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Systematic review and meta-analysis of the cost and cost-effectiveness of distributing insecticide-treated nets for the prevention of malaria

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ABSTRACT

Insecticide-treated nets are one of two core vector control interventions recommended by the World Health Organization for deployment in malaria-endemic regions around the world, especially sub-Saharan Africa. Although there are many factors that influence the type of distribution strategy chosen, among the most important considerations for the type of distribution strategy chosen is cost, both in terms of total expenditure required and in terms of relative cost-effectiveness. This research attempted to inform these decisions by conducting a systematic review and meta-analysis of the literature on the cost and cost-effectiveness of ITN distribution. The analysis compared the relative cost and cost-effectiveness of distribution strategies. Findings suggest that mass campaigns have lower average distribution costs per net compared with continuous/health facility distribution or sale/vouchers, although the relationship between distribution channel and cost were not statistically significant in the multivariate regression models. Continuous/health facility distribution channels were found to be more cost-effective than mass campaigns for averting DALYs, death, and cases of malaria. Those who design and budget for malaria programs should base decisions about distribution channels more on operational and epidemiological considerations than on cost per net, as the costs per net between distribution channels are not statistically different.

1. Introduction

Insecticide-treated nets (ITNs) are one of two core vector control interventions recommended by the World Health Organization (WHO) in endemic regions around the world, especially sub-Saharan Africa. ITNs have contributed over two-thirds of the reduction in malaria cases and deaths since 2000 (Bhatt et al., 2015). ITNs have been consistently shown to be effective and cost-effective methods for malaria prevention across a wide range of settings (Lengeler, 2004; Lim et al., 2011; Yukich et al., 2008a, b). However, progress in reducing the global burden of malaria has slowed in recent years, and funding for malaria control, though stable, remains far below that which will be required to achieve the WHO's Global Technical Strategy targets for malaria (World Health Organization, 2018). Within this context, it is critical to ensure that funds that are available are allocated to the most efficient interventions and deployment methods, to achieve maximum impact.

While ITN prices have fallen over the past ten years, making delivery at large scales more affordable, insufficient attention has been paid to the possibility that delivery system choice may contribute significantly to the relative costs of ITN programs and that ITN programs, might, through a more informed choice of how and when to distribute nets, be able to increase efficiency. This is a particularly pressing question given that ITN procurement also constitutes more than 60% of multilateral global expenditure on malaria control commodities (World Health Organization, 2015).

In most African countries, ITNs are distributed free-of-charge to the general population through mass campaigns that, ideally, occur every three years, though in practice the interval is often longer. Many countries also distribute ITNs to specific biologically vulnerable groups, namely pregnant women and infants, through routine antenatal care (ANC) or Expanded Programme on Immunization (EPI) services. A few countries distribute additional ITNs through continuous school or community-based channels to maintain access. The WHO recommends a combination of mass campaigns and continuous distribution while

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recognizing that different combinations of these channels are required depending on the setting. Although there are many factors that influence the type of distribution strategy chosen, among the most important considerations in the type of distribution strategy chosen is cost, both overall and in terms of relative cost-effectiveness.

A systematic review by White and colleagues examined the literature on the cost and cost-effectiveness of malaria prevention strategies published through 2010 (White et al., 2011). The analysis compared the cost and cost-effectiveness of malaria prevention strategies including ITNs, indoor residual spraying, and intermittent prevention and treatment. The authors found the mean financial cost of purchasing and distributing an ITN to be 8.26 USD and the mean economic cost to be 4.88 USD.[1] Cost-effectiveness estimates showed the median incremental cost-effectiveness ratio per Disability-Adjusted Life Year (DALY) averted of ITNs to be USD 31.73. Eisele and colleagues conducted a similar cost-effectiveness analysis using data from 2006–2009, concluding ITN distribution cost 118 USD (adjusted to 2016 USD) per DALY averted (Eisele et al., 2012).

Although these reviews are comprehensive, there has not been an update to the systematic review since 2010 despite likely changes in economies of scale and market conditions (White et al., 2011). Further, the relative cost and cost-effectiveness of the various ITN distribution channels have not been formally considered. A recent systematic review of the cost-effectiveness of malaria interventions considered the cost-effectiveness of ITNs used in conjunction with other prevention and treatment methods but did not examine the cost-effectiveness of ITNs alone nor compare distribution channels (Gunda and Chimbari, 2017). This leaves malaria programs to make decisions based on data which has not been updated or analyzed in sufficient detail.

We conducted a systematic review and meta-analysis of the literature on the cost and cost-effectiveness of ITN distribution including the papers reviewed by White et al. and articles published between January 2011 and May 2017. The analysis compares the relative cost and cost-effectiveness of distribution strategies. Findings from this work will support evidence-based decision making regarding ITN distribution strategies.

2. Material and methods

A systematic search of peer-reviewed and grey literature related to the cost of malaria interventions was conducted. In order to build on White's and Eisele's systematic reviews, we selected literature published between 2010 and May 2017 that was not included in either paper. There were no restrictions on the dates of data collection or study conduct. There were no restrictions on the study setting. Only articles published in English were found.

