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REVIEW

Implications of public-health insecticide resistance and replacement costs for malaria control: challenges and policy options for endemic countries and donors

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Abstract: Millions of people rely on public-health insecticides for malaria prevention. Yet growing insecticide resistance may threaten malaria control programs through decreasing effectiveness and possibly unsustainable cost-increases. Insufficient investment by stakeholders in the search for new public-health insecticides in recent decades has left malaria control programs with limited alternatives with which to manage resistance and maintain program effectiveness. While alternative insecticides are available, short of an unforeseen, significant increase in funding, their higher cost would compel programs to reduce malaria control coverage, leading to increased mortality and morbidity. In order to limit these negative effects on cost and coverage, we propose that policymakers and malaria stakeholders consider adoption of existing policies from successful efforts to secure reduced prices and increased access to other essential health interventions.

Keywords: vector control, indoor residual spraying (IRS), malaria control policy, research and development (R+D), priority review voucher (PRV), compulsory license

Introduction

Despite recent, encouraging gains against the disease, malaria claimed around 655,000 lives in 2010 and continues to exact a heavy social and financial toll, especially among African children. Deaths from malaria dropped from approximately one million in 2000 to the current level due to an increase in access to artemisinin combination therapies (ACTs) and a scale-up in coverage of insecticide-based prevention activities – especially insecticide-treated bed-nets and indoor residual spraying (IRS).[1] These gains are fragile and could be reversed. Drug resistance to ACTs now poses a real threat to malaria treatment, and growing evidence indicates insecticide resistance may similarly threaten malaria prevention. While novel or noninsecticide-based vector control interventions hold future promise in malaria prevention (as will vaccines), effective malaria control currently is dependent on the use of essential public-health insecticides.[2]

Our analysis of recent malaria control program data shows that the cost of new or alternative formulations of public-health insecticides to replace those experiencing resistance poses a threat to global disease vector control through significant and possibly unsustainable increases in program costs. The current response to the threat of insecticide resistance and its potential effect on access to prevention is insufficient and is a poor handling of known risk by stakeholders. While a long-term, research-driven strategy is essential to address this risk and improve access to essential public-health

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insecticides, several policy-based options conceived to improve access to essential treatments for malaria and for HIV/AIDS may have similar potential when adapted to essential public-health insecticides.

Insecticide resistance

World Health Organization (WHO)-approved public-health insecticides are limited to twelve products from four classes: organochlorines, organophosphates, carbamates, and pyrethroids. Insecticides from each of the four classes are approved for use in IRS programs; only pyrethroids are approved for use in insecticide-treated bed-nets. Insecticides from all WHO-approved vector control chemical classes are in use in agriculture today, with the exception of DDT, which was used widely until the 1970s.

The primary strategy for managing insecticide resistance is to use insecticides from two or more classes, alternating them geographically in a mosaic pattern, or temporally, with one class of insecticide sprayed one season and another sprayed the next season. Rotation is likely to limit the spread of insecticide resistance because of the low probability that mosquitoes will carry resistant genes for both classes of insecticide and over multiple seasons.[3] But because resistance grows to an entire class of insecticides rather than individual formulations, this approach is absolutely dependent on the availability of effective products from at least two classes. Of the twelve currently-approved insecticides, six belong to the pyrethroid class; therefore alternative insecticides to replace them must be drawn from one of the two carbamate insecticides, one of the three organophosphate insecticides, or DDT, which is the only organochlorine insecticide approved by WHO. Rotation and replacement options are limited by the potential of resistance to DDT given its long history of widespread use, the stigma associated with it and in some cases fear that any residues on exported produce will lead to its rejection from developed country markets.[4] Additionally, the phenomenon of cross-resistance between classes further complicates the process.

Research and development for new classes of public-health insecticides and risk

Since the cost of developing a new class of insecticide may exceed $290 million, "the small public-health market would hardly allow for such substantial investments."[5] As a consequence, almost all currently-available public-health insecticides are re-purposed products[6] from the nearly $11 billion annual global agricultural insecticides market.[7] While public-health insecticides benefit from agricultural development, the dependence has a double-edge because of the significant role of agricultural use in driving resistance. (In fact, mosquito resistance to insecticides in some cases was documented even before the chemicals were deployed in public-health programs).[8]

The source of this double-edge is that agricultural and most public-health insecticides rely primarily on killing action, which drives resistance through the vector population by imposing intense selective pressure. Ideally, in order to minimize or even eliminate these negative effects, public-health insecticides would be from different classes of chemicals than those used in agriculture. Additionally, because malaria control can benefit from lower vector density afforded by killing action, but is not dependent on it,[9] the strong killing action shared by agricultural and public-health insecticides may be an undesirable trait in the latter – a fact that could further hasten their divergence.

Taking such a divergent path from agriculture will require a substantial, new investment in public-health insecticide research and development. While research and development for malaria control overall has grown significantly in recent years, reaching a total of $612 million from all sources in 2009, vector control research (which also includes technologies other than insecticides) was only about 4.5% of the annual total for malaria. (Exact figures are unknown because of likely underreporting of industry investment in research and development of new insecticides).[10]

The exception to this paucity of research and development is the Innovative Vector Control Consortium (IVCC), a product-development partnership formed in 2008 and funded by the Bill and Melinda Gates Foundation that works in partnership with research institutions and industry to develop and bring to the market new public-health insecticides. In 2010, IVCC, the London School of Hygiene and Tropical Medicine, and chemical company BASF announced that BASF will bring to the market chlorfenapyr, a repurposed agricultural product that would represent a new class of public-health insecticide. According to the developers, it will be viable both for IRS applications and for treatment of insecticide-treated bed-nets.[5] If successful, this product will represent the first new class of active ingredients for public-health insecticides in decades.[2] IVCC's "pipeline" of new products promises to deliver longer-lasting formulations of existing insecticides new to public-health within 2–3 years and IVCC aims to bring three entirely new insecticide classes to market by 2020 (Personal communication, Tom McLean, IVCC).

The IVCC development agenda is both ambitious and welcome, but even with their efforts, total public-health insecticide research and development represents a significant underinvestment by stakeholders.[2,10] When compared to research and development spending for malaria treatments (38% of total research and development spending in the period from 2004–2009), the degree of underinvestment in new vector control products, including public-health insecticides, is quite stark.[10] More to the point, because public-health insecticides are essential to malaria control programs that account for around $2 billion annually,[1] and because stakeholders face a known, imminent threat to their effectiveness, current research and development spending represents poor management of known risk.

The practical implications for this underinvestment and poor handling of risk are that a great deal of uncertainty still surrounds the prospects for access to public-health insecticides of new chemical classes, and thus for effective vector control in the future. Many malaria control programs already face escalating resistance and vector control problems that will require them to switch from low-cost insecticides to relatively high-cost insecticides long before 2020.

Insecticide pricing and IRS costs

Insecticide prices are one of many factors that determine the overall cost (and thus coverage) of an IRS program. Other inputs include staff costs, logistics, rent, transportation, communications, equipment, and protective clothing, among others. Additionally, IRS costs can vary significantly from country to country and program to program, due to the size of houses and distance between them, different operating costs from country to country, the state of institutional and physical infrastructure (such as insectaries), and whether the existing malaria control personnel have experience in planning and managing an IRS program.

