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Designing Programme Implementation Strategies to Increase the Adoption and Use of Biosand Water Filters in Rural India

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ABSTRACT: Low-cost household water treatment systems are innovations designed to improve the quality of drinking water at the point of use. This study investigates how an NGO can design appropriate programme strategies in order to increase the adoption and sustained use of household sand filters in rural India. A system dynamics computer model was developed and used to assess 18 potential programme strategies for their effectiveness in increasing filter use at two and ten years into the future, under seven scenarios of how the external context may plausibly evolve. The results showed that the optimal choice of strategy is influenced by the macroeconomic situation, donor funding, presence of alternative options, and the evaluation time frame. The analysis also revealed some key programme management challenges, including the trade-off between optimising short- or long-term gains, and counter-intuitive results, such as higher subsidy fund allocation leading to fewer filter distribution, and technology advances leading to fewer sales. This study outlines how an NGO can choose effective strategies in consideration of complex system interactions. This study demonstrated that small NGOs can dramatically increase their programme outcomes without necessarily increasing operational budget.

KEYWORDS: Biosand water filter, household water treatment, innovation diffusion, project management, India

INTRODUCTION

Household water treatment and safe storage systems (HWTS) are innovations designed to improve the quality of drinking water at the point of use (Clasen, 2009). However, unless the target population widely and consistently practised HWTS over the long term, health and economic benefits may not be realised (Graf et al., 2010; Enger et al., 2012).

There are many complex and interrelated economic, social, technical and institutional issues influencing household adoption and use of HWTS (Meierhofer and Landolt, 2009). The first step of this study was to review constraints and structures that drive end use behaviour. The authors reviewed various diffusion theories (Bass, 1969; Brown, 1981; Utterback, 1996; Christensen, 1997; Miller and Garnsey, 2000; Rogers, 2003) and identified 100+ factors influencing the adoption and use of innovations. These factors could be roughly categorised into 5 themes – effective promotion and education, technology appropriateness and performance, supportive infrastructure and distribution networks, enabling policy and financial resources environment, and management capacity of the implementing organisations (Ngai, 2011). The authors also reviewed a number of social psychology theories such as the Theories of Reasoned Action and Planned Behaviour (Ajzen, 1991), Health Belief Theory (Murray-Johnson et al., 2001; Myers, 2005), Ideation model (Mason, 1997), SaniFOAM model

(Devine, 2009), and Stages of change model (Prochaska and DiClemente, 1982); as well as social marketing theories (Andreasen, 1995; Kotler et al., 2002; Heierli, 2008; Null et al., 2009). A number of major themes influencing the adoption behaviour of innovations, often similar to those from diffusion theories, were identified. Examples include individual's awareness that the technology exists, along with prevailing social norms, habits, extent of observable benefits, perceived threat, perceived barriers, skills to operate and maintain, affordability, and availability (Ngai, 2011). Agencies implementing HWTS should understand how these are connected at a systems level to improve programme management (Mowles et al., 2008).

To examine the interplay between these issues, a systems dynamics (SD) approach was used. A main advantage of SD modelling is that exhaustive real world experimentation is often resource-intensive or simply infeasible. SD is a virtual laboratory allowing systematic testing of various potential strategies under perfectly controlled settings (Sterman, 2000). SD's transparent, 'white-box' orientation allows the analyst to clarify the causes of problematic behaviour by tracing the model logic (Barlas, 1996). For example, Thompson and Duintjer-Tebbens (2008) used SD to successfully influence World Health Organization's polio policy by comparing short- and long-term trade-offs of eradication and control policies. SD has also been used to study the diffusion of technologies, such as evolving medical devices (Homer, 1987), agricultural innovations (Fisher et al., 2000) and alternative fuel vehicles (Struben and Sterman, 2008).

This paper focuses on a case study of a type of HWTS – the biosand filter (BSF), implemented by a non-governmental organization (NGO) – DHAN Foundation. An SD computer model was built and calibrated to represent the DHAN BSF programme.

The DHAN biosand programme

DHAN Foundation is an NGO based in the city of Madurai, Tamil Nadu state, India. DHAN promotes innovations such as micro financing, small-scale irrigation, and drinking water technologies for poverty alleviation. DHAN has about 700 staff and an annual budget of about US$4.0 million (DHAN, 2011).

DHAN initiated a BSF programme in 2005 in response to the poor drinking water quality in its operating region. By June 2012, the programme has expanded to 100+ villages. Of the 20,000+ households in these villages, about 3,600 households have purchased filters at a 70% subsidised rate (i.e. paying US$6 for a US$20 filter).

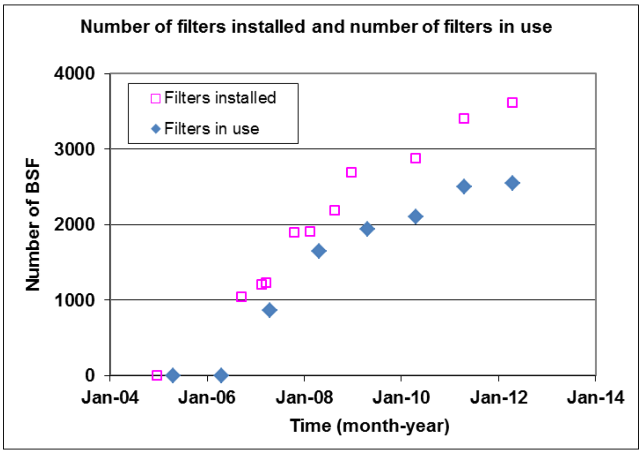
A BSF, as shown in Figure 1, is an adaptation of the traditional slow sand filters, but is smaller (about 1 m tall, 0.3 m wide on each side) and adapted for intermittent flow, making it suitable for use in people's homes. The filter is filled with layers of specially selected and prepared sand and gravel. To operate the filter, contaminated water is poured into the top of the filter. Pathogens and suspended solids are removed through biological and physical processes that take place in the sand, including mechanical trapping, predation, adsorption, and natural death. Treated water exits from the filter at the outlet by gravity. It takes about an hour to filter a bucket of water of 12-18 litres (CAWST, 2013). Field trials of the filter in multiple countries showed it can remove at least 99% protozoa, 90% bacteria, and 70% viruses, resulting in 40-50% reduction in diarrheal disease (Sobsey et al., 2008). The filter is robust and lasts for 20+ years without requiring any replacement parts (CAWST, 2013).