The initial search was conducted using PubMed, Google Scholar, African Journals Online, the Social Science Research Network, and the Bath Information Data System. The MeSH search terms used were (malaria OR falciparum OR plasmodium) AND (cost OR effective OR effectiveness OR benefit). A separate search was conducted using the search terms (malaria OR plasmodium) AND (cost). Abstracts were reviewed and papers that appeared to contain primary cost data related to ITN distribution were selected for further review and analysis. Those papers that were confirmed to contain primary data related to the cost of ITN distribution from arrival in-country to receipt by an individual were selected. Papers that only contained data on the retreatment of existing ITNs were excluded. Subsequently, the reference lists of all selected papers were reviewed. Additional relevant peer-reviewed literature and grey literature were identified through online search and inquiries to malaria researchers and included in the analysis. Requests for unpublished data and reports were also made to subject matter experts. No new doctoral dissertations meeting the search criteria were identified.

Costing analyses were categorized by distribution strategy: mass campaign, continuous/health facility, and sale/voucher. “Mass campaign” was defined as distribution within a limited timeframe. “Continuous/health facility” refers to a strategy that makes ITNs available at any time, most commonly through ANC and EPI. “Sale/voucher” encompasses strategies in which the purchase of nets is facilitated. Analyses were also categorized by level of distribution (local, sub-national, and national), costing year, the total number of nets distributed, country, and the World Bank lending group of the country in the year the study was performed (World Bank Group, 2016). Cost-effectiveness analyses were categorized based on region, costing year, costing perspective (provider or societal), and the event averted used as the outcome of the analysis (DALY, malaria case, death).

2.1. Inflation of costs

To compare costs incurred in different currencies across various years, the costs reported were converted to USD using exchange rates from the currency-year in which the original study reported, then inflated to 2016 USD using the US GDP Deflator (U.S Bureau of Economic Analysis, 2018).

2.2. Distribution costs

Distribution costs, whether financial or economic, were extracted from the original paper and included in this analysis. Financial costs are a measure of expenditures as they were incurred by the provider of the intervention. Economic costs are a measure of resource use by the provider of the intervention rather than financial expenditure alone. As such they include a valuation of donated goods as well as annuitization of capital goods. The perspective of the cost (i.e. provider or societal) was presented. The provider perspective refers to costs incurred by the organization(s) involved in distribution. Societal cost includes provider cost and also the cost to society, including the cost to the household receiving the net (for example, the retail price of the net). Only a small number of estimates (5/44 financial and 6/37 economic) represented the societal perspective; therefore, only provider cost estimates were included in the cost analyses.

The cost per treated net-year spreads the cost of distributing the net over the useful lifetime of the net. If a useful lifetime was presented in the article, that lifetime was used in this analysis. If no useful lifetime was provided, it was assumed to be three years. Additionally, it was assumed that each ITN covered two people. The mean and median financial and economic costs of distributing an ITN were summarized, both overall and by distribution channel. Trends in distribution costs over time were assessed. Multivariable regression was used to estimate the impact of the distribution channel and other factors on the cost of distributing an ITN. Standard errors were clustered by the original source (article, report, etc.) from which the cost estimates were obtained.

2.3. Cost-effectiveness

Cost-effectiveness measures were summarized based on the outcome presented in the original research: cases of malaria averted, Disability-Adjusted Life Years (DALYs) averted, and deaths averted. Mean and median costs per outcome were calculated. Multivariate regression was used to estimate the influence of the distribution channel on measures of cost-effectiveness, controlling for study characteristics. In response to the lack of heterogeneity among estimates that represented the provider perspective, both the provider and societal perspectives were included in the multivariate analysis. “Perspective” was included as a control variable. Due to high collinearity between distribution channel and target population (all campaigns were universal), target population was not included in the multivariate models.

[1] Costs have been adjusted to 2016 USD.

Table 1
Mean and median financial and economic cost per ITN distributed, by distribution characteristics.

	Financial cost				Economic cost			
	n	Mean	Median	Std error	*n*	Mean	Median	Std error
Overall	40	3.52	2.52	0.46	32	4.41	4.14	0.45
Distribution channel[*]								
Mass campaign	17	2.67	2.01	0.73	11	3.87	4.14	0.55
Continuous/ Health facility	16	4.05	2.72	0.74	14	4.69	4.27	0.70
Sale/Voucher	8	4.10	3.60	0.76	8	4.39	3.32	1.20
Region								
Africa	40	3.52	2.52	0.46	31	4.41	4.14	0.47
Asia	0	–	–	–	1	4.26	4.26	–
Year[a]								
Prior to 2000	0	–	–	–	2	10.23	10.23	2.01
2000–2009	26	2.89	2.13	0.54	20	3.23	3.30	0.30
2010–2016	14	4.68	4.28	0.77	10	5.60	5.30	0.76
World Bank lending group								
Low income	36	3.23	2.43	0.45	28	4.12	3.97	0.48
Low-middle/ High-middle income	4	6.12	6.84	1.98	4	6.41	6.88	1.04
Level								
Subnational/ Local	28	2.93	2.05	0.51	20	3.80	4.14	0.45
National	12	4.89	3.98	0.85	12	5.42	4.34	0.90
Nets distributed								
< 100K	16	2.93	1.68	0.86	12	3.60	3.72	0.61
100K-999,999	13	4.34	3.25	0.77	11	4.97	4.16	0.79
1M–4.9M	8	3.95	3.52	0.75	8	5.06	4.31	1.09
5M+	3	1.92	2.01	0.52	1	2.66	2.66	–

Notes: *n* = number of estimates reported in articles reviewed. All costs are shown in 2016 USD. All costs represent the provider perspective.

[*] One study (Yukich et al., 2009) involved multiple distribution channels.

[a] Year indicates currency year reported or, if unavailable, costing year.