Still, insecticides' cost per unit and their respective residual effectiveness are major determinants of a malaria prevention program's overall cost. Longer-lasting formulations require fewer spray rounds, so a relatively expensive insecticide with a long residual life could end up being more cost-effective than a relatively inexpensive insecticide with a shorter residual action that requires more frequent applications. (For example, carbamates remain effective for around 4 months and in real-world situations in much of tropical Africa, typically requiring more than one spray round during a transmission season and doubling an IRS program's insecticides costs). The organophosphate first used by the US President's Malaria Initiative (PMI) in 2011 was developed as a long-lasting formulation that would typically cover an entire transmission season with a single application. This insecticide has not yet been fully evaluated by the WHO's Pesticide Evaluation Scheme, but in their testing, IVCC and Syngenta have found that it can be effective for up to 8 months.[11]

In this paper, we based our analysis on IRS program costs incurred by the PMI, which has funded and directed much of the recent scale-up in IRS coverage in Africa and makes considerable programmatic data available to the public (see www.fightingmalaria.gov).[12] In 2010, the PMI sprayed over 6.6 million structures in 15 African countries, protecting over 27 million people.[12] Because of the extent of PMI funding of malaria control across sub-Saharan Africa, its cost allocations and country by country variations are very good indicators of the potential effect of resistance and increasing insecticide costs on IRS globally.

The costs of each of the different classes of insecticides, based on data made available by the PMI for 2008 to 2011, are shown in Table 1. Because contracts for supplying insecticides to the PMI are granted on a confidential tender basis, these figures do not include the cost of specific insecticides, but instead show a range of costs for the class of insecticide, which may comprise several different brands from different producers. The cost data presented are based on the cost per sachet of insecticide. On average, a sachet of insecticide covers approximately 220 m^2 of wall surface, and is thus comparable among classes, with only slight variations.

Between 2008 and 2011 the cost of pyrethroids declined steadily, falling by approximately 45% during the period, due to economies of scale in production and the vigorous competition among suppliers (from both originator firms and generic producers). The cost of DDT rose by approximately 10% between 2008 and 2010, and the cost of carbamates fluctuated but declined by approximately 2% over the period. We are unable to comment on the cost of organophosphates from 2008 to 2010, as PMI and its contractors did not procure any insecticides in this class until 2011.

Pyrethroids' significant decline in price and the relative high cost of carbamates and organophosphates signal onerous challenges for IRS programs seeking to expand or even sustain coverage. Organophosphates are approximately eleven times more expensive than the pyrethroids and about 2.5 times more expensive than available carbamates. Carbamates are themselves 4.8 times more expensive than pyrethroids. The potential magnitude of the effects due to increase in program costs and consequent decreases in coverage are clearly illustrated in the scenarios described below.

Table 1 Indoor residual spraying insecticide cost range and midpoints (US$); per sachet and on average covering 220 m^2 of wall

Insecticide class	2008 (US$)	2009 (US$)	2010 (US$)	2011 (US$)
Pyrethroid	3.30–4.60 (3.95)	2.40–4.63 (3.51)	2.20–3.60 (2.90)	1.89–2.40 (2.15)
Organophosphate	N/A	N/A	N/A	23.50–27.00 (25.25)
DDT	4.39	4.79	4.83	N/A
Carbamate	10.63	11.88	10.50–11.88 (11.18)	10.38

Source: USAID.

The average 2008 to 2010 cost data for all program input categories for seven PMI countries are summarized in Table 2 and are based on the PMI's 2011 economic analysis of IRS.[13] These simple mean data represent the costs for a single annual spray round using either DDT or pyrethroids. Table 3 summarizes the average number of structures sprayed, people protected, cost per structure, and cost per person protected for the 2008 to 2010 period. In the case of Malawi and Liberia, the cost data are calculated for just 2 years (2008 and 2009 in the case of Malawi, and 2009 and 2010 in the case of Liberia) because of their respective start and end dates. On average, current insecticide costs vary between around 5% and 20% of the total IRS expenditures. The average total cost per structure sprayed varies similarly, from between $7.91 in Ethiopia and $29.12 in Angola, reflecting various factors, such as existing infrastructure, local operating costs, and historic IRS expertise. The variation in average cost between countries as measured per person protected is lower, at $2.45 in Ethiopia and $6.87 in Malawi.

Cost and IRS coverage scenarios

We provide four scenarios based on the PMI's IRS economic analysis to illustrate the implications of substitution-costs for overall IRS costs and for coverage of target populations, substituting 2011 organophosphate and carbamate cost data for the actual insecticide (pyrethroids and DDT) cost data (see Appendix). In the first two scenarios, we use mean cost data for the years 2008 to 2010 as a basis for projecting possible substitution costs for new insecticides. In the third and fourth scenarios, we run roughly the same scenarios based on the latest available year of data only. For all four scenarios, we assume the overall budget for the IRS program remains static, based on the average 2008–2010 budget in the two scenarios where coverage data are averaged over the same period, and on the 1-year budget when only latest available single year of coverage data are used. These single-year scenarios may portray the implications of insecticide cost increases more accurately, as they account for investments in training and equipment that occur on a continuing basis in a mature program.

As noted above, the data we use as a basis for these scenarios relates to a single spray round, which makes cost comparisons relatively easy when modeling substitution with an insecticide that has a residual action that lasts a full transmission season. Based on the 2011 insecticide cost data presented, we assume that replacing pyrethroids with organophosphates increases insecticide costs elevenfold. We assume that replacing pyrethroids with carbamates increases insecticide costs 9.6-fold, further assuming two spray rounds are necessary for carbamates, given their shorter residual action. Additional, noninsecticide costs associated with going from one to two rounds annually for carbamates are detailed in the second and fourth scenarios.

Table 2 2008–2010 Average indoor residual spraying program expenses – President's Malaria Initiative

Cost category	Expenditures (US$ millions)						
	Ethiopia	Mozambique	Ghana	Angola	Mali	Malawi	Liberia
Spray operations	2.09	3.44	1.61	1.75	1.36	0.66	0.63
Insecticide	0.55	1.42	0.32	0.31	0.16	0.14	0.11
Spray equipment	0.19	0.06	0.08	0.02	0.04	0.01	0.02
PPE	0.12	0.14	0.08	0.11	0.09	0.01	0.03
Shipping	0.14	0.03	0.06	0.07	0.06	0.03	0.07
Local labor	0.15	0.38	0.37	0.40	0.26	0.07	0.10
Admin-local	0.12	0.67	0.55	0.42	0.56	0.21	0.14
STTA and US costs	0.21	0.22	0.10	0.17	0.08	0.09	0.08
US/Nairobi labor	0.19	0.70	0.15	0.38	0.40	0.21	0.33
Total	3.75	7.07	3.32	3.64	3.01	0.93	0.99

Source: USAID.
Abbreviations: PPE, personal protective equipment; STTA, short-term technical assistance.

Table 3 2008–2010 Average indoor residual spraying cost per structure and per person

	Ethiopia	Mozambique	Ghana	Angola	Mali	Malawi	Liberia
Structures sprayed	474,367	534,136	294,012	124,879	120,611	49,768	34,370
People protected	1,534,359	2,222,091	719,899	607,241	452,839	203,097	291,843
Cost per structure	$7.91	$13.23	$11.29	$29.12	$24.93	$18.69	$28.71
Cost per person protected	$2.45	$3.18	$4.61	$5.99	$6.64	$6.87	$5.07

Source: USAID.

We include seven countries (Ethiopia, Mozambique, Ghana, Angola, Mali, Malawi, and Liberia) in the analysis. On average 1.6 million houses were sprayed annually in these seven countries between 2008 and 2010, protecting an average of six million people annually. Although the data are available, we excluded Rwanda, Madagascar, and Senegal from our analysis; anomalies in the number of spray rounds and insecticides used resulted in difficulties running comparable cost and IRS coverage scenarios.

Projected changes to IRS coverage due to increases in insecticide costs are achieved by calculating a new cost per-structure sprayed. We then calculate a structure coverage rate by dividing the overall budget amount by the per-structure amount already contained in the original data. Population coverage is calculated by multiplying the average number of residents per-structure in the original data by the revised number of structures.

In scenario 1, IRS programs in the four countries using pyrethroids or DDT switch to a long-lasting organophosphate. We assume only one spray round per year, and include the up-front cost of all spray equipment and protective clothing captured in the original program data.