DHAN identified several challenges to the BSF programme. Figure 2 shows the number of filters installed and in regular use for the period 2004-2012, based on DHAN's records. While the number of filters installed continues to increase, the trend is tapering. It is because DHAN is increasingly reluctant to continue subsidising filters, yet households are unwilling to pay full prices for the filters. The BSF is newly introduced to this region of India. Households have hardly seen their neighbour using the filter, and are unconvinced of the benefits the filters can potentially bring. However, the filter production cost is high due to low sales volume, and thus the number of subsidised BSFs that can be offered by DHAN is limited. It is unclear to DHAN management whether the price should be adjusted upward or downward or stay the same. Second, many households discontinue filter usage after several months. Only about 70% of all filters installed are in regular use. Some of the reasons include lack of knowledge on proper operation and maintenance (O&M), not observing health benefits, and filter breakage. DHAN can spend more funds towards awareness generation, education, household visits, and filter repair but this will divert funds away from the filter subsidy. Third, there are conflicting opinions on whether the programme should be expanded to more villages in order to increase BSF adoption. Restricting the geographic area can reduce staff and household visit costs, but may limit the number of potential households reached. Finally, DHAN staff is generally unfamiliar with the BSF technology, as there is an inadequate budget towards staff training. Consequently, activities such as village education workshops are often ineffective to convince households to continue using their filters.

The primary aim of this investigation was to examine what programme implementation strategies DHAN should follow to maximise the number of filters in continued use, regardless of the number of villages covered. Specifically, this study investigated how programme resources should be allocated among various priorities and what the optimal price for the filters should be.

Figure 1. BSF installed by DHAN.

Figure 2. BSF installed and in use, 2004-2012.



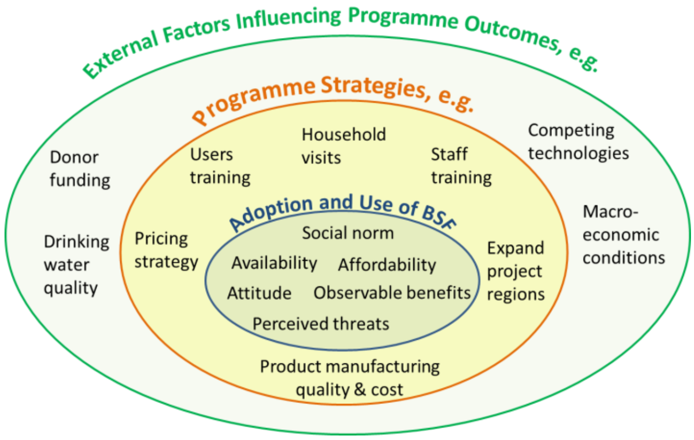
DEVELOPMENT OF A SYSTEM DYNAMICS MODEL

The modelling process consists of four stages operated iteratively, including conceptualisation, formulation and calibration, validation, and analysis (Sterman, 2000; Luna-Reyes and Andersen, 2003)

Model conceptualisation

The first stage is to conceptualise the SD model by clearly articulating its purpose, identifying the system to be studied and its structure. The purpose of the model is to assist DHAN in identifying programme implementation strategies to increase the adoption and sustained use of BSF. Considering the model purpose, and insights from NGO management literature (de Graff, 1987; Fowler, 1997; Lewis, 2007), the boundary of the model, as shown in Figure 3, was chosen to include (a) an inner core of interrelated factors and processes influencing the adoption and use of BSF at the household level, (b) a middle layer of various potential programme implementation strategies that DHAN can conduct to influence BSF adoption and use, together with how the effectiveness of these strategies can be influenced by the adoption and use of BSF at households, and (c) certain major external, exogenous factors believed to significantly influence programme outcomes, such as the ongoing efforts by governments to expand access to improved water supplies.

Figure 3. Component and processes included in the model.



Information needed to build the model was collected from both the literature and field visits to India. Literature relevant to accelerating the process of technology diffusion was reviewed (see Introduction section), and formed a foundation for model conceptualisation and formulation (Brooks and Tobias, 1996).

Field visits to India consisted of 25 and eight interviews to individual key informants and focus groups, respectively, including programme managers, projects staff, community workers, local authorities, manufacturers, and household members. All interviews were semi-structured, with the help of an interpreter for translation where necessary. All interviews were conducted according to applicable ethical guidelines. Because interviewees typically do not talk in feedback terms, the interviewees' response was written down on a portable whiteboard, mostly in pictorial format, with arrows and feedback loops added where possible. The whiteboard was shown to the interviewee at all times. This allowed the interviewees to appreciate and understand feedback loops, to start answering in feedback terms, and to correct any misinterpretation. This also helped to formalise the model structure.

Information was also collected through attending village meetings, visiting manufacturing sites, inspecting filters at households in various communities, and reviewing BSF programme records and historical trends. During field visits, recorded notes and data were continually reviewed, interpreted, and compared, often against theoretical constructs, to look for patterns and stories that cut across the material elicited.

The information collected covered many aspects, such as supply chain, human resource, technology performance, users' awareness, perceived benefits, willingness to pay, and donors' interest. Triangulation, standardised data-recording format, thick description, and interviewee confirmation were employed to enhance data reliability (Creswell, 2003).

Model formulation and calibration

The next modelling stage was to formally build a quantitative model. The software used was Vensim PLE Plus for Windows version 5.8b, academic version, release date 15 October 2008, produced by Ventana Systems, Inc, Massachusetts, USA.

Models are simplifications of the reality, and therefore three criteria were used to determine whether a component is to be included in the model. They were (1) whether a component falls within the system boundary, (2) whether the level of detail is appropriate, and (3) whether a component is mentioned by two or more independent sources. Components were linked endogenously where possible and appropriate, and populated with data extracted from documents and interviews. Some components remained exogenous in order to simplify the models, such as population growth rate, which can be reasonably assumed not to be influenced by the relative success or failure of the BSF programme.

Decision rules linking components were specified based on logic, credibility of the evidence and validity under normal and extreme conditions (Barlas, 1996). Common formulations from existing modelling literature such as fractional rates and dimensionless indexes were often used. For example, *filter production cost = reference production cost × effect of economy of production scale × effect of production experience*. Care was taken to ensure units were properly preserved during calculations.