3. Results

In total, 33 articles included in White's and Eisele's reviews contain primary distribution cost data for ITNs. The systematic search yielded four additional articles from peer-reviewed journals and five unpublished reports meeting the selection criteria, resulting in a total of 42 studies included in the analysis. Individual articles frequently included multiple analyses; for example, one article could contain three separate cost estimates from distribution campaigns in three regions. Overall, 20 of these 42 sources contained primary cost data only, 13 provided cost-effectiveness estimates only, and 9 contained both cost and cost-effectiveness information, resulting in a total of 44 financial distribution cost estimates, 37 economic distribution cost estimates (either provider, societal, or both) and 56 cost-effectiveness estimates. The selection process is illustrated in Appendix A.

3.1. Distribution costs and their determinants

Characteristics of the cost estimates representing the provider perspective are tabulated in Table 1.[2] The largest category of financial cost estimates were based on mass campaigns ($n = 17$), with a smaller number distributing through continuous/health facility ($n = 16$) and sale/voucher ($n = 8$) channels. Fourteen economic cost estimates were of continuous/health facility distributions and 11 were of mass campaigns. All ($n = 40$) financial estimates were based in Africa, while 31 economic cost estimates were based in Africa, and one was based in Asia. Among those based in Africa, the majority were from Sub-Saharan Africa, with 10 financial and 8 economic cost estimates from Tanzania/Zanzibar. The majority of cost estimates came from countries in the low-income bracket; the majority were from programs implemented at the subnational/local level, and in terms of distribution, the largest category was programs that distributed less than 100,000 nets.

The mean financial and economic costs, from the provider perspective, of distributing an ITN as estimated in each study are presented in Table 1 and illustrated in Fig. 1. Among the studies reviewed, the mean financial cost of distributing an ITN was 3.52 USD and the median financial cost was 2.52 USD (SE = 0.46). The mean economic cost was 4.41 USD and the median economic cost was 4.14 USD (SE = 0.45). The financial cost of distributing a net through a mass campaign (2.67 USD; SE = 0.73) was on average lower than through continuous/health facility-based channels (4.05 USD; SE = 0.74). Economic costs followed a similar pattern; the average mass campaign distributed at a cost of 3.87 USD per net (SE = 0.55) while continuous/health facility-based distributions had a mean cost of 4.69 USD (SE = 0.70). Sale/Voucher channels were the most expensive in terms of financial cost, and second most expensive in term of economic costs.

Countries were classified as low, low-middle income, and high-middle income based on the World Bank Country lending group classification of the country in the costing year (no studies from high-income countries were found). Due to low sample sizes, the low-middle and high-middle income categories were collapsed. Financial distribution costs were substantially higher in low-middle/high-middle income countries compared with low-income countries (6.12 versus 3.23 USD per net). Economic costs were also higher in low-middle/high-middle income countries (6.41 versus 4.12 USD per net). Financial distribution cost per net increased as the level of the distribution (subnational/local, national) increased; economic distribution costs displayed a similar pattern. In terms of the number of nets distributed, mean financial and economic costs were highest in the middle brackets (100K-4.9 M) and lowest in top volume bracket (five million or more nets). Bivariate analyses (not shown) indicate that overall, financial costs increased significantly over time ($p < 0.10$). This change was driven by significant increase in the cost of continuous/facility distribution ($p < 0.01$) (Fig. 2).

Although bivariate analyses (not shown) indicate that overall, economic costs did not increase over time, considered individually, continuous/health facility distribution costs increased significantly ($p < 0.10$) and sale/voucher costs decreased significantly ($p < 0.01$) (Fig. 3).

Results of the multivariate regression analysis found no significant differences in the cost of distributing an ITN via mass campaign compared with continuous/health facility channels or sale/voucher, respectively (Table 2). Higher financial costs were associated with programs implemented at the national level compared with the subnational/local levels ($\beta = 1.73$; $p < 0.05$).[3] Distributing five million or more nets was associated with lower financial and economic costs per net.

In total, 56 cost-effectiveness estimates, which may reflect the provider or societal perspective, were reviewed (Appendix C). Overall, DALYs averted were the most frequent outcome ($n = 26$), followed by deaths averted ($n = 22$) and cases of malaria averted ($n = 8$). Mean distribution costs by outcome are shown in Table 3. The provider and societal perspectives are presented separately. The mean provider cost per DALY averted by ITN distribution was 50 USD (SE = 9). Among the

[2] All estimates, both from the provider and societal perspectives, are presented in Appendix B.

[3] The beta coefficient (β) of 1.73 should be interpreted as follows: national-level programs are associated with a distribution cost per net that is 1.73 USD higher compared with the reference category (subnational/local level programs) after controlling for all other relevant factors. This association is significant at $p < 0.05$.

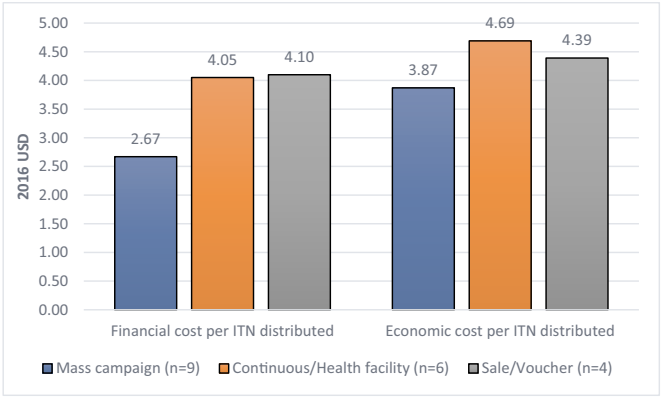

Fig. 1. Mean financial and economic costs per ITN distributed by distribution strategy. (All costs adjusted to 2016 USD. All costs represent the provider perspective.).

