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Article

Supply-Side Bottlenecks of Newly Introduced and Second-Year-of-Life Vaccines in Malawi: From Vaccine Availability to Delivery

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Abstract

Introduction: Existing evidence on why children miss vaccines after infancy has focused on the demand side, that is, on the attitudes and circumstances of caregivers. The supply side, meaning the system's capacity to make vaccines available, accessible, and deliverable, has received less attention, even though it determines whether a willing caregiver can be served. This study examined the supply-side determinants of second-year and newer vaccine uptake in Malawi through a coverage-cascade and bottleneck analysis. **Methods:** A mixed-methods study drew on one cross-sectional survey with a caregiver component ($n = 1177$) and a frontline health worker component ($n = 453$), a data quality assessment of stock records at 37 sites, and key-informant interviews and focus group discussions at community, facility, district and national level. Findings were organised through the Tanahashi coverage framework, which follows the steps from the availability of commodities and staff, through geographic access, to service contact and coverage. Supply-side constraints on uptake were profiled at each step and set against the coverage achieved for each antigen. **Results:** Coverage fell across the antigen sequence, from 93.4% for the second dose of measles–rubella vaccine and 91.2% for the second dose of inactivated polio vaccine, to 74.6% for the typhoid conjugate vaccine and 61.4% for the HPV vaccine. Stock management was largely in place. Stock records were maintained and reconciled at 35 of 37 assessed sites, and only 4.5% of caregivers who gave a reason for a missed dose named

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a stockout. Yet 24.8% (95% CI 21.2–28.8) of caregivers (district range 20–35%) reported having ever been turned away because a vaccine was unavailable. Human-resource readiness was weaker, with over half of frontline workers never receiving refresher training. Between 9% and 37% of caregivers, by district, lived more than five kilometres from a facility. Transport was the constraint on mobilisation most often named by health workers (72%). Interviews described outreach as dependent on fuel and external funding. Stock systems worked on paper, but vaccination was less reliably available when caregivers attended. Constraints appeared at this point of contact, in the continuity of outreach and in the maintenance of frontline capacity. National respondents placed these constraints within a financing system that is partly donor-dependent and fragmented across separate partner plans. **Conclusions:** The supply system delivered the established second-year antigens well. It was less consistent for the newer ones and at the point of contact. Sustaining uptake will require protecting stock at the point of need, resourcing outreach, maintaining frontline capacity, and adapting supply for the newer vaccines.

Keywords: immunisation; second year of life; supply side; coverage cascade; bottleneck analysis; Tanahashi; vaccine stockout; outreach; health workforce; Malawi

1. Introduction

Vaccination coverage depends on both demand-side and supply-side determinants. The two sides have not been equally studied [1]. A coverage figure records how many eligible children and adolescents were reached, without showing which side fell short [2]. The demand side has been mapped in depth. For example, in sub-Saharan Africa, successive reviews have synthesised the behavioural and social drivers of childhood immunisation, from caregiver knowledge and trust to maternal autonomy and access to information [3–5]. The reasons children and adolescents go unvaccinated have themselves been reviewed [6]. The supply side has drawn less attention. Reviews of coverage and equity note that supply-side determinants are frequently left out of the analysis altogether [7]. Where the supply side has been studied, the work has usually been confined to one country or tied to a single intervention rather than tracing the delivery pathway as a whole [8,9]. This leaves one side of coverage poorly understood. In this paper, the supply side means more than the logistics chain of warehouses, vehicles and cold rooms. It is the delivery system that turns a vaccine in stock into a vaccine given. It includes commodities and cold chain at the facility, the frontline workforce, outreach to distant communities and the point of care itself.

This imbalance matters most for vaccines given after infancy and for the newer antigens now entering national schedules. Over the past decade, Malawi has added several such vaccines to its routine schedule. These include the typhoid conjugate vaccine (TCV), the human papillomavirus vaccine (HPV), a second dose of inactivated polio vaccine (IPV2) and the second dose of measles–rubella vaccine (MR2). These vaccines do not ride on the established infant visit. They reach children through outreach, through schools and through repeat contact beyond the first year of life. The evidence on their delivery is thinner than for the infant series. It is scattered across vaccines and countries. It is dominated by accounts of introduction rather than any supply-side map of where uptake is lost after launch [10–13]. Over the same period, Malawi's health system has faced pressures related to intermittent stockouts, limited transport and fuel for outreach, dependence on external financing, and disruptions linked to the withdrawal of development assistance [14–16]. These pressures make the supply side central to understanding whether newer and later-scheduled vaccines can achieve and sustain high uptake.

The point of care itself is a place where supply can fail. Many routine vaccines are supplied in multi-dose vials. Under WHO policy, opened vials of reconstituted vaccines such as measles-containing vaccine must be discarded six hours after reconstitution or at the end of the session, whichever comes first [17]. To limit wastage, health workers may wait until enough children are present before opening a vial. Children who arrive at a quiet session may be asked to return on another day [18,19]. A caregiver sent away in this way may report that the vaccine was out of stock, even when vials are in the refrigerator. Vial presentation therefore shapes both the vaccinator's decision and the caregiver's account of it. The problem is sharpest for freeze-dried vaccines supplied in larger vials, such as 10-dose measles–rubella vials. It is one reason several African countries have moved to 5-dose presentations [19].

In Malawi, evidence on supply-side determinants is limited. Work on immunisation in the country has centred on coverage levels and on the demand side. Existing work has documented barriers to the second measles dose, including missed opportunities and delayed or cancelled vaccination sessions [20]. This evidence predates the introduction or expansion of newer vaccines such as TCV and HPV, and it does not examine multiple antigens through linked facility, provider and caregiver data [21]. How the supply system performs for the newer and second-year antigens has not been examined. Few studies have traced these vaccines through a supply-side cascade using caregiver, provider, facility and national data together. We therefore set out to examine the supply-side determinants of uptake for newly introduced and second-year vaccines in Malawi. We aimed to locate the steps at which the delivery system narrows, from the availability of commodities and staff, through geographic access and service contact, to effective coverage.