In scenario 2, IRS programs in the four countries substitute a carbamate that has a shorter residual life than the pyrethroid it replaces, therefore requiring an additional spray round during the year. The cost of the insecticide increases 9.6-fold, and costs such as local labor and spray operations are assumed to increase by 80%, due to the additional spray round. (These additional costs are not simply doubled, as we assume some efficiency gains with the second spray round). This scenario also includes the up-front cost of all spray equipment and protective clothing, but we assume that these can be reused for the second spray round.

Scenarios 3 and 4 are based on the same assumptions as scenarios 1 and 2, respectively; however, the baseline cost data are based on the latest available single year of data, which is 2010 for all countries, with the exception of Malawi, for which 2009 data are the last available.

The four scenario outcomes in terms of increased per-house protection costs are found in Table 4, and the resulting number of people in those seven sample countries who would not be protected under these IRS programs due to increasing costs and decreasing coverage are presented in Table 5.

Each of the scenarios above represents a full (100%), abrupt replacement of pyrethroids or DDT by either organophosphates or carbamates. Consensus does not exist on whether pyrethroids should be replaced simultaneously or on a more geographically limited basis and once resistance to pyrethroids actually appears. Some programs may elect to replace pyrethroids on an as-needed basis for reasons of cost and safety. Others may preemptively switch, in part or in whole, in order to stay ahead of the relatively rapid growth of pyrethroid resistance (Personal communication USAID). An approximate figure for increased program costs for partial replacement of pyrethroids (anything below 100%) can be calculated easily using the same data. However, additional or new costs associated with switching insecticides, procuring and deploying two different products, changing safety and storage protocols, and training must be considered as well.

In all scenarios involving a switch from pyrethroids to organophosphates or carbamates, overall costs to IRS programs will increase, sometimes dramatically, as the percentage of total IRS program cost of insecticides jumps from the current levels of 5%–20% up to 27%–74%. Due to the extent of pyrethroid resistance and the widespread reliance on pyrethroids in malaria control, incremental cost increases resulting from necessary insecticides replacement would seriously limit IRS operations and reduce the number of houses that can be sprayed, assuming the overall budgets for IRS specifically or malaria control broadly are not greatly increased.

As illustrated in Table 5, for the seven countries in question, based on our scenarios we find that the number of people protected by IRS could fall by as much as 46%, representing millions of people annually. The implications for increased costs and reduced coverage are most acute for smaller programs that do not have the economies of scale of larger programs and when the IRS program is forced to conduct additional (more than one) spray rounds each year, using more expensive non pyrethroid insecticides.

These illustrative scenarios include only seven of the 15 PMI focus countries and a fraction of all malaria-endemic

Table 4 Scenarios based on 2008–2010 average data (scenarios 1 and 2) and 2010 data (scenarios 3 and 4) – per-structure spray costs before (A) and after (B) insecticide price increases

Scenario	Ethiopia		Mozambique		Ghana		Angola		Mali		Malawi		Liberia		All-country average	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1 (2008–2010)	$7.91	$18.99	$13.23	$39.69	$11.29	$22.66	$29.12	$54.31	$24.93	$38.42	$28.04	$58.25	$43.06	$73.28	$22.51	$43.66
2 (2008–2010)	$11.68	$21.21	$18.96	$41.71	$16.68	$26.46	$42.89	$64.56	$35.63	$47.23	$39.61	$65.59	$59.82	$85.81	$32.18	$50.37
3 (2010)	$6.86	$21.09	$13.18	$38.57	$11.75	$19.92	$33.64	$55.72	$22.63	$33.63	$32.20	$56.27	$41.16	$72.19	$23.06	$42.48
4 (2010)	$11.34	$20.87	$19.24	$41.07	$17.49	$24.52	$49.13	$68.12	$32.18	$41.64	$38.95	$59.65	$58.20	$84.89	$32.36	$48.87

countries that conduct insecticide-based malaria prevention. The number of people affected by the higher insecticide prices is likely to be far greater when considering countries in southern Africa that have more extensive IRS programs than some of the countries examined in these scenarios, including Zimbabwe, Zambia, South Africa, and Namibia. Furthermore, many countries that conduct IRS have smaller budgets for the programs than do the PMI's focus countries we have analyzed, and the cost increases are likely to have more dramatic implications for access to prevention.

Policy proposals

A parallel scenario of increased cost and reduced access due to the growth of resistance emerged for malaria treatment during the late 1990s and early 2000s (and is still ongoing), where countries were compelled to adopt new ACTs that were many times more expensive than the treatments they replaced. The cost of the new, expensive treatments would have made malaria control programs unsustainable, were it not for private sector and public sector efforts. A similar but perhaps more dramatic situation arose in the early 2000s in HIV/AIDS treatment programs, where the high price of innovative antiretroviral drugs compelled stakeholders to pursue policies or programs that reduced costs and increased access.

As with malaria treatments, the lack of a sufficiently stable and lucrative market to drive the necessary research, development, and competition in essential public-health insecticides will ultimately require a more activist approach by stakeholders. Because of the lengthy and complex process of developing and marketing a new public-health insecticide, malaria control programs are very likely to assume increasing costs and decreasing effectiveness due to resistance, even with an immediate increase in public-health insecticide research and development funding.

To address these threats to continued coverage, in the near- to medium-term policymakers and stakeholders can consider several "no-cost" or "low-cost" options used already for other essential public-health technologies – and in some cases proven successful – to decrease cost and increase access to health interventions. While all four proposals we outline below can be adopted immediately, they do not represent a long-term strategy. Three do not appear to advance the development of public-health-specific compounds or otherwise decrease the reliance on agricultural use products as the main vehicle for development of public-health insecticides. Only one seeks to tap market forces as a "pull mechanism" for new public-health insecticide development; the other three rely on changes to the legal or regulatory frameworks

Table 5 Number of people lacking coverage following insecticide price increases, increased spray frequency (percentage change) – scenarios based on 2008–2010 average data (2008 & 2009 Malawi) (scenarios 1 and 2) and 2010 data (2009 Malawi) (scenarios 3 and 4)

Scenario	Ethiopia	Mozambique	Ghana	Angola	Mali	Malawi	Liberia	Total
Average 2008–2010 coverage	1,534,359	2,222,091	719,899	607,241	452,839	203,097	291,843	6,031,369
1 (2008–2010)	888,621 (–42)	1,325,868 (–40)	363,457 (–50)	283,584 (–53)	158,057 (–65)	103,672 (–49)	123,213 (–58)	3,246,472 (–46)
2 (2008–2010)	956,259 (–38)	1,369,424 (–38)	414,584 (–42)	334,960 (–45)	213,058 (–53)	114,805 (–43)	147,831 (–49)	3,550,920 (–41)
2010 coverage	2,064,389	2,945,721	849,620	649,842	440,815	299,744	420,537	7,670,668
3 (2010)	1,390,582 (–33)	1,931,570 (–34)	343,840 (–60)	256,165 (–61)	141,069 (–68)	154,725 (–48)	180,700 (–57)	4,398,651 (–43)
4 (2010)	1,425,078 (–31)	1,993,307 (–32)	438,666 (–48)	327,804 (–50)	198,756 (–55)	162,941 (–46)	216,582 (–49)	4,763,136 (–38)

to decrease costs and increase access to alternative but existing insecticides.

Priority review voucher (PRV)

Based on a concept by Ridley, Grabowski, and Moe,[14] in 2007 the US Government created a mechanism by which a pharmaceutical company that gains US Food and Drug Administration (FDA) approval for a new molecular entity "for which there is no significant market in developed nations and that disproportionally affects poor and marginalized populations" is granted a tradable voucher for a priority review by FDA of another drug of its choice.[15] In this case, the voucher granted for the approval of the drug for the developing world would provide a decreased time to market for a highly-profitable drug for the rich world, thus providing a clear financial incentive for the development of the former. It is perhaps too early to assess the effectiveness of the PRV for drug development; however, the concept is valid and deserves serious consideration to address the urgent need for new public health insecticides. A similar mechanism that would use the US Government's regulatory authority to overcome limited incentives for development of public-health insecticides for the poor could be constructed using the US Environmental Protection Agency's (EPA) and US Department of Agriculture's (USDA) regulatory authorities to entice the development of new public-health insecticides by granting a PRV for the nearly $4.4 billion annual market for insecticides in the United States.[7] In fact, a PRV in this case could be expanded and applied to any pesticide the government approves and regulates, including fungicides and herbicides, thus leveraging the $12.5 billion combined annual market in the United States.