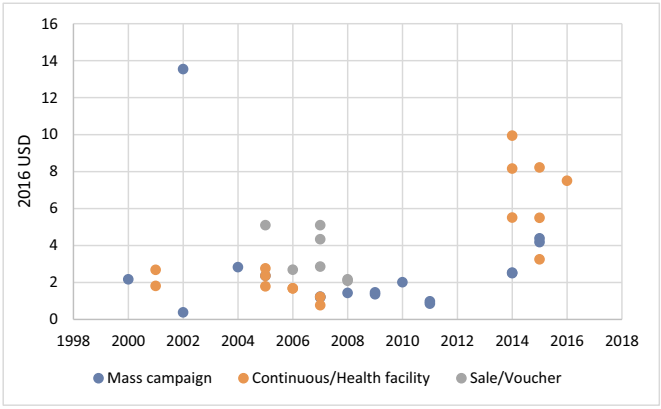

Fig. 2. Financial distribution costs per ITN over time, by distribution strategy. (All costs adjusted to 2016 USD. All costs represent the provider perspective.).

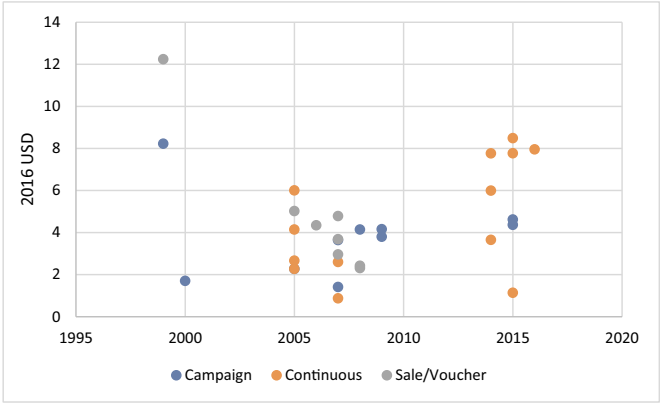

Fig. 3. Economic distribution cost per ITN over time, by distribution strategy. (All costs adjusted to 2016 USD. All costs represent the provider perspective.).

analyses reviewed it cost an average of 2143 USD (SE = 365) to the provider to avert one death. Preventing a case of malaria cost an average of 117 USD (SE = 48). The mean cost (from the provider perspective) per DALY averted by distribution strategy is shown in Fig. 4. Continuous/health facility distribution was the most cost-effective distribution strategy.

Multivariate analysis of the relationship between cost and outcomes (Table 4) found continuous/health facility distributions to be significantly more efficient than mass campaigns in averting deaths ($ß = -826.66$; $p < 0.05$)[4] and cases of malaria ($ß = -32.13$; $p < 0.10$). Sale/voucher channels were significantly less efficient at averting DALYs ($ß = 52.37$; $p < 0.001$) and deaths ($ß = 641.94$; $p < 0.001$).

Table 2
Multivariate regression model of the relationship between financial or economic distribution cost per ITN and study characteristics.

	Financial Cost (n = 40)		Economic cost (n = 32)	
	ß	Std error	ß	Std error
Distribution channel				
Mass campaign	[ref]		[ref]	
Continuous/Health facility	0.66	1.09	0.32	0.96
Sale/Voucher	2.03	1.41	0.38	1.02
Region				
Africa	[ref]		[ref]	
Asia	–	–	−0.04	0.84
Year[a]				
Prior to 2000	–	–	**4.94*****	**1.67**
2000–2009	**−2.77*****	**0.90**	−2.82	1.73
2010–2016	[ref]		[ref]	
World Bank lending group				
Low income	[ref]		[ref]	
Low-middle/Upper-middle income	0.45	2.12	−1.12	0.98
Level				
Subnational/Local	[ref]		[ref]	
National	**1.73****	**0.79**	1.46	0.84
Nets distributed				
< 100K	[ref]		[ref]	
100K-999,999	−0.53	1.05	0.11	1.15
1M–4.9M	−1.51	1.31	−1.26	1.30
5M+	**−2.72***	**1.40**	**−1.85***	**1.03**

Notes:
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.10$.
[a] Year indicates currency year reported or, if unavailable, costing year. All costs represent the provider perspective.

Findings suggest that mass campaigns have lower average distribution costs per net compared with continuous/health facility distribution or sale/vouchers, although the relationship between distribution channel and cost were not statistically significant in the multivariate regression models. This seems to indicate that malaria programs can deemphasize consideration of the cost per net when selecting a distribution channel. However, continuous/health facility distribution channels, all of which were targeted to pregnant women and children, were found to be more cost-effective than mass campaigns for averting DALYs, death, and cases of malaria. These findings are intuitive, as pregnant women and children are particularly vulnerable to malaria and so targeting them has the potential for greater returns

The body of evidence related to the cost and cost-effectiveness of ITNs has not been synthesized in nearly a decade, despite the sustained importance of the intervention. As a result, malaria programs must make decisions without the full benefit of evidence. Using meta-analysis techniques, we combined data from research performed over the course of more than twenty years, whether published or unpublished, that contained primary cost data on ITN distribution. Through this analysis, we sought to identify the trends in ITN distribution costs, the factors that are correlated with lower costs, and to describe the relative cost-effectiveness of various distribution strategies. Malaria programs may draw on these findings in the design, budgeting, and cost benchmarking of ITN distribution.