Calibration was conducted by adjusting parameter values within their plausible range of uncertainty, in order to obtain a good 'fit' between model outputs and actual historical trends. The reference mode is the number of filters in use for the period 2004 to 2012, derived from DHAN's household visits records. Using a historical programme budget spending as input, the model reproduced a very good fit of this reference mode.

Model structure

The model[1] consists of 4 major sub-systems, namely (1) household status, (2) demand, (3) technology, and (4) institutional factors. Figure 4 shows the sub-system on household status, adapted from social psychological models (Prochaska and DiClemente, 1982; Rogers, 2003) and confirmed by field visits. There are 3 rectangular boxes connected by double-lined arrows. Starting on the left, as DHAN expands the BSF programme to cover additional villages and regions, more potential adopter households (HH) are added to the box 'HH under BSF programme'. If these households are willing to purchase filters, then they are moved to the box 'HH using BSF'. However, households may stop using the BSF for three major reasons. First are low observable benefits or minor technical problems that the users cannot solve. In this case, the households are dissatisfied and moved to the box 'HH stopped using BSF'. Households may resume using their filters if they receive technical support from DHAN, or are re-motivated through education messages and/or peer pressure. The second reason to stop using the filters is breakage. While the filter is designed to last 20+ years, poor production quality can significantly reduce filter durability. Third, households may stop because they have moved house and are unwilling to bring the 100 kilogramme filter with them. In these last two instances, the household is moved back to the box 'HH under BSF programme'. They have to purchase a new filter again in order to become BSF users.

Figure 5 shows the sub-system #2 (demand), and its interaction with the previous sub-system. A filter sale will occur when a household's willingness-to-pay (WTP) equals to or exceeds the filter price set by DHAN. WTP is an endogenous parameter dependent on the availability of improved water sources and the perceived need for water treatment, knowledge of the existence, features, operation, and benefits of the BSF technology, perceived attractiveness of the BSF versus other water treatment technologies, word of mouth (WOM) recommendation by filter-possessing peers, and household income.

In the full model (not shown here), households without filters are actually further divided into three groups based on the estimated income distribution among households: (Group A) HH not willing to pay even the subsidised price, (B) HH willing to pay subsidised price only, or (C) HH willing to pay full price. Only households that are willing to pay either the subsidised price or the full price can make a purchase. When subsidy is available, both group B and C households purchase at the subsidised price. Purchase of subsidised filters ceases when there is no buyer, or when the subsidy fund is exhausted. In the latter case, group C pays the full price, while group B waits until additional subsidy fund is made available.

[1] Model available on request from the authors.

According to interviews and field data, at the beginning of the BSF programme in 2005, when knowledge of the BSF was limited, filter attractiveness was uncertain, word of mouth was zero, and micro-financing was unavailable, 50% of the households were willing to pay up to Indian rupees (INRs) 190 per filter (~US$ 4/filter).

Figure 4. Sub-system 1 shows the filter usage status of households.

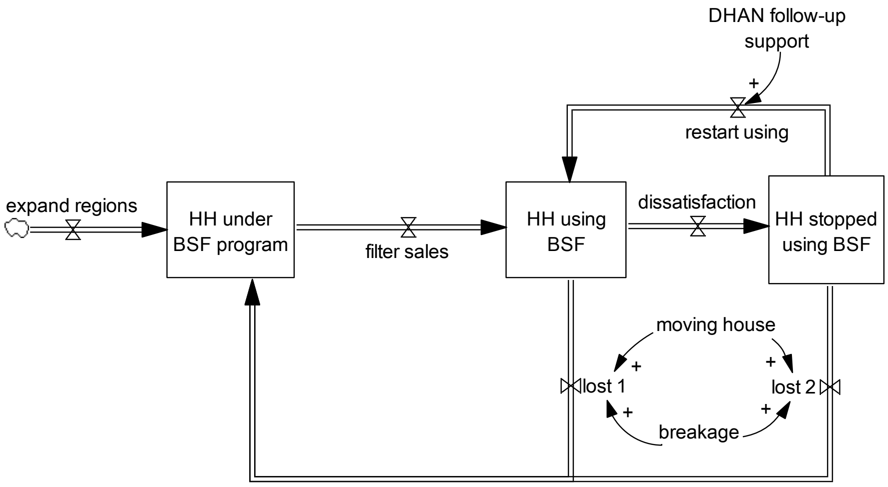
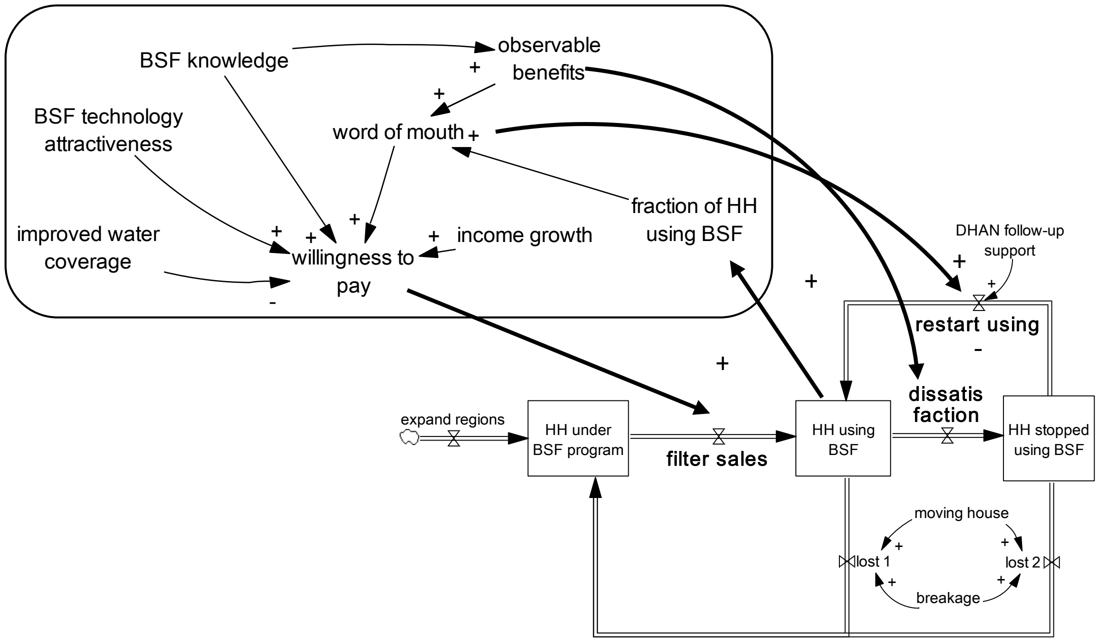


Figure 5. Sub-system on filter demand (#2) and its interaction with sub-system 1.