To structure this, we applied the Tanahashi framework [22,23]. The framework represents coverage as a sequence of stages. These run from the availability of services, through geographic accessibility and initial contact, to continued use and effective coverage. Each stage is a point at which eligible populations can be lost. The framework has been used to locate coverage losses in immunisation and in broader health services in comparable settings. That work shows that a single national or district figure can obscure very different underlying constraints [24–26]. We applied it descriptively to the supply side. We used caregiver, provider, facility and key-informant data to distinguish facility-level readiness from point-of-contact availability, geographic access, outreach continuity, workforce capacity and delivery-platform constraints.

2. Methods

2.1. Study Design and Reporting

This study used a mixed-methods design. The quantitative core was cross-sectional and observational and was complemented by key-informant interviews and focus group discussions. The quantitative components are reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidance [27]. The qualitative component is reported in accordance with the Consolidated Criteria for Reporting Qualitative Research [28].

2.2. Study Components

Data came from one cross-sectional study in the three districts. All components were fielded together and addressed one central question: vaccine uptake after the first year of life. Health facilities were sampled first. Health workers were interviewed in the sampled facilities. Caregivers were interviewed in the catchment areas of the same facilities. Different populations were interviewed so that each side of uptake could be examined. This

paper presents the supply side. The study had two survey components, a data quality assessment and a qualitative component:

Caregiver component: caregivers of age-eligible children (n = 1177) provided the coverage outcomes and the caregiver-reported experiences of access and contact. Health worker component: health surveillance assistants and community immunisation volunteers (n = 453) provided the provider account of workforce readiness and outreach. Data quality assessment: a record review at 37 sites in the study districts (35 health facilities and 2 district health offices) recorded whether stock records were maintained and reconciled, and whether data tools such as tally sheets and stock cards were available and current. It did not record vaccine availability or cold chain status.

Qualitative component: key-informant interviews at facility, district and national level, and focus group discussions with caregivers, explained the quantitative findings and situated them within the financing system. Two further instruments were used during the same fieldwork but did not inform this analysis: a data-reporting survey of records staff, and an EPI–NCD integration feasibility checklist completed at 16 facilities, 9 of them outside the study districts. Coverage estimates are reported with numerators, denominators and 95% confidence intervals (Section 3.7).

2.3. Setting and Period

The study was conducted between August and October 2025 in three districts of Malawi: Chikwawa in the Southern Region, Kasungu in the Central Region, and Mangochi in the Eastern Zone of the Southern Region. The districts were selected to represent variation in geography, facility density, and history of partner support. Immunisation in these districts is delivered through health facilities and outreach, supported by health surveillance assistants. All analyses were restricted to these three districts. Where facility assessments had also been conducted in other districts, those records were excluded so that every step of the cascade drew on the same three-district frame.

2.4. Populations and Sampling

Health worker survey: the sample size was calculated with Cochran's formula. It assumed that 15% of health workers in the study facilities handle immunisation data, with a 95% confidence level, a 5% margin of error, a design effect of 2 and 5% non-response. This gave a sample of 453 health workers.

Caregiver survey: a sample of 1177 caregivers was calculated with Cochran's formula. The calculation used 85% as the proportion of children receiving the Penta3 vaccine, the proxy indicator for vaccine coverage. It assumed a 95% confidence level, a 5% margin of error, 5% non-response and a design effect of 2.

Eligible caregivers were those aged 18 years or older, who had lived in the study area for at least six months, and who were the primary caregivers of an age-eligible child. Caregivers with severe cognitive or communication difficulties that precluded them from an interview were excluded.

Health facilities were selected randomly using a sampling frame of all health facilities and their catchment areas. Caregivers were drawn from the catchments of the 39 health facilities. Within each catchment, villages were chosen purposively for access. Households with children under five were identified from DCSA registers and visited consecutively from a central landmark. Health workers were interviewed in the same selected facilities and their catchments.

Data quality assessment: the record review was carried out at 37 sites in the study districts (Chikwawa 11, Kasungu 10, Mangochi 16), made up of 35 health facilities and the Kasungu and Mangochi district health offices. Twenty-nine of the 37 sites were also care-

giver survey facilities. Records from 13 sites assessed in Rumphi and Ntchisi were excluded. The assessment was not designed to be representative of all facilities in the three districts, so its results describe the assessed sites only.

Key informants at facility and district level included health surveillance assistants, facility managers, clinicians, and district officers. At national level, key informants included respondents from the Ministry of Health and development partners. These national respondents spoke to financing, procurement, and the supply chain. National respondents are attributed by role and institution rather than by name.

Participant selection for the qualitative component was guided by a purposive sampling strategy to ensure diverse and information-rich perspectives relevant to the study objectives. Eligibility was based on participants' roles, experiences, or involvement in the treatment, management, service delivery, policy, or use of EPI services.

Key informants such as Ministry of Health officials, district managers, planning officers and development partners (for example, UNICEF and Gavi) were selected for their technical or managerial role in child health, immunisation, digital health, planning or community engagement. Participants were identified through health facility in-charges, district health offices, existing community networks and stakeholder lists. Data were collected until saturation.

2.5. Framework and Measures

In this study, newly introduced vaccines are those added to Malawi's national routine immunisation schedule within the past decade, as distinct from the long-established infant antigens. These are the human papillomavirus vaccine, launched nationally in January 2019 and taken into the routine schedule in 2021; the typhoid conjugate vaccine, introduced in May 2023 and given routinely at nine months; and the second dose of inactivated polio vaccine, introduced in December 2024. Vaccines after the first year of life are doses scheduled beyond infancy, principally the second dose of measles–rubella vaccine, introduced in 2015 and given at 15 months. The four antigens differ in vial presentation. In Gavi's approvals for Malawi, MR vaccine is presented in 10-dose lyophilised vials, TCV in 5-dose liquid vials, IPV in 10-dose liquid vials and HPV vaccine in single-dose vials [29–32]. MR2 is therefore the antigen most exposed to reluctance to open a vial for few children.