[4] The beta coefficient ($ß$) of −1,602 should be interpreted as follows: a continuous/health facility distribution system is associated with a cost of averting a death that is 1602 USD less than the reference category (mass campaign), controlling for all other relevant factors. This association is significant at the $p < 0.10$ level.

Table 3
Mean and median cost per Disability-Adjusted Life Year (DALY) averted, death averted, and case of malaria averted by study characteristics, stratified by costing perspective.

	DALY averted				Death				Case of malaria			
	n	Mean cost	Median cost	Std error	*n*	Mean cost	Median cost	Std error	*n*	Mean cost	Median cost	Std error
Total: Provider perspective	19	50	46	9	11	2143	1998	365	7	117	83	48
Distribution channel												
Mass campaign	9	43	22	15	3	2775	2061	745	6	136	92	52
Continuous/Health facility	6	42	48	6	4	1172	1226	263	1	5	5	–
Sale/Voucher	4	80	82	19	4	2640	2720	617	0	–	–	–
Region												
Africa	18	50	39	9	11	2143	1998	365	6	120	64	56
Asia	1	51	51	–	0	–	–	–	1	100	100	–
Target population												
Universal	2	56	56	5	1	1998	1998	–	5	154	100	59
Women and/or children	17	50	33	10	10	2157	1873	404	2	25	25	20
Year												
Prior to 2000	4	63	36	32	2	3163	3163	1102	2	77	73	28
2000–2009	15	47	46	8	9	1916	1685	368	1	5	5	–
2010–2016	0	–	–		0	–	–	–	0	–	–	–

	DALY averted				Death				Case of malaria			
	n	Mean cost	Median cost	Std error	*n*	Mean cost	Median cost	Std error	*n*	Mean cost	Median cost	Std error
Total: Societal perspective	7	78	14	14	11	3903	887	887	5	57	9	9
Distribution channel												
Mass campaign	7	78	14	14	11	3903	887	887	5	57	9	9
Continuous/Health facility	0	–	–	–	0	–	–	–	0	–	–	–
Sale/Voucher	0	–	–	–	0	–	–	–	0	–	–	–
Region												
Africa	7	78	14	14	11	3903	887	887	5	57	9	9
Asia	0	–	–	–	0	–	–	–	0	–	–	–
Target population												
Universal	0	–	–	–	4	6398	1360	1360	2	40	11	11
Women and/or children	7	78	14	14	7	2476	776	776	3	68	7	7
Year[a]												
Prior to 2000	7	78	86.28	14	8	2556	2595	676	4	59	61.52	11
2000–2009	0	–	–	–	0	–			1	50	50.34	
2010–2016	0	–	–	–	3	7493	7935	1143	0	–	–	–

Notes: n = number of estimates reported in articles reviewed. All costs shown in 2016 USD.
[a] Year indicates currency year reported or, if unavailable, costing year.

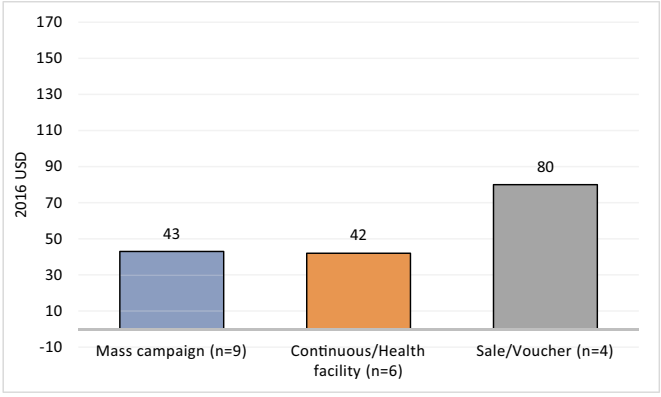

Fig. 4. Mean cost per DALY averted by ITN's, by distribution strategy. (All costs adjusted to 2016 USD. All costs represent the provider perspective.).

than targeting the general population. Further, continuous distribution, particularly in conjunction with ANC and EPI services, may reach these more vulnerable groups more efficiently than mass campaigns which occur periodically and may therefore miss women who become pregnant or babies who are born in the interim. It is important to note that research on the cost-effectiveness of ITNs has been limited in focus to the immediate outcomes of cases of malaria, DALYs and deaths averted, rather than on the long-term impacts of malaria such as school completion and growth in Gross Domestic Product (Sachs and Malaney, 2002).

The analysis found no evidence that ITN distribution programs are achieving economies of scale unless they were very large programs. In fact, programs that distributed higher volumes of ITNs tended to have higher costs per net distributed unless they distributed more than five million nets per year within a country. This may reflect the way that project budgets and work plans are established. In the lack of synthesized information on net distribution costs, simple estimates of the cost of distributing a net, which does not vary based on volume, may be used to set program budgets that are artificially high in small and moderate programs. Programs may tend to meet rather than underspend these budget expectations and therefore reverse the economies of scale that one might otherwise achieve.

Costs were on average higher in higher-income countries. These countries generally have higher price levels and so costs tend to be higher nominally. Due to limitations in the information provided in some of the papers reviewed, the costs in this analysis have not been adjusted for purchasing power parity which would likely equalize these differences to some degree. Nevertheless, the higher costs of salaries, insurance, and fuel in higher income countries may outweigh any potential savings due to better infrastructure and logistics as compared to low-income countries.