No-profit pricing and demand forecasting

The advent of ACTs was a significant breakthrough in the battle against widespread malaria treatment resistance, where failure rates in some areas in Africa reached 50%. Swiss drug manufacturer Novartis marketed the first fixed-dose combination ACT, Coartem® (artemether-lumefantrine), which it developed in the 1990s in collaboration with Chinese researchers. To increase access to the drug, Novartis and the WHO entered into a partnership whereby Novartis offered the drug to public clinics at a "no-profit" or "no-loss" price per dose, and the WHO and affiliates provided demand forecasts.[16] Likewise, Sanofi adopted a "no profit-no loss" pricing model for its fixed-dose combination ACT, which it developed in partnership with the Drugs for Neglected Diseases Initiative. While the Novartis–WHO program was not without early complications, the combination of "no-profit" or "no-loss" pricing and clear demand forecasts now provide benefits to the companies and to public-health alike. Both Novartis and Sanofi have greatly increased their production of ACTs to over 100 million treatment courses per year[17] and surely have sold far more of their product at a more predictable price than they would have with normal, commercial marketing.

A similarly-constructed program among public-health insecticide producers and the WHO (or another viable partner), where producers offered their products for public-health at "no-loss" or "no-profit" prices in exchange for demand forecasts, could provide lower replacement costs and valuable market stability and predictability for both the producer and for malaria control programs alike. Similar to ACT manufacturers' benefits from such programs, the benefits of high volume and demand and market predictability should be appealing to public-health insecticide producers, even if they are making little or no profit already on new products, and manufacturing costs still result in a higher-priced product than what they replace.

Forgoing market exclusivity and certain patent protections

Perhaps the most significant factors in the decrease in the cost of ACTs were the decisions by Novartis and Sanofi to effectively forgo patent protections and market exclusivity for their fixed-dose treatments. The result has been a proliferation of inexpensive copies of their original drugs completing WHO's prequalification process and becoming available for purchase by country malaria control programs, including those funded by donors. This proliferation of WHO prequalified generic versions has had a significant, positive effect on the availability and price of fixed-dosed treatments.

A similar, positive effect on availability and pricing for public-health insecticides could be realized with generic, WHO-approved versions of what are now patented, market-exclusive products. Such a model would require the WHO to establish a robust and transparent approval process, presumably within WHO's Pesticide Evaluation Scheme, which has limited capacity. Also, public-health insecticide producers would have to agree to forego intellectual property protections on their innovative products in a manner similar to that of Novartis and Sanofi, even though very little (if any) government or activist pressure exists on them for aggressive measures to improve access.

Because most public-health insecticides are modified forms of original agricultural-use products, such agreements would require stakeholder guarantees and protections against uses of the products outside of malaria-endemic country public-health applications. Ideally, and in order to make them universal in nature, relevant United Nations agencies such as the WHO and the Food and Agriculture Organization would be a party to such agreements.

Such arrangements could have additional benefits for producers and for public-health. WHO-approved, inexpensive, generic versions could significantly limit the appeal of substandard copies or any unregulated insecticides by reducing or even eliminating a perceived cost-advantage in the malaria-endemic countries, where substandard copies and counterfeit versions of patented public-health insecticides are already a problem.[18] Also, these arrangements could obviate a perceived need for public-health emergency-based compulsory licenses of the insecticides. For producers and endemic countries alike, structured, universal agreements should be preferable to the prospect of country-by-country compulsory licensing processes and agreements.

A US Government program for generic public-health insecticides in foreign assistance

In order to reduce high treatment costs and ensure drug quality in its overseas HIV/AIDS programs, in 2004 the US Government established a policy to allow its HIV/AIDS country programs to buy copies of patented versions of antiretroviral treatments, so long as the products completed an FDA evaluation process adapted for this purpose and were not sold in the United States. The drug would be given "tentative approval" by the FDA, allowing it to be marketed in the United States only once the patent-holder's protections expired, but purchased immediately for use in foreign assistance.[19] (Previously, the US Government purchased only antiretroviral drugs approved by the FDA for use in the United States, in effect limiting the program to branded drugs manufactured by rich world pharmaceutical companies – an expensive and politically unpopular position.) The program has been highly successful in increasing the number of available treatments, significantly reducing treatment costs, and providing the country programs with a universally-accepted standard of quality and effectiveness of the drugs.[20] To date, the FDA has approved more than 140 drugs for this purpose, significantly expanding the competitive tender options for country programs.[19]

The application of such a policy to public-health insecticides could provide similar cost-benefits to malaria programs by providing multiple, inexpensive, generic versions of essential public-health insecticides of known quality and efficacy. In this case, EPA and USDA would establish a similar "tentative approval" process for generic versions of patented public-health insecticides. Although purchase by the US Government for malaria control could itself be an incentive, to strengthen the appeal of the program, policymakers could link government approval of the public-health insecticide to the agricultural-use version of the compound, providing generic manufacturers with potentially lucrative US market access once the originator's exclusivity expires.

Conclusion

Insecticide resistance remains a threat to global malaria control programs through decreasing effectiveness and significant potential cost-increases resulting from high replacement costs for new insecticides. Millions of people depend on these insecticides and malaria control programs for life and health, especially in Africa. The limited investment by stakeholders in the search for new public-health insecticides in recent decades has left malaria control programs compromised in their ability to effectively manage the problem and represents a poor handling of risk by stakeholders. While alternative insecticides are available, short of a significant increase in spending on malaria prevention, their higher cost would compel programs to limit malaria control coverage, leading to increased mortality and morbidity. Policymakers and other stakeholders should consider a range of different options to stimulate the search for new public-health insecticides and should consider adoption of existing policies from other, successful efforts to secure reduced prices for and increase access to essential public-health insecticides.

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Appendix

Summary of scenarios

Scenario 1 – Insecticide replaced with OP, all other costs remain the same

Scenario 2 – Insecticide replaced with Carbamates, 2 spray rounds, operation costs and labor costs increase by 80%

Scenario 3 – Insecticide replaced with OP, spray equipment cost reduced by 80%, PPE cost reduced by 60%, local labor cost reduced by 20%

Scenario 4 – Insecticide replaced with Carbamates, 2 spray rounds, equipment cost reduced by 60%, PPE cost reduced by 40%, operation cost, labor cost increased by 80%

	Ethiopia	Mozambique	Ghana	Angola	Mali	Malawi	Liberia	Overall	Overall % change
Houses protected									
Ave No houses protected 2008–2010	474,367	534,136	294,012	124,879	120,611	49,768	34,370	1,632,143	
Scenario 1	197,675	178,057	146,483	66,964	78,261	23,958	20,195		
Scenario 2	176,970	169,404	125,472	56,334	63,659	21,275	17,247		
People without protection									
Ave people covered 2008–2010	1,534,359	2,222,091	719,899	607,241	452,839	203,097	291,843	6,031,369	
Scenario 1	888,621	1,325,868	363,457	283,584	158,057	103,672	123,213	3,246,472	–46%
Scenario 2	956,259	1,369,424	414,584	334,960	213,058	114,805	147,831	3,550,920	–41%
Percentage change in coverage									
Scenario 1	–42%	–40%	–50%	–53%	–65%	–49%	–58%	–46%	
Scenario 2	–38%	–38%	–42%	–45%	–53%	–43%	–49%	–41%	
Cost per house sprayed									
Scenario 1	$18.99	$39.69	$22.66	$54.31	$38.42	$58.25	$73.28	$43.66	
Scenario 2	$21.21	$41.71	$26.46	$64.56	$47.23	$65.59	$85.81		
Cost of insecticide per house sprayed									
Scenario 1	$12.18	$29.10	$12.51	$27.71	$14.84	$33.23	$33.25		
Scenario 2	$10.63	$25.40	$10.92	$24.18	$12.95	$29.00	$29.01		
% cost accounted for by insecticide									
Scenario 1	64.16%	73.33%	55.20%	51.02%	38.62%	57.05%	45.37%		
Scenario 2	50.13%	60.89%	41.26%	37.46%	27.42%	44.21%	33.81%		