The Tanahashi framework organised the analysis [22,23]. It represents coverage as a sequence of steps, from the availability of commodities and staff, through geographic accessibility, to service contact and coverage. The framework was applied descriptively. Each step was operationalised using measures already present in the study instruments rather than the framework's own validated instruments. We define the supply system broadly. It covers commodities and cold chain, the frontline workforce, outreach and the point of care. It is not limited to the logistics chain.

Availability had two components. Commodity availability was measured from the data quality assessment, as whether stock records were maintained and reconciled and whether stock cards and other data tools were available and current, and from key-informant accounts of stockouts and resupply. No study instrument recorded vaccine stock or cold chain status at the time of a caregiver's visit. Workforce availability was measured from the health worker survey as training to communicate about the newer vaccines, refresher training, supervision, job aids, and access to registers and defaulter lists. Accessibility was measured from the caregiver survey as the distance travelled to the vaccination site, and from the health worker survey as the reach and constraints of outreach. Contact was measured from the caregiver survey as being turned away when a vaccine was unavailable and as the convenience of service days, and from the health worker survey as the follow-up of children who missed doses. The turned-away item asked, "Have you ever

been turned away from a health facility due to unavailability of vaccines?", so its recall period was the caregiver's whole experience of the service. It cannot distinguish a stockout from a health worker's decision not to open a multi-dose vial, so we interpret it as vaccine unavailability as experienced by the caregiver. The caregiver survey also asked the main reason a child had not received a vaccine, and we report the share of caregivers who named a stockout or vaccine unavailability.

Coverage was measured from the caregiver survey as receipt of each antigen among children in the age group for it. We use the term coverage rather than effective coverage. The endpoint is recorded receipt, not quality-adjusted coverage in Tanahashi's sense. The analysis foregrounded supply-side determinants while recognising that demand and quality determinants act at the same steps.

2.6. Analysis

Supply-side constraints were summarised as counts, percentages and 95% confidence intervals at each step of the cascade, using the study component appropriate to that step. Confidence intervals were calculated on the logit scale, with standard errors adjusted for clustering of respondents within health facilities. Differences between districts were tested with Rao–Scott corrected chi-square tests, which allow for this clustering. Ranges reported in the text give the lowest and highest district values.

Coverage was calculated as the proportion of children in each age group with a recorded dose of each antigen: children aged 18–59 months for MR2, children aged 13–59 months for IPV2 and TCV, and girls aged 9–14 years for HPV. Because the survey was cross-sectional, every child in the age group at the time of the survey was counted, whether the dose was given through routine services or through catch-up or campaign activities. For IPV2, introduced in December 2024, the estimate is therefore the proportion of surveyed children aged 13–59 months with a recorded dose. It is not coverage of an eligible birth cohort. Malawi's EPI delivers all routine antigens, including IPV, to children under five who have missed doses, through periodic intensification of routine immunisation (PIRI) and other catch-up activities (Malawi EPI programme, personal communication, October 2026). Estimates were unweighted, and standard errors were adjusted for clustering within facility catchments. Facility and workforce indicators were summarised overall and by district. The survey components and the data quality assessment drew on different respondents and sites. They were not linked at the level of the individual child or facility. The cascade therefore integrates evidence across components rather than tracing one child through every step. It is therefore a descriptive bottleneck analysis rather than a formally linked estimate of effective coverage. In the integrated bottleneck tables, each step was classified as a relative strength or a constraint by the authors' joint judgement of its quantitative indicators and the qualitative evidence. The steps draw on different populations and denominators. They were therefore not compared numerically. Missing data were handled using complete-case analysis. Analyses were conducted in R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria).

2.7. Qualitative Data Collection and Analysis

The qualitative component was designed to explain the survey findings, with particular attention to the completion gap and the concerns about the newer vaccines. Focus group discussions (n = 4) and key-informant interviews (n = 20) were conducted across the three districts. Focus group discussions were held with caregivers. Key-informant interviews were held with community immunisation volunteers (n = 2), facility in-charges (n = 2), other health facility and district staff (n = 9: health promotion officers, health surveillance assistants (HSAs), the district director of health services, district environmental

health officers and EPI coordinators), HMIS and data officers ($n = 2$), teachers ($n = 1$), community leaders ($n = 1$), religious leaders ($n = 1$) and national-level respondents from the Ministry of Health and development partners ($n = 2$). Trained interviewers used semi-structured guides in the local language. Discussions were audio-recorded, transcribed, and translated into English where necessary. Transcripts were analysed thematically. A deductive framework was applied first, organised around the quantitative findings and the steps of the Tanahashi framework. Codes were grouped into themes, and illustrative quotations were selected to represent each theme. The two components were integrated through a joint display. Each quantitative finding was placed alongside the qualitative evidence that related to it. The qualitative findings were used to explain, support, contrast with or verify the quantitative findings. They were not used to infer associations.

2.8. Ethical Considerations

Ethical approval was obtained from the College of Medicine Research and Ethics Committee of Malawi, reference P.06/25-1638. All participants provided informed consent. Identifiers were removed before analysis.

3. Results

Figure 1 presents the supply-side bottleneck cascade used to interpret uptake of second-year and newly introduced vaccines. The cascade begins with national financing and procurement, moves through facility-level readiness, geographic access and outreach to point-of-contact delivery, and ends with coverage by antigen. The figure highlights that stock management at facilities was largely in place, but reliability was less consistent downstream at the point of contact, where caregivers experienced stockouts, inconvenient sessions, and fragile outreach. The resulting coverage gradient was highest for established second-year vaccines, lower for TCV and lowest for HPV, consistent with weaker supply arrangements for newer or less-established delivery platforms.