Trends in cost over time appeared to show that both financial and economic distribution costs appear to be rising since 2000, while we did not find evidence that cost effectiveness has improved over time. This may reflect the increasing complexity of distribution, for example, data collection and reporting requirements, behavior change communication, and quality assurance processes. Donors and malaria control programs could explore whether lessening monitoring and evaluation

Table 4
Multivariate regression models estimating the relationship between cost per Disability-Adjusted Life Year (DALY) lost, death, and case of malaria averted and study characteristics.

	DALY averted (n = 26)		Death (n = 22)		Case of malaria (n = 12)	
	ß	Std error	ß	Std error	ß	Std error
Distribution channel						
Mass campaign	[ref]		[ref]		[ref]	
Continuous/Health facility	14.24	12.95	**−826.66****	**324.73**	**−32.13***	**15.32**
Sale/Voucher	**52.37*****	**10.77**	**641.94*****	**1.97**	–	–
Region						
Africa	[ref]		[ref]		[ref]	
Asia	−15.43	42.74	–	–	–	–
Costing perspective						
Provider	[ref]		[ref]		[ref]	
Societal	52.37	10.77	−606.27	1256.98	13.46	15.32
Year[a]						
Prior to 2000	[ref]		[ref]		[ref]	
2000–2009	−38.86	44.08	−1164.16	926.38	−8.17	15.32
2009–2016	–	–	**4936.32*****	**849.61**	**–**	**–**

Notes:
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.10$.
[a] Year indicates currency year reported or, if unavailable, costing year.

requirements and reducing the complexity of distribution planning can lower costs or improve cost effectiveness.

This study has several limitations to note. First, although malaria is endemic in 97 countries (RMB Partnership to End Malaria, 2018), all but one of the estimates included in the meta-analyses were from 14 countries in Africa and roughly one in four estimates were from Tanzania/Zanzibar alone. This limits the generalizability of the findings. Second, information on the specific cost categories included in each analysis was not available. This translates to a lack of precision in the meta-analysis, as some types of costs (for example, behavior change communication) may be included in some estimates but not others, which would tend to bias cost estimates down. Additionally, a detailed comparison of the line item contributions to cost is hampered by limited comparability of cost classification between studies.

5. Conclusions

This analysis contributes detailed information on the factors related to cost and cost-effectiveness of ITN distribution. Overall, those who design and budget for malaria programs should base decisions about distribution channels more on operational and epidemiological considerations than on cost per net, as the costs per net between distribution channels are not statistically different. The total program costs, however, will differ vastly depending on the size of the population targeted for distribution. Those operating high-volume programs should be aware that economies of scale may not automatically occur. Finally, those concerned with relative cost-effectiveness might select continuous/health facility-based strategies to distribute ITNs to pregnant women and infants in conjunction with ANC and EPI services. Most of the analyses of these channels either were conducted on highly functional ANC/EPI services or assumed that these services were highly functional. As such, their superior cost-effectiveness might not hold in situations with diminished functionality. Therefore, investment in the monitoring and maintenance of these channels is warranted and might be a cost-effective use of funds when combined with ANC/EPI ITN distribution. Cost and cost-effectiveness analyses from ITN programs in a wider range of African countries, as well as countries outside of Africa, are also needed.

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Declaration of Competing Interest

The authors have no competing interests.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.actatropica.2019.105229.

Appendix A. Source selection process

Appendix B. Costing study descriptions (2016 USD)