Summary – Based on last year of spray coverage (2010 or 2009 – Malawi)

Scenario 1 – Insecticide replaced with OP, all other costs remain the same

Scenario 2 – Insecticide replaced with Carbamates, 2 spray rounds, operation costs and labor costs increase by 80%

Scenario 3 – Insecticide replaced with OP, spray equipment cost reduced by 80%, PPE cost reduced by 60%, local labor cost reduced by 20%

Scenario 4 – Insecticide replaced with Carbamates, 2 spray rounds, equipment cost reduced by 60%, PPE cost reduced by 40%, operation cost and labor cost increased by 80%

	Ethiopia	Mozambique	Ghana	Angola	Mali	Malawi	Liberia	Overall	Overall % change
Houses protected									
Ave No houses protected last year	646,870	618,290	342,876	135,856	127,273	74,772	48,347		
Scenario 1	210,565	211,281	202,312	82,016	85,642	36,255	27,567		
Scenario 2	199,785	198,420	164,381	67,091	69,160	34,201	23,443		
People without protection									
Ave people covered last year	2,064,389	2,945,721	849,620	649,842	440,815	299,744	420,537	7,670,668	
Scenario 1	1,390,582	1,931,570	343,840	256,165	141,069	154,725	180,700	4,398,651	–42.66%
Scenario 2	1,425,078	1,993,307	438,666	327,804	198,756	162,941	216,582	4,763,136	–37.90%
Percentage change in coverage									
Scenario 1	–32.64%	–34.43%	–59.53%	–60.58%	–68.00%	–48.38%	–57.03%		
Scenario 2	–30.97%	–32.33%	–48.37%	–49.56%	–54.91%	–45.64%	–48.50%		
Cost per house sprayed									
Scenario 1	$21.09	$38.57	$19.92	$55.72	$33.63	$56.27	$72.19	$42.48	
Scenario 2	$22.22	$41.07	$24.52	$68.12	$41.64	$59.65	$84.89	$48.87	
Cost of insecticide per house sprayed									
Scenario 1	$15.64	$27.93	$8.98	$24.29	$12.10	$26.48	$34.13		
Scenario 2	$13.65	$24.38	$7.84	$21.20	$10.56	$23.11	$29.78		
% cost accounted for by insecticide									
Scenario 1	74.19%	72.41%	45.10%	43.59%	35.98%	47.06%	47.28%		
Scenario 2	61.44%	59.35%	31.98%	31.12%	25.36%	38.74%	35.09%		

Ethiopia

Ethiopia	DDT 2008	DDT 2009	Pyrethroids 2010	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	1.95	1.98	2.34	6.27	2.09	
Insecticide	0.34	0.38	0.92	1.64	0.55	14.56%
Spray equipment	0.12	0.17	0.28	0.57	0.19	
PPE	0.15	0.12	0.09	0.36	0.12	
Shipping	0.23	0.03	0.15	0.41	0.14	
Local labor	0.08	0.17	0.19	0.44	0.15	
Admin-local	0.07	0.12	0.18	0.37	0.12	
STTA and US Costs	0.2	0.36	0.07	0.63	0.21	
US/Nairobi labor	0.19	0.16	0.22	0.57	0.19	
Total	3.33	3.49	4.44	11.26	3.75	
	2008	**2009**	**2010**			
Houses sprayed	316,829	459,402	646,870	1,423,101	474,367	
Cost per structure	$10.51	$7.60	$6.86	$7.91	$7.91	
People protected	1,000,526	1,538,163	2,064,389	4,603,078	1,534,359	
Cost per person protected	$3.33	$2.27	$2.15	$2.45	$2.45	
People per house	3.20	3.40	3.20	3.27	3.27	
Sachets per structure	0.37	0.43	0.46	0.42	0.42	
Cost of insecticides	$340,000	$380,000	$920,000	$1,640,000	$546,666.67	
Total number of sachets	117,227	197,543	297,560	612,330	204,110	
Cost per sachet	$2.90	$1.92	$3.09	2.68	$2.64	
Insecticide cost per person protected	$0.34	$0.25	$0.45	0.36	$0.34	
Insecticide cost per house	$1.07	$0.83	$1.42	$1.15	$1.11	

Scenario 1 Changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 3 years		Based on 2010 cost data only	
Average number of structure sprayed 2008–2010	474,367	Structures sprayed 2010	646,870
People protected	1,534,359	People protected	2,064,389
People per house	3.27	People per house	3.20
Cost per house	$7.91	Cost per house	$6.86
Insecticide cost per house sprayed	$1.11	Insecticide cost per house sprayed	$1.42
Cost of insecticide per house at new prices	$12.18	Cost of insecticide per house at new prices	$15.64
Cost per house at new prices	$18.99	Cost per house at new prices	$21.09
Number of houses sprayed at new prices	197,675	Number of houses sprayed at new prices	210,565
Number of people protected at new prices	645,738	Number of people protected at new prices	673,807
Number of people without protection	**888,621**	**Number of people without protection**	**1,390,582**

Scenario 2 Changing from 1 spray round with DDT to 2 spray rounds with Carbamates

Costs		Based on 2010 cost data only	
Spray operations	3.76	Spray operations	4.21
Insecticide	0.55	Insecticide	0.92
Spray equipment	0.19	Spray equipment	0.28
PPE	0.12	PPE	0.09
Shipping	0.14	Shipping	0.15
Local labor	0.26	Local labor	0.34
Admin-local	0.12	Admin-local	0.18
STTA and US Costs	0.21	STTA and US Costs	0.07
US/Nairobi labor	0.19	US/Nairobi labor	0.22
Total	5.54	**Total**	6.46
Average number of structure sprayed 2008–2010	474,367	Structures sprayed 2010	646,870
People protected	1,534,359	People protected	2,064,389
People per house	3.27	People per house	3.20
Cost per house	$11.68	Cost per house	$9.99
Insecticide cost per house sprayed	$1.11	Insecticide cost per house sprayed	$1.42
Cost of insecticide per house at new prices	$10.63	Cost of insecticide per house at new prices	$13.65
Cost per house at new prices	$21.21	Cost per house at new prices	$22.22

(*Continued*)

Scenario 2 (*Continued*)

Number of houses sprayed at new prices	176,970	Number of houses sprayed at new prices	199,785
Number of people protected at new prices	578,100	Number of people protected at new prices	639,311
Number of people without protection	**956,259**	**Number of people without protection**	**1,425,078**
Summary	**People without protection**		**Based on 2010 data only**
1. DDT/PYR to OP	888,621		1,390,582
2. DDT/PYR to Carbamates, 2 rounds	956,259		1,425,078