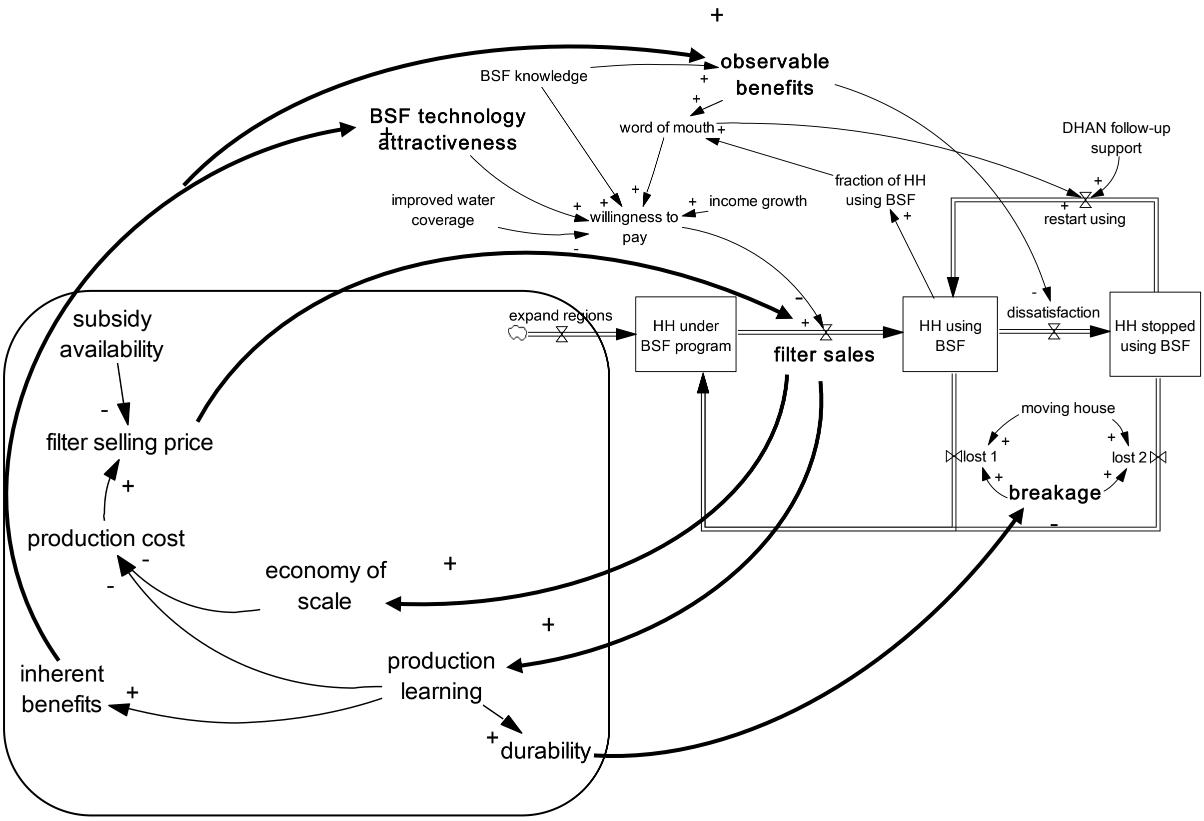
Word of mouth (WOM) is determined by the fraction of HH who are current users, the level of observable benefits experienced by these users, and the frequency of contact and the level of trust between peers. Households which have never used a BSF do not impact word of mouth. There is no evidence from the field visits that households which have stopped using the BSF contribute to negative WOM, nor WOM influences discontinuance. Discontinuance is dependent only on observable benefits.

Observable benefits are favourable outcomes observed by the filter users. The extent of benefits observed is dependent on the inherent technical quality and performance of the filter, and the knowledge of households to correctly operate and maintain the filters. Because observable benefits are not always realised by households immediately, the model considers a six month perception delay time.

There are two important reinforcing feedback loops. First, as more people purchase filters and become regular users, WOM would strengthen, leading to higher willingness to pay by potential adopters, and subsequently increasing sales. Second, as WOM strengthens, people who have previously stopped using the filter will more likely restart using again due to peer pressure. This increases the number of people using the filter, and further increases WOM strength.

Figure 6 shows the sub-system on BSF technology and its interaction with previous sub-systems. Filter selling price is set by DHAN and is influenced by the production cost, and whether filter subsidy is available. There are a number of important reinforcing feedback loops. First, as filter sales increase, economy of production scale can be achieved through bulk purchase of raw materials and bulk transportation, which lowers the production cost, allowing DHAN to set the selling price lower.

Figure 6. Sub-system on technology (#3) and its interaction with previous sub-systems.