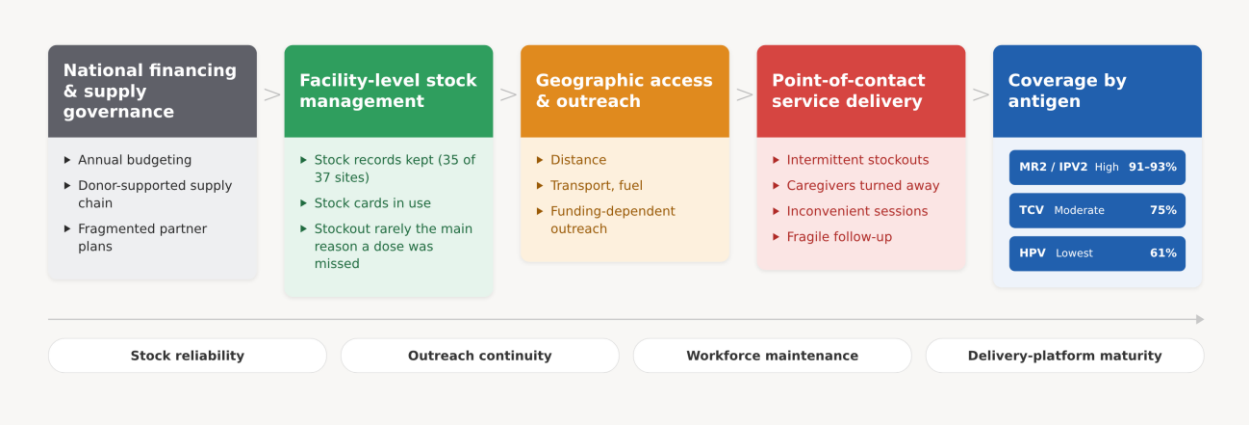


Figure 1. Supply-side bottleneck cascade for second-year and newly introduced vaccines in Malawi.

3.1. Upstream Financing and Supply Governance

The supply of vaccines begins well beyond the facility, in national budgeting and procurement. National respondents described how that upstream tier works and where it is strained. A Ministry of Health respondent described immunisation financing as an annual negotiation, in which the programme takes stock of its priorities and then agrees on an amount with the Ministry of Finance. The respondent also described challenges that external funding introduces. Donor-driven plans cause fragmentation and have to be integrated into a single planning and budgeting framework by the government.

"We have donors and implementing partners that do their separate [and] problematic plan… we are implementing [a] framework, call it one plan one budget."

(National-level respondent, Ministry of Health, key-informant interview)

A development partner respondent described the support that partners provide to keep the immunisation supply chain functioning, covering both the supply chain itself and the staff who manage the data behind it.

"They [development partners] focus on immunization supply chain so that it is very responsive… [and provide] data clerk consultants to strengthen the data collection."

(National-level respondent, development partner, key-informant interview)

The respondents located the constraints in the system that funds and supervises them. A national monitoring respondent described supervision, on which the collection of field data depends, as reliant on externally funded programmes, that is, partner-supported projects that pay for supervision.

"The data we rely on from supervision are a bit tricky because mostly are funded programs. Without them we cannot be able to do so."

(National-level respondent, Ministry of Health, key-informant interview)

This national tier frames the cascade that follows. The commodities and the supply chain are supported, in part through external funding. The constraints documented downstream sit within a financing system that is partly donor-dependent and only now being drawn into a single plan.

3.2. Facility-Level Stock Management

Stock management at the assessed sites was largely in place. Stock records were maintained and reconciled at 35 of the 37 sites in the study districts (94.6%), partially at one and not at all at one. Data tools such as tally sheets and stock cards were available and current at 30 of the 37 sites and partially available at the other seven. These measures show that stock was being documented and reconciled. They do not show whether a given vaccine was in the refrigerator on the day a caregiver attended, which no study instrument recorded.

3.3. Point-of-Contact Stock Reliability

Overall, 291 of 1173 caregivers (24.8%; 95% CI 21.2–28.8) reported having ever been turned away because the vaccine was not available. The proportion ranged from 19.8% in Kasungu to 35.4% in Mangochi (Rao–Scott $p = 0.007$). Stockouts were rarely given as the main reason a child had not received a vaccine. Of 822 caregivers who gave a main reason for a missed vaccine, 37 (4.5%; 95% CI 2.8–7.2) named a stockout or vaccine unavailability. The facility and caregiver measures differ in sample, unit and reference period. The data quality assessment shows whether stock was documented and reconciled, not whether vaccine was present at a given session. The caregiver item records any refusal the caregiver has ever experienced. The difference is consistent with intermittent stockouts. It may also reflect health workers declining to open a multi-dose vial for a small number of children.

"You find vaccines are out of stock when you have already made the journey to come and collect the vaccines. So you go back without it."

(Health surveillance assistant, key-informant interview, Mangochi)

Health workers described stockouts as short-lived, with resupply usually arriving quickly.

"When they run out of stock, they inform us so we should wait. But it usually doesn't take time for transport to make deliveries of the vaccine."

(Health surveillance assistant, key-informant interview, Mangochi)

HPV was delivered through schools by arrangement with teachers, on set dates, with vaccinators given allowances for the day.

"During the HPV campaign, they give them allowances for the day, because they also do it together with the teachers. So they book the teachers, we are coming to vaccinate the girls on this date, and on the said date they go and get vaccinated."

(EPI coordinator, key-informant interview, Mangochi)

"When we come to schools on a set date to conduct immunisation, guardians are already informed, such that some even come to escort the child, because in some cases children may run away from school."

(Health surveillance assistant, key-informant interview, Mangochi)

District staff also reported gaps in HPV delivery after the move from campaign to routine immunisation.

"Among the new vaccines, HPV data often shows gaps, especially after transitioning from campaign to routine immunisation, because adolescents are not present at routine outreach clinics."

(District EPI analysis, Kasungu)

District staff described a further problem for tracing. The child's health record did not follow the child.

"Parents frequently present with a different health passport each month, making it difficult to trace a child's vaccination history."