Mozambique

Mozambique	DDT/Pyrethroid 2008	DDT/Pyrethroid 2009	DDT/Pyrethroid 2010	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	3.45	2.73	4.15	10.33	3.44	
Insecticide	1.00	1.70	1.57	4.27	1.42	20.14%
Spray equipment	0.05	0.05	0.08	0.18	0.06	
PPE	0.07	0.16	0.19	0.42	0.14	
Shipping	0.09	0.00	0.00	0.09	0.03	
Local labor	0.38	0.24	0.53	1.15	0.38	
Admin-local	0.75	0.60	0.65	2.00	0.67	
STTA and US Costs	0.29	0.17	0.19	0.65	0.22	
US/Nairobi labor	0.37	0.95	0.79	2.11	0.70	
Total	6.45	6.60	8.15	21.20	7.07	
	2008	**2009**	**2010**			
Houses sprayed	412,923	571,194	618,290	1,602,407	534,136	
Cost per structure	$15.62	$11.55	$13.18	$13.23	$13.23	
People protected	1,457,142	2,263,409	2,945,721	6,666,272	2,222,091	
Cost per person protected	$4.43	$2.92	$2.77	$3.18	$3.18	
People per house	6.30	4.00	4.80	5.03	5.03	
Sachets per structure	0.66	0.72	0.84	0.74	0.74	
Cost of insecticides	$1,000,000	$1,700,000	$1,570,000	$4,270,000	$1,423,333	
Total number of sachets	272,529	411,260	519,364	1,203,152	401,051	
Cost per sachet	$3.67	$4.13	$3.02	3.55	$3.61	
Insecticide cost per person protected	$0.69	$0.75	$0.53	0.64	$0.66	
Insecticide cost per house	$2.42	$2.98	$2.54	$2.66	$2.65	

Scenario 1 Changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 3 years		Based on 2010 cost data only	
Average number of structure sprayed 2008–2010	534,136	Structures sprayed 2010	618,290
People protected	2,222,091	People protected	2,945,721
People per house	5.03	People per house	4.80
Cost per house	$13.23	Cost per house	$13.18
Insecticide cost per house sprayed	$2.65	Insecticide cost per house sprayed	$2.54
Cost of insecticide per house at new prices	$29.10	Cost of insecticide per house at new prices	$27.93
Cost per house at new prices	$39.69	Cost per house at new prices	$38.57
Number of houses sprayed at new prices	178,057	Number of houses sprayed at new prices	211,281
Number of people protected at new prices	896,222	Number of people protected at new prices	1,014,151
Number of people without protection	1,325,868	Number of people without protection	1,931,570

Scenario 2 Changing from 1 spray round with DDT to 2 spray rounds with Carbamates

Costs		Based on 2010 cost data only	
Spray operations	6.20	Spray operations	7.47
Insecticide	1.42	Insecticide	1.57
Spray equipment	0.06	Spray equipment	0.08
PPE	0.14	PPE	0.19
Shipping	0.03	Shipping	0.00
Local labor	0.69	Local labor	0.95
Admin-local	0.67	Admin-local	0.65

(*Continued*)

Scenario 2 (*Continued*)

STTA and US Costs	0.22	STTA and US Costs	0.19
US/Nairobi labor	0.70	US/Nairobi labor	0.79
Total	10.13	**Total**	11.89
Average number of structure sprayed 2008–2010	534,136	Structures sprayed 2010	618,290
People protected	2,222,091	People protected	2,945,721
People per house	5.03	People per house	4.80
Cost per house	$18.96	Cost per house	$19.24
Insecticide cost per house sprayed	$2.65	Insecticide cost per house sprayed	$2.54
Cost of insecticide per house at new prices	$25.40	Cost of insecticide per house at new prices	$24.38
Cost per house at new prices	$41.71	Cost per house at new prices	$41.07
Number of houses sprayed at new prices	169,404	Number of houses sprayed at new prices	198,420
Number of people protected at new prices	852,666	Number of people protected at new prices	952,414
Number of people without protection	**1,369,424**	**Number of people without protection**	**1,993,307**
Summary	**People without protection**		**Based on 2010 data only**
1. DDT/PYR to OP	1,325,868		1,931,570
2. DDT/PYR to Carbamates, 2 rounds	1,369,424		1,993,307

Ghana

Ghana	Pyrethroid 2008	Pyrethroid 2009	Pyrethroids 2010	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	1.59	1.34	1.9	4.83	1.61	
Insecticide	0.41	0.28	0.28	0.97	0.32	9.74%
Spray equipment	0.1	0.06	0.07	0.23	0.08	
PPE	0.13	0.04	0.06	0.23	0.08	
Shipping	0.08	0.1	0	0.18	0.06	
Local labor	0.27	0.28	0.56	1.11	0.37	
Admin-local	0.35	0.42	0.88	1.65	0.55	
STTA and US Costs	0.14	0.09	0.08	0.31	0.10	
US/Nairobi labor	0.17	0.08	0.2	0.45	0.15	
Total	3.24	2.69	4.03	9.96	3.32	
	2008	**2009**	**2010**			
Houses sprayed	254,305	284,856	342,876	882,037	294,012	
Cost per structure	$12.74	$9.44	$11.75	$11.29	$11.29	
People protected	601,973	708,103	849,620	2,159,696	719,899	
Cost per person protected	$5.38	$3.80	$4.74	$4.61	$4.61	
People per house	2.40	2.40	2.50	2.43	2.43	
Sachets per structure	0.27	0.25	0.21	0.24	0.24	
Cost of insecticides	$410,000	$280,000	$280,000	$970,000	$323,333	
Total number of sachets	68,662	71,214	72,004	211,880	70,627	
Cost per sachet	$5.97	$3.93	$3.89	4.58	$4.60	
Insecticide cost per person protected	$0.68	$0.40	$0.33	0.45	$0.47	
Insecticide cost per house	$1.61	$0.98	$0.82	$1.10	$1.14	

Scenario 1 Changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 3 years		Based on 2010 cost data only	
Average number of structure sprayed 2008–2010	294,012	Structures sprayed 2010	342,876
People protected	719,899	People protected	849,620
People per house	2.43	People per house	2.50
Cost per house	$11.29	Cost per house	$11.75
Insecticide cost per house sprayed	$1.14	Insecticide cost per house sprayed	$0.82
Cost of insecticide per house at new prices	$12.51	Cost of insecticide per house at new prices	$8.98
Cost per house at new prices	$22.66	Cost per house at new prices	$19.92
Number of houses sprayed at new prices	146,483	Number of houses sprayed at new prices	202,312
Number of people protected at new prices	356,442	Number of people protected at new prices	505,780
Number of people without protection	363,457	Number of people without protection	343,840

Scenario 2 Changing from 1 spray round with DDT to 2 spray rounds with Carbamates

Costs		Based on 2010 cost data only	
Spray operations	2.90	Spray operations	3.42
Insecticide	0.32	Insecticide	0.28
Spray equipment	0.08	Spray equipment	0.07
PPE	0.08	PPE	0.06
Shipping	0.06	Shipping	0.00
Local labor	0.67	Local labor	1.01
Admin-local	0.55	Admin-local	0.88
STTA and US Costs	0.10	STTA and US Costs	0.08
US/Nairobi labor	0.15	US/Nairobi labor	0.20
Total	4.90	**Total**	6.00
Average number of structure sprayed 2008–2010	294,012	Structures sprayed 2010	342,876
People protected	719,899	People protected	849,620
People per house	2.43	People per house	2.50
Cost per house	$16.68	Cost per house	$17.49
Insecticide cost per house sprayed	$1.14	Insecticide cost per house sprayed	$0.82
Cost of insecticide per house at new prices	$10.92	Cost of insecticide per house at new prices	$7.84
Cost per house at new prices	$26.46	Cost per house at new prices	$24.52
Number of houses sprayed at new prices	125,472	Number of houses sprayed at new prices	164,381
Number of people protected at new prices	305,315	Number of people protected at new prices	410,954
Number of people without protection	**414,584**	**Number of people without protection**	**438,666**
Summary	**People without protection**		**Based on 2010 data only**
1. PYR to OP	363,457		343,840
2. PYR to Carbamates, 2 rounds	414,584		438,666