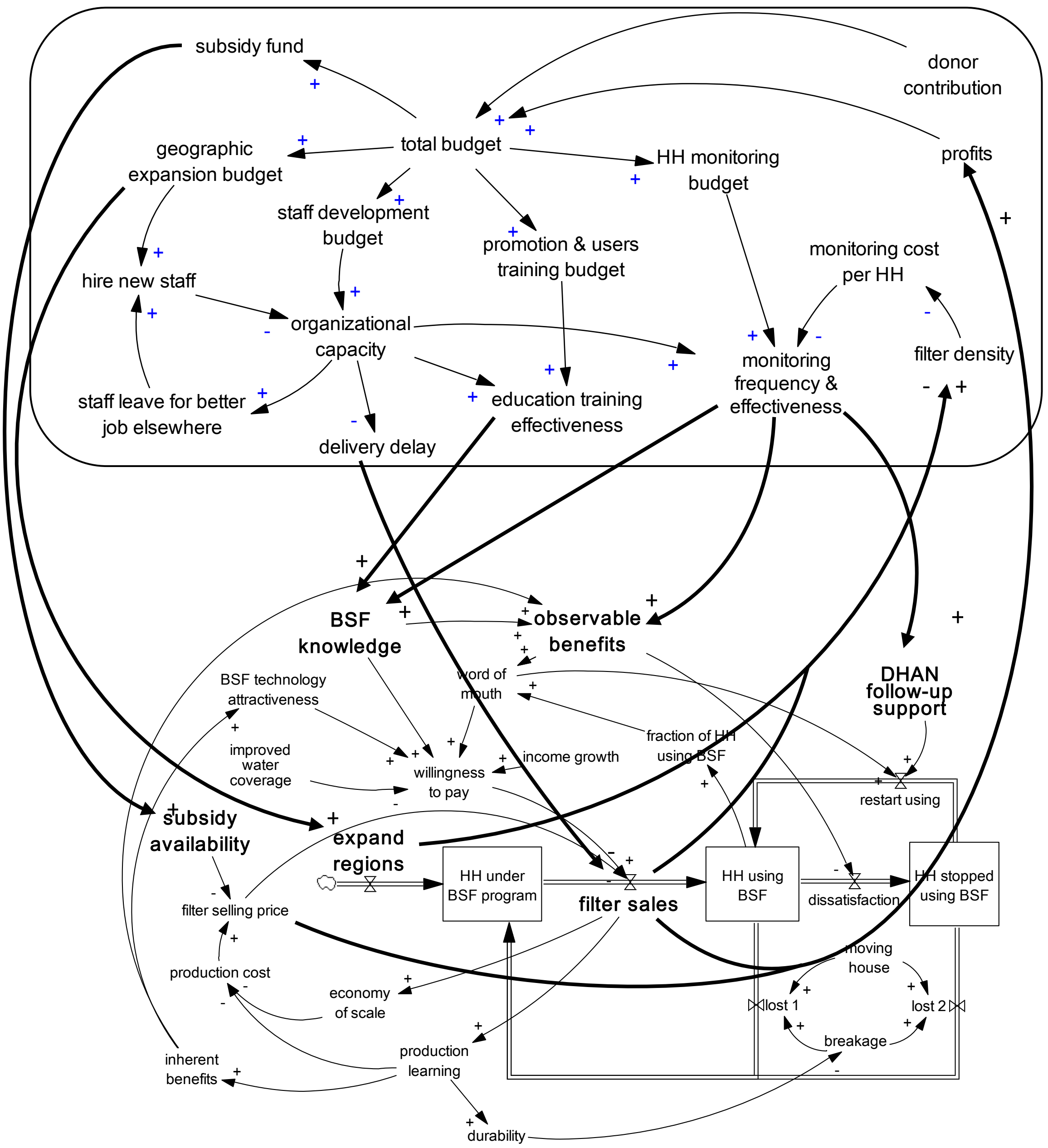


Increase in sales also allows production workers to gain experience in optimising production processes and quality, leading to reduced production cost, improved durability and reduced breakage. Lower breakage means higher portion of household using filters, impacting WOM and ultimately filter sales.

Moreover, improvements in production quality lead to higher BSF technology and attractiveness, and WTP by potential adopters results in higher sales. Finally, improvements in production quality lead to higher observable benefits, which reduce dissatisfaction and discontinuance, increasing the number of people using the filters, WOM, WTP, and ultimately sales.

The fourth sub-system includes DHAN programme implementation and institutional components. Figure 7 shows the sub-system and its interaction with previous sub-systems. The total budget available to the BSF programme is the sum of potential profits from sales (i.e. selling price higher than production cost), and donor funding. During the course of this study, the authors made several serious attempts to make donor funding endogenous. There are many factors affecting donor funding such as their resources availability, perception of BSF, DHAN's reputation, DHAN's advocacy capacity, and national and regional politics. Because this is quite complex and many relationships are not well-defined, donor funding is considered exogenous as a simplifying assumption.

Figure 7. Sub-system on institutional factors (#4) and its interaction with other sub-systems.



DHAN can choose to spend the total budget in a number of ways, with different consequences. They include (1) providing a subsidy fund to make the BSF more affordable, (2) expanding programme geographic region and hiring more staff to cover more villages and potential adopters, (3) building knowledge and skills of existing and newly hired staff in order to increase their work effectiveness, and reducing delivery delays (4) conducting education and awareness activities to villagers on the importance of safe drinking water, and (5) conducting households monitoring visits to reinforce health messages, ensure proper BSF operations, and troubleshoot problems, leading to higher observable benefits and users satisfaction, and encouraging households that have stopped using their filters to restart using them. The effectiveness of monitoring depends on the monitoring budget, monitoring cost per household, and staff capacity.

How DHAN chooses to spend the budget is a balancing act. If DHAN spends a higher proportion of its funds on a particular activity, inevitably DHAN has to spend a lower proportion of its funds on another activity.

An important balancing loop within this sub-system is that as the staff capacity and effectiveness increase, they are more likely to leave DHAN to find better jobs with higher pay elsewhere. It is DHAN's policy to replace them with new, inexperienced staff, which lowers the overall organisational capacity.

Another important feedback loop is related to filter density. Density increases when more filters are sold, and decreases when the project region expands. The higher the density, the lower the monitoring cost per households, which leads to higher monitoring effectiveness and higher filter usage and ultimate sales through WOM.

The last important feedback loop is related to profits. If DHAN can manage to sell filters with a profit margin, then profits earned would feed into the overall programme budget, allowing DHAN to expand its programme activities.

Model validation

The model was validated such that its outputs can be reasonably trusted for policy analysis. Eight common SD model verification tests were conducted during subsequent visits to DHAN, including boundary adequacy test, model structure test, parameter relationship test, dimensional consistency test, extreme behaviour test, integration error test, historical match test, and sensitivity test (Barlas, 1996; Sterman, 2000). Through these tests, logical flaws, formulation errors and inconsistent assumptions were found and corrected.

The model was able to reproduce behaviour that matched the trends of a separate, independent dataset from the manufacturing records regarding the number of filters produced, number of filters installed, and filter production cost. About half of all input parameters were found to have low sensitivity (i.e. even if the values are at the extreme of their plausible ranges, the model behaviour remained robust). For more sensitive parameters, additional information was sought and further calibration was conducted to justify their numerical values.