(District EPI analysis, Kasungu)

3.4. Workforce Readiness and Maintenance

The frontline workforce was in place, but its readiness and capacity to deliver were uneven, as shown in Table 1. Training to communicate about the newer vaccines, access to registers and defaulter lists, and regular supervision were reported by most workers. Monthly follow-up of missed doses was reported by 63% to 75% of workers. The clearest gap was in the maintenance of capacity. More than half of workers in every district had never received refresher training on immunisation and defaulter tracing. The system therefore depended on frontline workers to generate contact through defaulter follow-up, yet more than half of them had not received the refresher training needed to keep this work aligned with current tracing practices.

Table 1. *Provider-reported supply capacity, by district. Values are % (95% CI). Confidence intervals are adjusted for clustering within health facilities.*

Element	Chikwawa (*n* = 194)	Kasungu (*n* = 193)	Mangochi (*n* = 66)
Trained to communicate about the newer vaccines	71.1% (58.9–80.9)	83.4% (76.2–88.8)	87.9% (74.1–94.8)
Information materials or job aids	62.3% (52.6–71.2)	59.1% (45.1–71.7)	78.8% (68.3–86.5)
Access to registers or defaulter lists	69.1% (56.7–79.2)	65.8% (56.5–74.0)	81.8% (66.9–90.9)
Regular supervision and supplies	78.4% (63.1–88.4)	72.5% (62.5–80.7)	87.9% (79.4–93.2)
Never received refresher training	53.1% (39.5–66.2)	52.8% (35.7–69.4)	54.5% (42.4–66.2)
Monthly follow-up of missed doses	62.7% (55.6–69.3)	74.6% (61.6–84.3)	69.7% (56.4–80.3)

Qualitative accounts helped explain the gap in refresher training. They described training as a single event rather than a maintained competence. They also described thin staff establishments.

"Constant and refresher training for EPI staff is needed."

(Health facility staff, key-informant interview, Chikwawa)

A member of health facility staff described staff shortages at under-five clinics that left no time to check each child's health passport for missed doses. In this account, missed opportunities to vaccinate went unnoticed.

"Shortage of staff at under-five clinics prevents them from scrutinising health passports for missed doses."

(Health facility staff, key-informant interview, Kasungu)

3.5. Outreach and Geographic Accessibility

Overall, 253 of 1177 caregivers (21.5%; 95% CI 13.2–33.0) lived more than five kilometres from the facility or outreach site. The proportion ranged from 8.9% in Chikwawa to 36.5% in Kasungu (Rao–Scott $p < 0.001$). Transport was the constraint on community mobilisation most often named by providers, cited by 325 of 453 (71.7%; 95% CI 63.6–78.7) (Table 2). Outreach is the supply-side response to distance. The survey did not ask directly whether facilities ran outreach, but outreach featured in health workers' accounts of their work: a quarter of them (114 of 453; 25.2%, 95% CI 18.8–32.8) used outreach or mobile clinic sessions to remind caregivers about doses due after the first year. Continuity was the weak point. Inadequate transport or outreach support was named as a challenge to post-infant mobilisation by 103 of 453 health workers (22.7%; 95% CI 15.9–31.4), and interviews described outreach as constrained by fuel.

In the rainy season, rivers cut off some areas. Outreach transport was not always provided, so workers relied on personal means or borrowed equipment.

"Some locations become unpassable due to rivers during the rainy season, leading to failure to reach everyone; transport is not always provided."

(Health surveillance assistant, key-informant interview, Kasungu)

Table 2. Provider-reported constraints to community mobilisation (n = 453; multiple responses allowed; values are n (%; 95% CI), with confidence intervals adjusted for clustering within health facilities).

Constraints	*n* (%; 95% CI)
Transport	325 (71.7%; 63.6–78.7)
Lack of materials	135 (29.8%; 23.8–36.6)
Low community engagement	111 (24.5%; 17.7–32.8)
Financial capability to conduct mobilisation	105 (23.2%; 18.7–28.4)
Lack of training	74 (16.3%; 12.2–21.5)
Too busy with other work	42 (9.3%; 6.7–12.6)

3.6. Service Contact and Follow-Up

Service hours also shaped contact. Overall, 139 of 1167 caregivers (11.9%; 95% CI 9.1–15.4) reported that vaccination was not offered on days convenient for them. The proportion ranged from 7.8% in Chikwawa to 20.5% in Mangochi (Rao–Scott $p = 0.007$). Reminder and follow-up systems relied mainly on direct and labour-intensive methods. Home visits were the most common approach, used by 43–61% of providers across districts, followed by child health passports or appointment cards, reported by 37–56%. Community announcements were used by about one-third of providers in each district. These methods show that contact generation was not automated. It depended on staff, time, mobility, community networks, and paper-based tracking. For newer and later-schedule vaccines, such as TCV and HPV, this reliance on manual follow-up makes uptake vulnerable to the same workforce, transport, and outreach constraints identified elsewhere in the cascade.

An EPI coordinator noted that HPV vaccination depends on parental consent. A girl is missed when a parent refuses or is absent. This bottleneck is specific to the school platform (EPI coordinator, Mangochi).

3.7. Coverage by Antigen

Coverage differed markedly by antigen. Among children aged 18–59 months, caregivers reported receipt of the second dose of measles–rubella vaccine for 550 of 589 children (93.4%; 95% CI 90.1–95.6). Among children aged 13–59 months, 663 of 727 (91.2%; 95% CI 87.2–94.1) had received the second dose of inactivated polio vaccine and 542 of 727 (74.6%; 95% CI 67.5–80.5) the typhoid conjugate vaccine. Among girls aged 9–14 years, 266 of 433 (61.4%; 95% CI 53.3–68.9) had received HPV vaccine. Coverage did not differ significantly between districts for any antigen (Rao–Scott $p > 0.1$ for all four).

3.8. Integrated Bottleneck Analysis

Table 3 sets the supply-side constraints on uptake against the steps of the cascade and locates the bottleneck. Stock management at facilities was largely in place. Availability as caregivers experienced it was less reliable. Constraints appeared at the point of contact, where intermittent stockouts, inconvenient sessions and possible reluctance to open multi-dose vials sent some caregivers away, at the maintenance of the workforce, where refresher training was largely absent, and at the continuity of outreach, where distance was met by a service that fuel and funding made fragile. These constraints fell hardest on the newer antigens, which depend on supply arrangements that are not yet as established as those for the routine second-year doses.