Angola

Angola	Pyrethroids 2008	Pyrethroids 2009	Pyrethroids 2010	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	1.33	1.82	2.09	5.24	1.75	
Insecticide	0.37	0.27	0.3	0.94	0.31	8.62%
Spray equipment	0.02	0.02	0.03	0.07	0.02	
PPE	0.06	0.12	0.15	0.33	0.11	
Shipping	0.13	0.09	0	0.22	0.07	
Local labor	0.32	0.35	0.54	1.21	0.40	
Admin-local	0.52	0.47	0.26	1.25	0.42	
STTA and US Costs	0.03	0.19	0.28	0.5	0.17	
US/Nairobi labor	0.11	0.12	0.92	1.15	0.38	
Total	2.89	3.45	4.57	10.91	3.64	
	2008	**2009**	**2010**			
Houses sprayed	136,051	102,731	135,856	374,638	124,879	
Cost per structure	$21.24	$33.58	$33.64	$29.12	$29.12	
People protected	685,908	485,974	649,842	1,821,724	607,241	
Cost per person protected	$4.21	$7.10	$7.03	$5.99	$5.99	
People per house	5.00	4.70	4.80	4.83	4.83	
Sachets per structure	0.47	0.53	0.56	0.52	0.52	
Cost of insecticides	$370,000	$270,000	$300,000	$940,000	$313,333.33	
Total number of sachets	63,944	54,447	76,079	194,471	64,824	
Cost per sachet	$5.79	$4.96	$3.94	4.83	$4.90	
Insecticide cost per person protected	$0.54	$0.56	$0.46	0.52	$0.52	
Insecticide cost per house	$2.72	$2.63	$2.21	$2.51	$2.52	

Scenario 1 Changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 3 years		Based on 2010 cost data only	
Average number of structure sprayed 2008–2010	124,879	Structures sprayed 2010	135,856
People protected	607,241	People protected	649,842
People per house	4.83	People per house	4.80
Cost per house	$29.12	Cost per house	$33.64
Insecticide cost per house sprayed	$2.52	Insecticide cost per house sprayed	$2.21
Cost of insecticide per house at new prices	$27.71	Cost of insecticide per house at new prices	$24.29
Cost per house at new prices	$54.31	Cost per house at new prices	$55.72
Number of houses sprayed at new prices	66,964	Number of houses sprayed at new prices	82,016
Number of people protected at new prices	323,657	Number of people protected at new prices	393,677
Number of people without protection	283,584	Number of people without protection	256,165

Scenario 2 Changing from 1 spray round with PYR to 2 spray rounds with Carbamates

Costs		Based on 2010 cost data only	
Spray operations	3.14	Spray operations	3.76
Insecticide	0.31	Insecticide	0.30
Spray equipment	0.02	Spray equipment	0.03
PPE	0.11	PPE	0.15
Shipping	0.07	Shipping	0.00
Local labor	0.73	Local labor	0.97
Admin-local	0.42	Admin-local	0.26
STTA and US Costs	0.17	STTA and US Costs	0.28
US/Nairobi labor	0.38	US/Nairobi labor	0.92
Total	5.36	**Total**	6.67
Average number of structure sprayed 2008–2010	124,879	Structures sprayed 2010	135,856
People protected	607,241	People protected	649,842
People per house	4.83	People per house	4.80
Cost per house	$42.89	Cost per house	$49.13
Insecticide cost per house sprayed	$2.52	Insecticide cost per house sprayed	$2.21
Cost of insecticide per house at new prices	$24.18	Cost of insecticide per house at new prices	$21.20
Cost per house at new prices	$64.56	Cost per house at new prices	$68.12
Number of houses sprayed at new prices	56,334	Number of houses sprayed at new prices	67,091
Number of people protected at new prices	272,282	Number of people protected at new prices	322,038
Number of people without protection	**334,960**	**Number of people without protection**	**327,804**
Summary	**People without protection**		**Based on 2010 data only**
1. PYR to OP	283,584		256,165
2. PYR to Carbamates, 2 rounds	334,960		327,804

Mali

Mali	Pyrethroids 2008	Pyrethroids 2009	Pyrethroids 2010	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	1.08	1.71	1.28	4.07	1.36	
Insecticide	0.19	0.15	0.14	0.48	0.16	5.32%
Spray equipment	0.03	0.04	0.05	0.12	0.04	
PPE	0.04	0.1	0.12	0.26	0.09	
Shipping	0.15	0.04	0	0.19	0.06	
Local labor	0.29	0.24	0.24	0.77	0.26	
Admin-local	0.63	0.51	0.53	1.67	0.56	
STTA and US Costs	0.1	0.09	0.06	0.25	0.08	
US/Nairobi labor	0.41	0.34	0.46	1.21	0.40	
Total	2.92	3.22	2.88	9.02	3.01	
	2008	**2009**	**2010**			
Houses sprayed	107,638	126,922	127,273	361,833	120,611	
Cost per structure	$27.13	$25.37	$22.63	$24.93	$24.93	

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People protected	420,580	497,122	440,815	1,358,517	452,839
Cost per person protected	$6.94	$6.48	$6.53	$6.64	$6.64
People per house	3.90	3.90	3.50	3.77	3.77
Sachets per structure	0.27	0.19	0.35	0.27	0.27
Cost of insecticides	$190,000	$150,000	$140,000	$480,000	$160,000.00
Total number of sachets	29,062	24,115	44,546	97,723	32,574
Cost per sachet	$6.54	$6.22	$3.14	4.91	$5.30
Insecticide cost per person protected	$0.45	$0.30	$0.32	0.35	$0.36
Insecticide cost per house	$1.77	$1.18	$1.10	$1.33	$1.35

Scenario 1 Changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 3 years		**Based on 2010 cost data only**	
Average number of structure sprayed 2008–2010	120,611	Structures sprayed 2010	127,273
People protected	452,839	People protected	440,815
People per house	3.77	People per house	3.50
Cost per house	$24.93	Cost per house	$22.63
Insecticide cost per house sprayed	$1.35	Insecticide cost per house sprayed	$1.10
Cost of insecticide per house at new prices	$14.84	Cost of insecticide per house at new prices	$12.10
Cost per house at new prices	$38.42	Cost per house at new prices	$33.63
Number of houses sprayed at new prices	78,261	Number of houses sprayed at new prices	85,642
Number of people protected at new prices	294,782	Number of people protected at new prices	299,746
Number of people without protection	158,057	Number of people without protection	141,069

Scenario 2 Changing from 1 spray round with DDT to 2 spray rounds with Carbamates

Costs		**Based on 2010 cost data only**	
Spray operations	2.44	Spray operations	2.30
Insecticide	0.16	Insecticide	0.14
Spray equipment	0.04	Spray equipment	0.05
PPE	0.09	PPE	0.12
Shipping	0.06	Shipping	0.00
Local labor	0.46	Local labor	0.43
Admin-local	0.56	Admin-local	0.53
STTA and US Costs	0.08	STTA and US Costs	0.06
US/Nairobi labor	0.40	US/Nairobi labor	0.46
Total	4.30	**Total**	4.10
Average number of structure sprayed 2008–2010	120,611	Structures sprayed 2010	127,273
People protected	452,839	People protected	440,815
People per house	3.77	People per house	3.50
Cost per house	$35.63	Cost per house	$32.18
Insecticide cost per house sprayed	$1.35	Insecticide cost per house sprayed	$1.10
Cost of insecticide per house at new prices	$12.95	Cost of insecticide per house at new prices	$10.56
Cost per house at new prices	$47.23	Cost per house at new prices	$41.64
Number of houses sprayed at new prices	63,659	Number of houses sprayed at new prices	69,160
Number of people protected at new prices	239,781	Number of people protected at new prices	242,059
Number of people without protection	**213,058**	**Number of people without protection**	**198,756**
Summary	**People without protection**		**Based on 2010 data only**
1. PYR To OP	158,057		141,069
2. PYR To Carbamates, 2 Rounds	213,058		198,756