Model analysis – Interventional strategies

The model simulated programme outcomes from January 2005 to January 2023 with intervention strategies applied from January 2013 onwards. The success indicator was chosen to be the number of filters in use at two and ten years after applying the intervention strategies, regardless of geographic location. NGOs often have to demonstrate short-term results to donors; therefore, comparing programme outcomes at two years is reasonable from an operational perspective. However, because households must continually use BSF over the long term to sustain health benefits, and the impacts of some strategies become evident only after several years, comparing outcomes at ten years can adequately capture these longer-term dynamics and potential trade-offs.

Five different resources allocation strategies (current, expansion, awareness, capacity, and distribution) and four different pricing strategies (70% subsidy, 30% subsidy, full cost, and 30% profit) were considered. In combination, these yielded 20 unique intervention strategies (see Table 1), of which 18 were tested (S-1 to S-18), and two were deemed irrelevant as explained below.

Table 1. Eighteen unique intervention strategies were tested.

Strategies	70% subsidy	30% subsidy	Full cost	30% profit
Current	S-1	S-2	S-3	S-4
Expansion	S-5	S-6	S-7	S-8
Awareness	S-9	S-10	S-11	S-12
Capacity	S-13	S-14	S-15	S-16
Distribution	S-17	S-18	n/a	n/a

Note: n/a = Not applicable

The 'current' strategy is a continuation of the historical trend of rapid expansion to new regions, with limited new users' education and staff training. The budget allocation towards the six categories of activities from January 2013 onwards is the same as the historical average (see Table 2). The 'expansion' strategy aims to reach more potential adopters by introducing the BSF to more regions faster. In contrast, the 'awareness' strategy aims to consolidate education and promotion efforts in existing regions. The 'capacity' strategy attempts to increase the competency of the field workers, by emphasising slow programme expansion and hiring, and intensified staff training. In the 'distribution' strategy, more resource is allocated towards the subsidy fund, such that more subsidised filters can be offered.

Table 2. Resource distribution for different allocation strategies.

	Expand region (%)	Promotion (%)	New user training (%)	Monitoring (%)	Staff development (%)	Subsidy (%)
Current	15	5	5	5	5	65
Expansion	25	5	5	5	5	55
Awareness	5	5	15	15	5	55
Capacity	5	5	5	5	25	55
Distribution	7.5	2.5	2.5	2.5	2.5	82.5

In the '70% subsidised' pricing strategy, DHAN continues the historical trend of offering subsidised BSFs at a 70% discount of the production cost. In the '30% subsidised' pricing strategy, the discount is reduced to 30% starting January 2013. In the 'full cost' pricing strategy, all households must pay full cost. In the '30% profit' pricing strategy, filters are sold at full cost plus a 30% mark-up. The profits earned are injected back to the overall programme budget to be spent. Because a subsidy fund is no longer needed under the 'full cost' and '30% profit' strategies, resources allocated to expand region, staff development, promotion, new users' training, and monitoring are increased proportionally. The distribution strategy is not relevant for the 'full cost' and '30% profit' options and thus these two combinations were not tested.

Model analysis – Scenarios

The 18 potential implementation strategies were tested under seven different scenarios. These scenarios were designed to reflect wide uncertainty in how the circumstances external to the BSF programme may plausibly evolve. These scenarios were also chosen because they offer revealing insights on how DHAN should design more effective programme implementation strategies suitable to the external circumstance. Table 3 shows the assumptions used in the baseline scenario. Table 4 shows the setup and key difference of the seven scenarios.

Table 3. Assumptions of the baseline scenario.

Parameter	Description	Value for 2013-2023	Justification
Donor funding level	Average monthly funding to the BSF programme	45,000 INRs/month plus inflation adjustments	Average historical funding was about INRs45,000/month (US$900/month).
Inflation rate	Average annual inflation rate	+7.2%/year	The average annual inflation rate in India from 1991 to 2011 was 7.4% (IMF, 2012).
Income growth	Average annual income increase for rural households	+11.8%/year	The average annual GDP growth per capita in India from 1991 to 2011 was 11.8% (IMF, 2012).
Improved water coverage	Average increase in coverage of improved water supplies	+1.0%/year	The average annual increase in improved water coverage in rural India from 1990 to 2010 was 1% (UNICEF and WHO, 2012).
Alternative technology benefits	The benefits derived from alternative technologies	+6%/year	New technologies are developing quickly, which may overtake the BSF in the future.
BSF inherent benefits	The benefits derived from a BSF	+4%/year	BSF technology will continued be researched and developed by the worldwide scientific community.

Table 4. Key difference between the seven scenarios.

Scenarios	Donor funding level (per month)	Inflation (per year)	Income growth (per year)	Improved water coverage (per year)	Alternative technology benefits (per year)	BSF inherent benefits (per year)
A	US$900	+7.2%	+11.8%	+1.0%	+6%	+4%
B	US$225	+7.2%	+11.8%	+1.0%	+6%	+4%
C	US$3600	+7.2%	+11.8%	+1.0%	+6%	+4%
D	US$900	+7.2%	+9.5%	+1.0%	+6%	+4%
E	US$900	+7.2%	+16.4%	+1.0%	+6%	+4%
F	US$900	+7.2%	+11.8%	+1.0%	+3%	+8%
G	US$900	+7.2%	+11.8%	+1.0%	+12%	+2%

Scenario A (baseline) assumes that historical trends related to the technology, external circumstances, and actions by others will continue in the future. It further assumes the income growth in rural areas of India will be equal to the national average GDP growth.

Scenarios B and C explore variations and uncertainty in future donor funding. Scenario B assumes a hypothetical situation in which funding from January 2013 onwards is only 25% of the baseline. Scenario C assumes funding is four times the baseline.

Scenarios D and E explore variations and uncertainty in future macroeconomic conditions. In the baseline, the real purchasing power, calculated by subtracting inflation rate from the income growth rate, is +4.6%. Scenario D considers the income growth in rural areas is only +9.5%, which give a real purchasing power growth of 2.4% – half the baseline. Scenario E assumes the income growth in rural areas to be higher than the national average, giving a real purchasing power growth of 9.2% – twice the baseline.

Scenarios F and G explore the effects of technology performance and competition. Scenario F assumes alternative technologies are introduced by private sector at a rate of half the baseline, such that the alternative technology benefits increases at +3%/year. Moreover, enhanced BSF research and development will double the rate of increase in BSF performance to 8%/year. Scenario G assumes competition accelerates to twice the baseline, and BSF research slows to half the baseline.