Table 3. *Integrated supply-side bottleneck analysis across the immunisation delivery cascade.*

Cascade Step	Quantitative Evidence	Qualitative Evidence	Bottleneck	Relevance for Newer Vaccines
National financing and supply	No quantitative measure (qualitative evidence only)	Annual budget negotiation; donor and partner plans being drawn into one plan; supply-chain and data staff partner-supported; supervision and data functions depend on funded programmes (national KIIs)	Supported, but partly donor-dependent and fragmented	Sustained delivery of newer vaccines depends on external financing and coordination
Availability, commodities	Stock records maintained and reconciled at 35 of 37 sites; stockout named as the main reason for a missed dose by 4.5% of caregivers	Stock runs out and staff wait for resupply (HSA, Mangochi)	Stock documented and reconciled at facilities, but intermittent at the point of need	Newer antigens need reliable stock at the point of contact, not only in the stock records
Availability, workforce	Trained to communicate about newer vaccines 71–88%; regular supervision 73–88%; never received refresher training 53–55%	Training is a one-off, refresher rare, establishments thin (health facility staff, Chikwawa; data officer, Kasungu)	Present but not maintained	Newer schedules require updated knowledge, which refresher gaps erode
Accessibility and outreach	9–37% live over 5 km; transport the largest provider barrier at 72%; inadequate transport or outreach support named by 23%	Rivers impassable in the rains, outreach transport not always provided (HSA, Kasungu); outreach constrained by fuel (interviews); staff linked reduced	Distance met by fragile outreach	Affects later doses and school and community platforms

		outreach to funding withdrawal (KIIs)		
Contact	Turned away 20–35% (district range); inconvenient service days 8–21% (district range); reminders labour-intensive (home visits 43–61%, passports or cards 37–56%)	Caregivers turned away after making the journey (HSA, Mangochi); HPV depends on parental consent (EPI coordinator, Mangochi)	A constraint; unreliable point-of-contact availability; may include reluctance to open multi-dose vials	Undermines uptake despite attendance; TCV and HPV sit on weaker, manual channels
Coverage (endpoint)	MR2 93.4%, IPV2 91.2%, TCV 74.6%, HPV 61.4% (Section 3.7)	HPV shows data gaps after the campaign-to-routine shift, as adolescents are absent from routine outreach (district EPI analysis, Kasungu)	Coverage declines across the antigen sequence	Coverage is lowest for TCV and HPV, which rely on newer delivery arrangements

4. Discussion

4.1. Principal Findings

Supply-side constraints on uptake of second-year and newer vaccines in these districts lay less in stock management at facilities than in the system's ability to sustain reliable contact with eligible children and adolescents. Viewed through the Tanahashi framework, the cascade did not fail primarily at nominal availability; it narrowed downstream after availability where services had to be geographically accessible, predictably open, stocked at the point of delivery, and supported by a workforce able to trace and follow up on missed doses [22,33]. This treats availability as a condition to be sustained rather than merely documented, consistent with effective-coverage cascades in which input readiness sets an upper limit on, but does not determine, coverage actually achieved [34]. This is an important distinction because facility-level readiness indicators can overstate effective supply when they do not capture intermittent stockouts or cancelled or inconvenient sessions [34,35].

The pattern observed here aligns with immunisation bottleneck studies in Ghana and Uganda, where losses in effective coverage were linked to constraints beyond basic service availability, including access, utilisation, and service continuity [24–26]. It also aligns with broader evidence that vaccine stockouts are associated with lower immunisation coverage in low- and middle-income countries [14]. The coverage gradient from established second-year antigens to TCV and HPV suggests that newer vaccines are particularly vulnerable when their delivery requirements have not yet been fully routinised through staff training, logistics, school or community platforms, recording tools, and outreach financing [10–12,35]. The principal finding is therefore that vaccine introduction and facility-level availability are necessary but insufficient: uptake depends on maintaining the delivery system that converts supply into actual vaccination at the point of need.

4.2. From Stock Records to Point-of-Contact Reliability

The findings point to a gap between stock management at facilities and reliability at the point of contact. Stock records were kept and reconciled at almost every assessed site, yet caregivers still reported being turned away because the vaccine was unavailable on the day they attended the session. Such failures are easy to miss in facility assessments, which capture whether stock is documented, or present on the day of the visit, but not whether vaccine is consistently available across sessions, outreach days, or different

points of care. For caregivers, however, intermittent stockouts are experienced as service failure. A wasted journey imposes time and transport costs, weakens confidence in the service, and may reduce the likelihood of returning, especially where distance and opportunity costs are already high. In these districts, 20 to 35 per cent of caregivers reported having ever been turned away, while stock records were in order at 35 of 37 assessed sites. The two measures come from different samples and reference periods, and neither records stock at the moment a caregiver attended. They cannot show that stock levels caused refusals. They are compatible with intermittent stockouts that a record review was not designed to detect. They are also compatible with a vaccinator declining to open a multi-dose vial for one or two children. Health workers are often reluctant to open a vial outside high-attendance sessions because of concern about wastage [18,19]. A caregiver asked to return on another day may report this as a stockout. Our data cannot separate the two explanations. Stock-card data over a defined period, combined with session-level observation, would be needed to do so. Caregivers also rarely named a stockout as the main reason for a missed vaccine (Section 3.3). Being turned away is therefore best read as a marker of service reliability and not a measure of doses lost. This is consistent with a companion analysis of the same survey, accepted for publication in Vaccines, in which being turned away was not associated with completion of second-year doses (adjusted odds ratio 0.93, 95% CI 0.52–1.66) [36].