Malawi

Malawi	Pyrethroid 2008	Pyrethroid 2009	2010	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	0.31	1.00	0	1.31	0.66	
Insecticide	0.09	0.18	0	0.27	0.14	9.67%
Spray equipment	0.00	0.01	0	0.0105	0.01	
PPE	0.00	0.01	0	0.0105	0.01	
Shipping	0.02	0.03	0	0.05	0.03	
Local labor	0.04	0.09	0	0.13	0.07	
Admin-local	0.14	0.28	0	0.42	0.21	
STTA and US Costs	0.05	0.12	0	0.17	0.09	
US/Nairobi labor	0.10	0.32	0	0.42	0.21	
Total	0.75	2.04	0	2.791	1.40	
	2008	**2009**	**2010**			
Houses sprayed	24,764	74,772	0	99,536	49,768	
Cost per structure	$30.33	$27.28		$28.04	$28.04	
People protected	106,450	299,744	0	406,194	203,097	
Cost per person protected	$7.05	$6.81		$6.87	$6.87	
People per house	4.30	4.00	0	4.15	4.15	
Sachets per structure	0.57	0.56	0	0.57	0.57	
Cost of insecticides	$90,000	$180,000	0	$270,000	$135,000	
Total number of sachets	14,115	41,872	0	55,988	27,994	
Cost per sachet	$6.38	$4.30	0	4.82	$5.34	
Insecticide cost per person protected	$0.85	$0.60	0	0.66	$0.72	
Insecticide cost per house	$3.63	$2.41	0	$2.71	$3.02	

Scenario 1 Changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 3 years		Based on 2009 cost data only	
Average number of structure sprayed 2008–2010	49,768	Structures sprayed 2009	74,772
People protected	203,097	People protected	299,744
People per house	4.15	People per house	4.00
Cost per house	$28.04	Cost per house	$32.20
Insecticide cost per house sprayed	$3.02	Insecticide cost per house sprayed	$2.41
Cost of insecticide per house at new prices	$33.23	Cost of insecticide per house at new prices	$26.48
Cost per house at new prices	$58.25	Cost per house at new prices	$56.27
Number of houses sprayed at new prices	23,958	Number of houses sprayed at new prices	36,255
Number of people protected at new prices	99,425	Number of people protected at new prices	145,019
Number of people without protection	103,672	Number of people without protection	154,725

Scenario 2 Changing from 1 spray round with DDT to 2 spray rounds with Carbamates

Costs		Based on 2009 cost data only	
Spray operations	1.18	Spray operations	1.80
Insecticide	0.14	Insecticide	0.18
Spray equipment	0.01	Spray equipment	0.01
PPE	0.01	PPE	0.01
Shipping	0.03	Shipping	0.03
Local labor	0.12	Local labor	0.16
Admin-local	0.21	Admin-local	0.28
STTA and US Costs	0.09	STTA and US Costs	0.12
US/Nairobi labor	0.21	US/Nairobi labor	0.32
Total	1.97	**Total**	2.91
Average number of structure sprayed 2008–2010	49,768	Structures sprayed 2009	74,772
People protected	203,097	People protected	299,744
People per house	4.15	People per house	4.00
Cost per house	$39.61	Cost per house	$38.95

(*Continued*)

Scenario 2 (*Continued*)

Insecticide cost per house sprayed	$3.02	Insecticide cost per house sprayed	$2.41
Cost of insecticide per house at new prices	$29.00	Cost of insecticide per house at new prices	$23.11
Cost per house at new prices	$65.59	Cost per house at new prices	$59.65
Number of houses sprayed at new prices	21,275	Number of houses sprayed at new prices	34,201
Number of people protected at new prices	88,292	Number of people protected at new prices	136,803
Number of people without protection	**114,805**	**Number of people without protection**	**162,941**
Summary	**People without protection**		**Based on 2009 data only**
1. PYR to OP	103,672		154,725
2. PYR to Carbamates, 2 rounds	114,805		162,941

Liberia

Liberia	2009 Pyrethroid	2010 Pyrethroid	Overall costs	Average	% ave cost attributed to insecticides
Spray operations	0.35	0.90	1.25	0.63	
Insecticide	0.06	0.15	0.21	0.11	7.09%
Spray equipment	0.01	0.02	0.03	0.02	
PPE	0.01	0.05	0.06	0.03	
Shipping	0.05	0.08	0.13	0.07	
Local labor	0.06	0.13	0.19	0.10	
Admin-local	0.12	0.16	0.28	0.14	
STTA and US Costs	0.09	0.06	0.15	0.08	
US/Nairobi labor	0.22	0.44	0.66	0.33	
Total	0.97	1.99	2.96	1.48	
	2009	**2010**			
Houses sprayed	20,393	48,347	68,740	34,370	
Cost per structure	$47.57	$41.16	$43.06	$43.06	
People protected	163,149	420,537	583,686	291,843	
Cost per person protected	$5.95	$4.73	$5.07	$5.07	
People per house	8.00	8.70	8.35	8.35	
Sachets per structure	0.56	0.70	0.63	0.63	
Cost of insecticides	$60,000	$150,000	$210,000	$105,000	
Total number of sachets	11,420	33,843	45,263	22,631	
Cost per sachet	$5.25	$4.43	4.64	$4.84	
Insecticide cost per person protected	$0.37	$0.36	0.36	$0.36	
Insecticide cost per house	$2.94	$3.10	$3.05	$3.02	

Scenario 1 changing from 1 spray round of DDT/pyrethroid to 1 spray round with OP

Based on ave costs for 2 years		Based on 2010 cost data only	
Average number of structure sprayed 2008–2010	34,370	Structures sprayed 2010	48,347
People protected	291,843	People protected	420,537
People per house	8.35	People per house	8.70
Cost per house	$43.06	Cost per house	$41.16
Insecticide cost per house sprayed	$3.02	Insecticide cost per house sprayed	$3.10
Cost of insecticide per house at new prices	$33.25	Cost of insecticide per house at new prices	$34.13
Cost per house at new prices	$73.28	Cost per house at new prices	$72.19
Number of houses sprayed at new prices	20,195	Number of houses sprayed at new prices	27,567
Number of people protected at new prices	168,630	Number of people protected at new prices	239,837
Number of people without protection	123,213	Number of people without protection	180,700

Scenario 2 changing from 1 spray round with DDT to 2 spray rounds with Carbamates

Costs		Based on 2010 cost data only	
Spray operations	1.13	Spray operations	1.62
Insecticide	0.11	Insecticide	0.15
Spray equipment	0.02	Spray equipment	0.02
PPE	0.03	PPE	0.05
Shipping	0.07	Shipping	0.08

(*Continued*)

Scenario 2 (*Continued*)

Local labor	0.17	Local labor	0.23
Admin-local	0.14	Admin-local	0.16
STTA and US Costs	0.08	STTA and US Costs	0.06
US/Nairobi labor	0.33	US/Nairobi labor	0.44
Total	2.06	**Total**	2.81
Average number of structure sprayed 2008–2010	34,370	Structures sprayed 2010	48,347
People protected	291,843	People protected	420,537
People per house	8.35	People per house	8.70
Cost per house	$59.82	Cost per house	$58.20
Insecticide cost per house sprayed	$3.02	Insecticide cost per house sprayed	$3.10
Cost of insecticide per house at new prices	$29.01	Cost of insecticide per house at new prices	$29.78
Cost per house at new prices	$85.81	Cost per house at new prices	$84.89
Number of houses sprayed at new prices	17,247	Number of houses sprayed at new prices	23,443
Number of people protected at new prices	144,012	Number of people protected at new prices	203,955
Number of people without protection	**147,831**	**Number of people without protection**	**216,582**
Summary	**People without protection**		**Based on 2010 data only**
1. PYR to OP	123,213		180,700
2. PYR to carbamates, 2 rounds	147,831		216,582