SIMULATION RESULTS

Altogether 126 runs were simulated to systematically test all possible combinations of 18 strategies in seven scenarios to be implemented starting January 2013. The goal of the simulation was to provide insights to DHAN on what strategies would work better than others under various situations, and the underlying reasons.

Refer to the Appendix for the full details on the numbers of filters in operation at two and ten years into the future, for each scenario. Table 5 summarises the best strategy in each scenario. It shows that if programme success is gauged at two years, the combination of awareness focus + 30% subsidy (S-10) is often the best strategy. In contrast, if success is gauged at ten years, the best strategy is highly dependent on the context. The simulations reveal many insights into choosing effective strategies.

Table 5. The best strategy ranked after two and ten years for all scenarios.

Scenario	After two years		After ten years	
A: Baseline	S-10	(awareness and 30% subsidy)	S-10	(awareness and 30% subsidy)
B: Low funding	S-18	(distribution and 30% subsidy)	S-9	(awareness and 70% subsidy)
C: High funding	S-10	(awareness and 30% subsidy)	S-2	(current and 30% subsidy)
D: Low income growth	S-10	(awareness and 30% subsidy)	S-9	(awareness and 70% subsidy)
E: High income growth	S-10	(awareness and 30% subsidy)	S-3	(current and full cost)
F: Low competition	S-10	(awareness and 30% subsidy)	S-5	(expansion and 70% subsidy)
G: High competition	S-10	(awareness and 30% subsidy)	S-17	(distribution and 70% subsidy)

Choosing a short-term strategy

In terms of resources allocation, the 'awareness' strategy produces the best outcomes under most scenarios. Intensive education activities in a reduced number of villages resulted in households becoming motivated to correctly operate the filters. They observe high levels of benefits, and are unlikely to stop using the filters. As filters are concentrated in fewer villages, the monitoring cost per household is low. Together with a higher monitoring budget, the frequency of household visits is high, and users who had stopped using their filters are much more likely to restart using their filters.

In the 'current' and 'expansion' strategies, which focus on expanding the programme coverage, the resource per household becomes diluted resulting in insufficient promotion, user training, and household visits to support users on correctly operating the filters. Fewer benefits are observed and households become disappointed and discontinue usage.

The 'capacity' strategy is successful in building up staff competency to convince households to adopt the BSF. Delivery delays are reduced, and stopped users are more likely to restart because of effective troubleshooting and persuasion. However, staff training takes time; thus this strategy lags behind the awareness strategy.

The 'distribution' strategy results in high filters sales and use over the short-term due to the higher number of subsidised filters offered. Yet, as the resource is diverted away from users’ education and training, households receiving filters lack proper knowledge to operate and maintain the BSF, leading to technical problems and dissatisfaction. An interesting exception is scenario B in which project funding is so low that the limited promotion, education and monitoring activities fail to generate any significant interest among households to adopt or restart using their filters. Therefore, the awareness strategy in this case marginally lags behind the distribution strategy.

In terms of pricing, a 30% subsidy is slightly more effective than a 70% subsidy. This is because there are currently many households interested in obtaining BSFs. Most of them can pay the 70% subsidised price, and some can pay the 30% subsidised price. Yet, none is willing to pay full cost. However, due to the limited amount of subsidy funds, the number of filters that can be offered at a 70% discount is small. Therefore, if the filter discount is only 30%, then the subsidy fund can be stretched to offer a higher number of subsidised filters.

Choosing a long-term strategy

Under the baseline scenario (A), the awareness strategy continues to be successful. In addition to the reasons mentioned earlier, a long-term benefit is the increasing number of satisfied users in every village, strengthening word of mouth (WOM) effects. Potential buyers are convinced by peers, and are willing to pay higher prices. Full price purchase begins to accelerate soon after 2015. The increase in sales then activates three reinforcing loops. The first is more sales, leading to economy of production scale, lower price, and subsequently more sales. The second is more sales, leading to production learning and process optimisation, resulting in lower price and higher quality, and subsequently more sales. The third is more sales, leading to higher filter density, lower monitoring cost per household, higher household visit frequency, resulting in users’ higher observable benefits, satisfaction and continued use, and subsequently strengthened WOM, higher WTP and higher sales.

However, by 2018, users’ training and monitoring cannot keep up with the rapid sales. Households increasingly lack adequate knowledge on proper BSF O&M, and are having problems with their filters. Also, because of the restriction in the expansion of the programme region, BSF sales slowdown as programme villages become increasingly saturated with BSF.

The 'capacity' strategy slightly lags behind the awareness strategy for two reasons. Because DHAN’s BSF staff spend only 10% of their time on BSF-related activities (90% on other projects due to the way DHAN is structured), it is more efficient to increase household awareness and filter use simply by spending more towards promotion and users training, rather than indirectly through staff training. Moreover, as staff become competent, they leave DHAN for better jobs elsewhere, and are replaced by inexperienced staff.

The current, expansion and distribution strategies remain unsatisfactory due to the same reasons discussed under short-term strategy. Households lack conviction and knowledge to properly use BSF.

Many users encounter O&M problems, yet there is inadequate DHAN support in fixing the problems. Users are dissatisfied and discontinue quickly.

In the low-funding Scenario (B), all strategies produce appalling outcomes. The lack of promotion, awareness and monitoring leads to filter problems not being fixed, resulting in high discontinuation rates, lower sales and high production costs. Selling filters cheaply together with user education (i.e. awareness + 70% subsidy strategy) produces marginally better results. In contrast, under a high funding Scenario (C), it is important not to concentrate too much resources and activities to too few potential adopters, or else the resources are 'wasted'. For example, both 'awareness' and 'capacity' strategies suffer from market saturation – almost everyone in the programme villages have already adopted, so further awareness and education are unnecessary and cannot increase filter use. Instead, spreading the abundant resources over many villages (i.e. 'current' and 'expansion' strategies) is more effective. Moreover, because the available subsidy fund is excessively large, DHAN can afford to set the price low, encouraging adoptions from lower-income households, strengthening WOM effects, driving further household sales and use in villages newly covered by the expanding programme.

