseline coverage among Gavi-supported and transitioning countries (Former-Gavi MICs), alongside higher average growth rates over time. Estimated time interactions suggest steeper coverage increases among countries receiving Gavi support and among those transitioning under the MICs approach, relative to countries never supported by Gavi.

Taken together, the descriptive comparisons and growth-model estimates indicate that HPV vaccination coverage is higher and increases more rapidly among Gavi-supported countries than among non-Gavi countries with comparable income levels. Although the analysis is descriptive and does not support causal inference, these patterns are broadly consistent with prior evidence suggesting that Gavi has contributed to reducing between-country inequities in access to immunization, alongside more mixed findings regarding utilization and downstream health outcomes (Gandhi, 2015; Jaupart et al., 2019).

Several limitations in this study are to be considered. The analysis is intentionally designed to focus on comparisons at the country-group level, emphasizing differences by income group and Gavi status. Country-specific trajectories and within-group heterogeneity are therefore not explicitly modeled, and group averages may mask substantial variation in performance across individual countries. Based on the time period of this study we observe there is substantial heterogeneity within policy groups; for example, Uzbekistan (MICs approach), Cabo Verde (Gavi-supported), and Costa Rica (never Gavi) exhibit markedly different coverage trajectories, underscoring the importance of national context alongside international support. While country-level analyses could provide additional insight into sources of divergence in vaccination uptake. However, such extensions fall outside the scope of the present study.

The analysis is further restricted to first-dose HPV vaccination coverage. Although first-dose uptake provides an informative indicator of program reach, completion of the full vaccination schedule is essential for effective protection. Differences in follow-up rates, dosing schedules, and vaccine formulations may therefore play an important role in shaping overall program effectiveness and warrant further investigation. Vaccine affordability was also initially considered as a potential explanatory factor, but substantial missingness in vaccine price data limited its suitability for systematic analysis; exploratory code related to this component is provided in the accompanying GitHub repository, where we have added a market segment variable for vaccine pricing.

Finally, an exploratory mediation analysis was conducted to assess whether delivery modality may represent one mechanism linking Gavi support to HPV vaccination coverage. The analysis focused on school-based delivery, given its frequent use in HPV vaccination programs. Descriptive statistics and mediation results indicate that Gavi-supported countries are more likely to adopt school-based delivery strategies. However, neither the estimated direct effect of Gavi support on coverage nor the indirect effect through delivery modality was statistically significant. This finding should be interpreted cautiously, as Gavi support encompasses a broad set of interventions. These include pricing, procurement, dosing strategy, and supply chain support, that may operate through multiple, overlapping channels. Evaluating a single mediator therefore provides only a partial view of the mechanisms through which policy support may influence vaccination uptake. Future research could apply multi-mediator or structural modeling approaches to better capture these pathways.

Contribution Statement

This paper is authored by Khaira Abdillah and Hengyi Liu and is based entirely on work completed by the authors over the course of the semester, including data collection, cleaning, documentation, and analysis. Components of this work were previously referenced in a group project but were not included in its final version. The underlying data processing and analysis were conducted incrementally throughout the semester. All data sources, scripts, and documentation are publicly available, and all results reported in this paper are fully reproducible from the original raw data.

Notes

We initially estimated a growth model with both random intercepts and random slopes for time. When the random-slope specification did not converge, we report results from a reduced model with a random intercept only. All results are descriptive and do not support causal inference.

Gavi status is treated as time-varying and is based on official eligibility and policy records. The designation of middle-income country (MIC) entry into Gavi support in 2022 reflects formal policy approval rather than the timing of actual financial disbursement or program implementation; post-2022 patterns should therefore be interpreted as reflecting policy status rather than immediate operational effects. Time is measured in years since 2015 in all growth-model analyses.

Observations with missing HPV vaccination coverage were excluded. Coverage values equal to zero were retained and interpreted as structural zeros, reflecting either pre-introduction years without vaccine availability or post-introduction years with no reported uptake following vaccine introduction.

The data and code can be found in this Github repository (Abdillah & Liu, 2026).

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