Reference	Country	Year*	Perspective	World Bank lending group	Distribution channel and description	Level	Nets distributed	Financial cost† per net distributed	Economic cost† per net distributed
Wisniewski and Yukich (2017)	Tanzania	2016	Provider	Low	Continuous/Health facility: ANC & EPI	National	793,320	7.50	7.95
Scates and Yukich (2016)	Mali	2015	Provider	Low	Continuous/Health facility	National	992,267	8.22	8.49
Scates and Yukich (2016)	Mali	2015	Provider	Low	Mass campaign: Bamako region	Subnational/ Local	1571,834	4.39	4.62
Scates and Yukich (2016)	Mali	2015	Provider	Low	Mass campaign: Segou region	Subnational/ Local	1752,092	4.18	4.37
Scates and Yukich (2017)	Tanzania	2015	Provider	Low	Continuous/Health facility: School-based	Subnational/ Local	494,407	3.25	1.13
Yukich (2016)	Zanzibar	2015	Provider	Low	Continuous/Health facility	Subnational/ Local	216,310	5.50	7.77
Ntuku et al. (2017)	DR Congo	2014	Provider	Low	Mass campaign: Door-to-door	Subnational/ Local	624,532	2.53	
Ntuku et al. (2017)	DR Congo	2014	Provider	Low	Mass campaign: Fixed distribution point	Subnational/ Local	2843,442	2.50	
Smith Paintain et al. (2014)	Ghana	2014	Societal	Low-middle/ Upper-middle	Mass campaign: Universal coverage in Western region	Subnational/ Local	1340,404	7.60	3.24
Yukich (2014)	Ghana	2014	Provider	Low-middle/ Upper-middle	Continuous/Health facility: EPI	National	797,550	9.94	7.76
Yukich (2014)	Ghana	2014	Provider	Low-middle/ Upper-middle	Continuous/Health facility: School-based	National	2747,000	5.51	3.65
Yukich (2014)	Ghana	2014	Provider	Low-middle/ Upper-middle	Continuous/Health facility: ANC	National	4342,100	8.16	5.99
Smith Paintain et al. (2014)	Ghana	2013	Societal	Low-middle/ Upper-middle	Mass campaign: Universal coverage in Central region	Subnational/ Local	996,023	7.91	3.55
Smith Paintain et al. (2014)	Ghana	2012	Societal	Low-middle/ Upper-middle	Mass campaign: Universal coverage in Brong Ahafo region	Subnational/ Local	1327,601	5.41	2.37
Renggli et al. (2013)	Tanzania	2011	Provider	Low	Mass campaign: Universal coverage	Subnational/ Local	17,617,891	0.98	
Sedlmayr et al. (2013)	Zambia	2011	Provider	Low-middle/ Upper-middle	Mass campaign: LLINs distributed to randomly selected cotton farmers	Subnational/ Local	39,963	0.85	
Bonner et al. (2011)	Tanzania	2010	Provider	Low	Mass campaign: Catch-up for children under five	Subnational/ Local	8753,438	2.01	
World Health Organization (2009a)	Zanzibar	2009	Provider	Low	Mass campaign: Universal	Subnational/ Local	249,773	1.36	4.16
World Health Organization (2009a)	Uganda	2009	Provider	Low	Mass campaign: Pregnant women and children under five	National	219,537	1.46	3.80
World Health Organization (2009a)	Zanzibar	2008	Provider	Low	Mass campaign: Children under five	Subnational/ Local	219,537	1.43	4.14
World Health Organization (2009c)	Kenya	2008	Provider	Low	Voucher/sale: subsidized for ANC	National	1853,178	2.17	2.42
World Health Organization (2009c)	Kenya	2008	Provider	Low	Voucher/sale: subsidized for rural residents	Subnational/ Local	214,370	2.09	2.31
Kolaczinski et al. (2010)	Uganda	2007	Provider	Low	Mass campaign: Pregnant women and children under five in Adjumani District	Subnational/ Local	15,188	1.19	1.41
Kolaczinski et al. (2010)	Uganda	2007	Provider	Low	Continuous/health facility: ANC in Jinja District	Subnational/ Local	12,994	0.77	0.87
Kolaczinski et al. (2010)	Uganda	2007	Provider	Low	Continuous/health facility: ANC in Adjumani District	Subnational/ Local	15,188	1.22	2.60
World Health Organization (2009b)	Uganda	2007	Provider	Low	Mass campaign: Pregnant women and children under five	Subnational/ Local	21,707	1.23	3.64
World Health Organization (2009c)	Kenya	2007	Provider	Low	Voucher/sale: subsidized for ANC	National	1593,522	2.86	2.96
World Health Organization (2009c)	Kenya	2007	Provider	Low	Voucher/sale: subsidized for urban residents	Subnational/ Local	65,868	5.10	4.78
World HealthOrganization (2009c)	Kenya	2007	Provider	Low	Voucher/sale: subsidized for rural residents	Subnational/ Local	292,436	4.34	3.68

De Allegri et al. (2009)	Burkina Faso	2006	Provider	Low	Continuous/health facility: ANC	Subnational/ Local	5227	1.68	
De Allegri et al. (2009)	Burkina Faso	2006	Provider	Low	Voucher/sale: subsidized	Subnational/ Local	15,000	2.69	
De Allegri et al. (2009)	Burkina Faso	2006	Societal	Low	Continuous/health facility: ANC	Subnational/ Local	5227		4.34
De Allegri et al. (2009)	Burkina Faso	2006	Societal	Low	Voucher/sale: subsidized	Subnational/ Local	15,000		4.34
Mulligan et al. (2008)	Tanzania	2006	Societal	Low	Voucher/sale: subsidized	National	1157,885	7.34	
World Health Organization (2009a)	Zanzibar	2006	Provider	Low	Continuous/health facility: ANC	Subnational/ Local	21,717	1.68	4.39
Becker-Dreps et al. (2009)	DR Congo	2005	Provider	Low	Continuous/health facility: ANC	Subnational/ Local	17,893	1.79	
Hansen et al. (2012)	Uganda	2005	Provider	Low	Continuous/health facility: ANC	Subnational/ Local	1752		4.14
Hansen et al. (2012)	Uganda	2005	Provider	Low	Continuous/health facility: ANC with IPT	Subnational/ Local	1778		6.00
Yukich et al. (2007)	Senegal	2005	Provider	Low	Sale/vouchers: vouchers for pregnant women and children under five	National	750,000	5.10	5.02
Yukich et al. (2007)	Tanzania	2005	Provider	Low	Continuous/health facility: Pregnant women and children under five	National	6383,805	2.76	2.66
Yukich et al. (2009)	Eritrea	2005	Provider	Low	Hybrid Mass campaign and continuous/health facility: Universal	National	900,000	2.36	2.27
Mueller et al. (2008)	Togo	2004	Provider	Low	Mass campaign	National	907,500	2.83	
Hanson et al. (2003)	Tanzania	2003	Societal	Low	Voucher/sale: subsidized	Subnational/ Local	65,111	8.42	1.70
Grabowsky et al. (2005)	Ghana	2002	Provider	Low	Mass campaign: EPI	Subnational/ Local	14,600	0.38	
Ngugi (2004)	Kenya	2002	Provider	Low	Mass campaign	Subnational/ Local	39,131	13.54	
Guyatt et al. (2002a)	Kenya	2001	Provider	Low	Continuous/health facility: ANC at district level	Subnational/ Local	70,000	2.68	
Guyatt et al. (2002a)	Kenya	2001	Provider	Low	Continuous/health facility: ANC at national level	Subnational/ Local	1440,000	1.81	
Guyatt et al. (2002b)	Kenya	2000	Provider	Low	Mass campaign	Subnational/ Local	15,000	2.17	1.70
Goodman et al. (2001)	South Africa	1999	Provider	Low-middle/ Upper-middle	Mass campaign	Subnational/ Local	5450		8.22
Stevens et al. (2005)	Malawi	1999	Provider	Low	Voucher/Sale	National	1461,941		12.24
Haque et al. (2014)	Bangladesh	not stated	Provider	Low	Mass campaign	Subnational/ Local	3110,000		4.26

Acronyms: ANC = antenatal care; EPI = expanded programme on immunization; ITN = insecticide-treated net; LLIN = Long-Lasting Insecticide Treated Net.
Notes. *Year indicates currency year reported or, if unavailable, costing year. †All costs converted to 2016 USD.