This interpretation is consistent with coverage-cascade and bottleneck analyses in other settings, which show that losses in immunisation coverage often occur after nominal service availability, at the stages of access, contact, continued utilisation, and effective coverage [22,24–26]. It also aligns with supply-chain evidence from low- and middle-income countries showing that vaccine stockouts are associated with lower immunisation coverage [14], and with broader assessments of immunisation supply systems that identify stock reliability, outreach costs, transport, and recurrent operating inputs as persistent constraints [8,15,37,38]. The contribution of this study is to show how these general supply-side vulnerabilities appear for second-year and newer vaccines in Malawi: the system kept stock documented and reconciled at facilities, but was less able to guarantee that eligible children and adolescents would encounter a stocked, dependable service when they came for vaccination.

4.3. Workforce Maintenance and Contact Generation

This study shows that contact for second-year and newly introduced vaccines is not generated automatically once vaccines and staff are present at a facility. It depends on a maintained frontline workforce able to identify missed doses, communicate schedule changes, mobilise caregivers, and follow up on children and adolescents who do not attend the scheduled sessions. In these districts, workers were generally available, and many had received orientation training at introduction, but refresher training was limited. In every district, more than half (53 to 55 per cent) had never received it. This matters because later-scheduled and newly introduced antigens impose demands beyond those of the first year of life, including revised eligibility criteria, updated registers and defaulter forms, counselling of caregivers of older children, and coordination with outreach and school-based platforms [39–41]. Where these functions lapse, children miss opportunities for vaccination. Missed opportunities remain common in African programmes, and they arise as much from what health workers know and do, and from how sessions are organised, as from whether vaccine is in stock [35]. Health-worker practice on opening multi-dose vials is one such factor [18,19].

Evidence from low- and middle-income settings indicates that supportive supervision, refresher training, and reliable recording tools sustain service quality and make defaulter tracing feasible [34,37,42–44]. The same pattern is evident for later doses regionally,

where default on the 24-month RTS,S dose in Ghana was attributed to provider communication and follow-up gaps [45]. Similarly, in Malawi, weak HPV recording tools and target enumeration produced unreliable coverage estimates and stockouts [46]. The bottleneck is therefore not a shortage of frontline workers but insufficient maintenance of the functions that generate contact, which for these antigens means treating refresher training, supervision, and defaulter tracing as core supply-side inputs.

Frontline staff described a further constraint on defaulter tracing. They reported that caregivers often presented a different health passport each month. A child's vaccination history could then not be reconstructed. Missed doses could not be identified (district EPI analysis, Kasungu). Tracing is usually framed as a problem of workforce time and outreach cost, but this account suggests a further constraint, namely that the document meant to follow the child does not. Where the record is discontinuous, even a well-supervised worker cannot see who has defaulted, so contact generation fails before a home visit is attempted [35,46].

4.4. Outreach, Access, and Financing Fragility

Outreach was the main supply-side mechanism for overcoming distance, and health workers' accounts suggest that the programme has the right access strategy. Its weakness was continuity. Interviews described outreach as dependent on fuel or other modes of transport that were not always available, consistent with costing evidence that recurrent operating inputs, rather than vaccine costs, largely determine whether outreach sessions function as planned [38,47]. Two of the 20 key informants also linked reduced outreach and supervision to the 2025 withdrawal of external funding. This evidence is qualitative. We lack before-and-after measures of outreach volume. The evidence therefore cannot show that coverage fell because funding was withdrawn. It shows that the outreach response to distance rests on inputs that are exposed when external support contracts. Access therefore remained conditional even where services formally existed. Outreach reduces travel time only if sessions are predictable, staffed, supplied and resourced. When fuel shortages interrupt them, the access barrier reappears, particularly for later-scheduled doses requiring caregivers to return after the first year, and for school-based HPV delivery [10,45]. Geographical access is therefore not secured by the mere scheduling of outreach sessions. It is secured only where the session is financed and regular enough to create dependable contact. Across the districts, 9 to 37 per cent of caregivers lived more than five kilometres from a facility. Transport was the single largest provider barrier, at 72 per cent. The outreach that answers distance is therefore the most exposed link in the chain.

The financing accounts offer an explanation for this fragility. Immunisation financing was described as negotiated annually with the Ministry of Finance, fragmented across donor and implementing-partner plans, and only partly consolidated through a single planning and budgeting framework, with supply-chain functions and parts of the data workforce externally supported. This mirrors wider concerns about donor dependence and transition risk in immunisation systems [47–49], sharpened by the 2025 contraction in development assistance [50]. The field-level fragility of outreach and supervision may therefore reflect a structural feature of the financing model, not only a local operational problem. In this model, core delivery functions depend on external, sometimes fragmented, support. Whether Malawi's move toward one plan and domestic financing reduces or entrenches this fragility will determine whether outreach remains a reliable access strategy.

4.5. Implications for Newer Vaccines

The findings suggest that Malawi's immunisation system can introduce vaccines, but sustaining uptake depends on whether supply-side functions remain reliable at the point where eligible children and adolescents encounter the service. Established second-year antigens benefit from mature delivery routines: they are given at clinic visits that caregivers already attend, recorded in familiar registers and delivered by staff who know the schedule. TCV and HPV have had less time to build these routines, and HPV depends on a separate school platform [46,51]. TCV was introduced in 2023 through an integrated campaign with follow-on routine delivery [52]. Each newer antigen adds supply requirements. These include cold-chain volume and storage [53], recording tools and revised registers, training and session planning. For HPV, they also include coordination with the education sector [40,54].

The coverage gradient therefore cautions that vaccine introduction is not equivalent to delivery; post-introduction evaluations in comparable settings show that uptake of newly introduced antigens depends on how far these arrangements were established and maintained [11–13]. Newer antigens require deliberate strengthening of their specific supply arrangements rather than an assumption that the existing system will absorb them.

A distinct weakness emerged where a vaccine moved from campaign to routine delivery. District respondents reported that HPV data showed gaps once the vaccine shifted from its launch campaign into routine immunisation, because adolescent girls are not present at the routine outreach clinics that serve infants. The model that reached girls during a time-bound, school-based campaign was not rebuilt for continuous delivery, a difficulty documented in HPV programmes elsewhere and in Malawi's own experience of unreliable HPV recording and enumeration [46,51]. These accounts suggest that, for antigens introduced by campaign, coverage may decline as the campaign infrastructure is withdrawn, unless the routine platform is deliberately adapted to the eligible age group.

HPV delivery also requires parental consent, which infant immunisation does not. A girl is missed when a parent refuses or is absent on the vaccination day. Consent processes and communication with parents are therefore part of the supply arrangement for HPV.

4.6. Programme and Policy Implications

The coverage framework helps direct investment toward the points in the delivery pathway where the system is narrowing. For sustained vaccine uptake, stock reliability must be protected at the point of delivery, not only documented at facility level. This means strengthening buffer stocks, session-level stock planning, real-time stock monitoring, and rapid redistribution between facilities so that vaccines are available when caregivers attend sessions. Health workers should also be trained and supported to open a multi-dose vial for every eligible child who attends. Supervisors should reinforce this practice. Wastage monitoring should not discourage it [17–19]. Dependable vaccination sessions are equally important: willing caregivers should not be turned away because vaccines, staff, or sessions are unavailable on the day they seek care. For the workforce, the priority is to institutionalise refresher training and supportive supervision, especially for staff responsible for defaulter tracing, caregiver communication, and follow-up under evolving vaccine schedules. For geographic access, outreach should be treated as a core delivery function rather than an optional activity; this requires secured funding for fuel, transport, supervision, and community mobilisation, so that services reaching distant communities are not disrupted by external financing shocks. For newer antigens, programme planning should recognise that each vaccine may require distinct supply arrangements, including specific recording tools, delivery platforms, training needs, and coordination mechanisms. The implication is that vaccine introduction should not end at

procurement or launch. It should include sustained investment in the operational systems that convert vaccine availability into reliable vaccination at the point of need.

4.7. Strengths and Limitations

The key strength of this study is the mixed-methods design, which enabled supply-side constraints to be examined from several complementary perspectives. By combining data from caregivers, frontline providers, facility assessments, district-level respondents, and national-level informants, the study was able to compare how constraints appeared across different levels of the immunisation system, from national financing and procurement to point-of-contact service delivery. The use of the Tanahashi framework provided a structured approach to identifying bottlenecks along the pathway, allowing the analysis to move beyond overall coverage estimates and to identify where eligible children and adolescents were most likely to be lost before receiving vaccines. Another strength is the inclusion of a diverse set of antigens including established second-year vaccines and newer vaccines, delivered through different vial presentations and delivery platforms. This allowed the study to assess whether supply-side constraints differed by vaccine type, and to generate findings that may be relevant to other vaccines with similar delivery requirements.

Several limitations should be acknowledged. First, the survey components, the data quality assessment and the qualitative interviews drew on different respondents and sites within the same three districts. The cascade therefore integrates evidence across complementary sources rather than following the same individuals, facilities, or districts through each step. As a result, it should be interpreted as a descriptive bottleneck analysis rather than a formally linked estimate of effective coverage. Second, vaccination status and caregiver experiences of services were self-reported and may be affected by recall or reporting bias. The IPV2 estimate counts any recorded dose among children aged 13–59 months. IPV2 was introduced in December 2024, so these doses may have been given at the routine age or through later catch-up or campaign activities. The estimate is therefore not directly comparable with national routine coverage estimates. The HPV estimate should be interpreted with caution, because HPV vaccination is delivered through school-based platforms rather than routine immunisation contacts, making it less directly comparable with other antigens. Third, no instrument measured vaccine or cold chain availability directly. The data quality assessment recorded whether stock records were kept, at a single visit, at 37 sites that were not selected to represent all facilities in the districts. It cannot detect intermittent or session-level stockouts, and its findings should not be generalised beyond the assessed sites. More broadly, the study covers three districts, and the findings may not hold for districts with different geography or partner support. Fourth, the cross-sectional design limits causal inference; the supply-side constraints identified here are associated with where the cascade narrows, but the study cannot demonstrate that they caused specific missed vaccinations. The caregiver item also cannot distinguish a stockout from a decision not to open a multi-dose vial. Fifth, the funding-withdrawal theme was based on qualitative accounts from two key informants and should be interpreted as evidence of perceived programme vulnerability rather than a measured effect of funding changes. Finally, supply-side, demand-side, and quality-related constraints often operate at the same cascade steps. This analysis deliberately foregrounded the supply-side determinants and therefore does not estimate their relative contribution compared with demand-side factors examined elsewhere.

Immunisation records were also inconsistent across sites, with separate registers for local and visiting children, which were reported to produce mismatches between rec-

orded and administered doses (district EPI analysis, Kasungu). This may affect the denominators underlying coverage and reinforces the reading of the cascade as descriptive rather than exact [46,55].

5. Conclusions

In these districts of Malawi, the supply side of second-year and newer vaccine uptake appeared strong at the level where it is commonly measured, but weaker at the point where it most directly determines whether eligible children and adolescents are vaccinated. Stock records were kept and reconciled at almost every assessed facility, yet a quarter of caregivers reported having been turned away when they sought vaccination. This suggests that the reliability of service delivery at the point of contact, rather than stock management at facilities, was a key constraint. Providers most often named transport as a constraint on outreach. Interviews described outreach as dependent on fuel and external funding. More than half of frontline workers had never received refresher training. Coverage was lower for TCV and HPV than for the established second-year doses, which points to the need for sustained investment in delivery systems after launch. Improving uptake after the first year of life will therefore require protecting stock at the point of delivery, ensuring dependable vaccination sessions, consistently financing outreach, maintaining frontline workforce capacity, and strengthening the specific supply arrangements each newer vaccine requires. The message is therefore encouraging but conditional. Vaccine introduction is not the same as delivery. Uptake beyond infancy will hold only where the point of contact, and the workforce that sustains it, are financed and maintained.

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