Appendix C. Cost-effectiveness study descriptions

Reference	Country and dates	Distribution channel	Target population*	Perspective	Event averted	Cost per event averted (2016 USD)	
Smith Paintain et al.-(2014)	Ghana (2010–2012)	Mass campaign with hang-up and BCC	Universal	Societal	child death	Brong Ahafo	5329
						Central	7935
						Western	9214
Becker-Dreps et al. (2009)	Uganda (2004–2007)	Fixed/Health facility: ANC	Pregnant women	Provider	DALY	ITN	54
						IPT + ITN	53
Smithuis et al. (2013)	Myanmar (1998–1999)	Mass campaign	Universal	Provider	DALY	51	
Bhatia et al. (2004)	India (1997- 1998)	Mass campaign	Universal	Provider	Case of malaria	100 (85; 120)	
Becker-Dreps et al. (2009)	DR Congo (2005- 2006)	Fixed/Health facility: ANC	Children and pregnant women	Provider	Death	550 (474; 1452)	
					DALY	23 (11; 41)	
Yukich et al. (2009)	Eritrea (2001- 2005)	Mass campaign	Universal	Provider	Child death	1998 (1650; 7992)	
					DALY	61 (30; 242)	
Mueller et al. (2008)	Togo (2004)	Fixed/Health facility: EPI	Children	Provider	Death	929	
					DALY	24 (4.45; 40)	
					Case of malaria	4.76 (0.89; 7.98)	
Yukich et al. (2008b)	Malawi (1999–2005)	Fixed/Health facility: ANC	Children and pregnant women	Provider	Child death	1524	
					DALY	46	
		Fixed/Health facility: ANC and retreatment	Children and pregnant women	Provider	Child death	1685	
					DALY	51	
Yukich et al. (2007)	Senegal (2000–2005)	Sale/voucher: ANC	Children and pregnant women	Provider	Death	3033	
					DALY	92	
		Sale/voucher: ANC and retreatment	Children and pregnant women	Provider	Death	4036	
					DALY	122	

Yukich et al. (2007)	Tanzania (2002–2005)	Sale/voucher: ANC	Children and pregnant women	Provider	Death	1086
					DALY	33
		Sale/voucher: ANC and retreatment	Children and pregnant women	Provider	Death	2407
					DALY	73
Wiseman et al. (2003)	Kenya (1996- 1999)	Mass campaign	Children	Societal	Death	3216
					DALY	128
		Mass campaign	Children	Societal	Death	2388 (1650; 2663)
					DALY	96
Hanson et al. (2003)	Tanzania (1997- 1999)	Mass campaign	Children	Societal	Death	2802.62 (1055; 2803)
					DALY	102 (39; 102)
Guyatt et al. (2002b)	Kenya (1999- 2000)	Mass campaign	Universal	Provider	Case of malaria	50
Goodman et al. (2001)	South Africa (1998-1999)	Mass campaign	Universal	Provider	Death	3116 (1140; 14,254)
					Case of malaria	29 (11; 135)
Coleman et al. (2004)	Sub-Saharan Africa	Mass campaign	Children	Societal	DALY	86 (35; 167)
Some (1999)	Kenya (1993- 1994)	Mass campaign with retreatment	Children		Death	6490 (6100; 6586)
Guyatt et al. (1999)	Sub-Saharan Africa	Mass campaign	Children	Provider	DALY	18
		Mass campaign			DALY	11
		Mass campaign			DALY	30
		Mass campaign			DALY	19
Graves (1998)	Gambia (1990)	Mass campaign	Children	Provider	Death	2061 (1538; 2890)
					Case of malaria	45 (33; 63)
Aikins et al. (1998)	Gambia (1992- 1993)	Mass campaign	Children	Societal	Death	1149 (873; 1874)
					DALY	77 (59; 125)
					Case of malaria	66 (49; 108)
Binka et al. (1997)	Ghana (1993- 1994)	Mass campaign	Children	Provider	Death	4265 (2004; 4623)
					DALY	157 (74; 170)
Evans et al. (1997)	Gambia	Mass campaign	Children	Provider	DALY	22- 44 (19- 266)
WHO (1996)	Sub-Saharan Africa, (1990)	Mass campaign	Children	Provider	DALY	20- 41
Picard et al. (1993)	Gambia	Mass campaign	Children	Societal	Death	544
					DALY	23
					Case of malaria	82
		Mass campaign	Children	Societal	Death	746
					DALY	31
					Case of malaria	57

Acronyms: ANC = antenatal care; BCC = behavior change communication; DALY: Disability-Adjusted Life Years; IPT = intermittent prevention and treatment; ITN = Insecticide-Treated Bed Net.

Notes.*There was variation in the age ranges of children targeted: children under five, children under six, and children under ten. The target age group was not specified in every study. For this analysis, all interventions specifically targeting children are combined.

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