The best strategies for difficult economic times (Scenario D) are those that lower the affordability barrier for potential buyers (i.e. lower price), or those that enhance potential buyers' WTP (i.e. awareness generation). In contrast, when income growth is high, (Scenario E), it is possible to charge higher prices and still expect high sales and use. Full cost pricing is better than a 30% subsidised pricing because most households can afford full cost anyway; thus eliminating the subsidy altogether means funds can be used to strengthen other programme activities. However, a 30% profit pricing is found to be too expensive. Because filters are affordable, expanding the market size (i.e. current and expansion strategies) leads to more purchase and use. An interesting counter-intuitive result is that increasing purchasing power has shown to reduce filter satisfaction. The model explained that increasing purchase power results in earlier purchase of BSF by the majority of households. However, these earlier versions of the filters are technically less superior to the later versions, thus many households may experience few benefits and become dissatisfied with their filters over the longer term.

As the relative attractiveness of BSF versus other options increases (Scenario F), potential buyers become more interested and are willing to pay higher prices for BSF. Current users are less likely to discontinue, and are more successful in convincing their peers to adopt BSF. When current users move house, they will attempt to move the filters with them, rather than to leave the filters behind, creating an impression to peers that the BSFs are valuable assets. In this situation, there is little advantage to raise BSF awareness by distributing more BSF in existing villages. Instead, expanding the programme areas to make the filter more widely available is more effective to increase filter use. Perplexingly, despite continual technology development, in some of the simulation runs, users are not observing higher benefits. The model explains that these cases generally involve very few or no filter sales. Technology advancements do not increase households' observable benefits unless these improved filters are widely distributed and used at households. Another noteworthy finding is that as filter durability increases, breakage is reduced, thus replacement sales are reduced, impacting sales.

The accelerated introduction of increasingly effective alternative (Scenario G) produces opposite results to Scenario F. Potential adopters become less interested in obtaining BSF, and current users are more likely in discontinuing BSF in favour of other options. Giving away the largest number of filters at low prices through a distribution strategy is shown to be most effective in increasing BSF use. However, it can be argued that increasing the BSF use in this situation is not necessarily desirable. It may be better for households to adopt alternative options that can provide more health and other benefits, and are indeed more appropriate, aspirational and sustainable. Therefore, this scenario highlights a challenge in NGO management. The choice of success indicator(s) determines what strategies should be taken. Yet, different stakeholders may have very different values on what is success, and the actions or strategies by a stakeholder to achieve its version of success may undermine another's effort. Potential solutions for this challenge may lie in partnerships, shared vision, cooperation and coordination.

Summary of results and tipping point dynamics

In many of the simulation runs that produce successful programme outcomes, there is a point at which the system behaviour and trajectory change suddenly. The consequence is rapid increase in sales and use that is seemingly unstoppable. This point is often referred to as the 'tipping point' (Gladwell, 2000). In this study, it occurs when full price purchase begins, can be reached by a multiplicity of pathways, as expected from complex systems (Bossel, 2007). Examples include increasing disposable income, acquiring sufficient knowledge, technology improvements, production optimisation, or capacity building. Some pathways can lead to the tipping point earlier than others. The above analysis demonstrated insights on how to choose strategies to reach the tipping point more efficiently in different scenarios, and how to avoid undesirable outcomes.

In all cases, once this point is reached, a number of beneficial reinforcing loops are then activated to initiate and sustain the rapid sales. Some of these mechanisms include filter density, WOM, economy of scale, production learning, and filter quality. The growth rate eventually slows down as balancing mechanisms such as inadequate post-purchase support and restricted market size start to dominate.

The implication is that DHAN should not be limited to one, but should consider the multiple pathways to tipping point, and choosing the most efficient pathway(s) according to the situation. Once the tipping point is reached, then DHAN should seek to remove as many of the limiting factors as possible. A successful execution of this plan requires clear appreciation of the diffusion dynamics, together with an effective programme monitoring and evaluation system to allow the management to implement timely strategies.

RECOMMENDATIONS

The optimal choice of strategy is dependent on what is considered success, the time-frame (e.g. short-term or long-term), and how the future context may evolve (e.g. will India's rapid economic growth continue and trickle down to these communities?). Assuming a hypothetical condition that (1) the baseline scenario is valid for the next ten years, (2) it is desirable to increase the number of BSF in operation at ten years into the future, and (3) the structure of the BSF programme remains unchanged, then it is possible to formulate a 'recommended' strategy to increase BSF in operation over current practice.

First, programme expansion should be restricted. Instead, emphasis should be placed in maintaining high knowledge and favourable conviction among households, enhancing users' satisfaction, reducing discontinuance, and increasing adoption and use. Training of new users tends to be more cost-effective than monitoring to generate knowledge, and therefore should be a priority. Moreover, synergy is created by training field workers to effectively educate and motivate households. Although it may seem non-intuitive, the model shows that restricting the programme area actually results in a larger number of people using the filters – from the start – than if the programme expands rapidly.

When full price purchase starts, a different set of strategies should be pursued to remove as many growth barriers as possible. The programme should be expanded to reach additional households. Yet, expansion should be gradual, in order not to hire many new staff at once, undermining average staff capacity. Staff competency can be increased through knowledge-sharing between senior and newer staff. Facilitating visits by households in the new regions to long-term regular users in older regions can help to establish interest and motivation, leading to enhanced WTP and adoption. Subsidy should be gradually eliminated, and the filter price should increase to match with median WTP. The ultimate goal is a financially and institutionally self-sustained programme in which users not only pay for the filter cost, but also for education, monitoring and management.

Table 4 shows that the recommended strategy is expected to significantly outperform the current strategies (current focus + 70% subsidy), not only in terms of number of filters in operation, but also at the rate of regular use and filter production cost.

Table 4. Comparing results between the recommended with current strategies.

	Current	Recommended
Net change in filters in operation in January 2023 compared to January 2013	+727	+29,540
New filters sold between Jan 2013 to Jan 2023	3361	44,561
% of filters in regular operation in Jan 2023	66%	85%
Filter production cost in Jan 2023 (INRs/filter)	3198	2633

CONCLUSIONS

This study is about how NGOs can improve their programme implementation strategies in order to increase the adoption and sustained use of household water treatment, focusing on a case study of DHAN's biosand filter programme in India. This is an important and timely question and although HWT has been demonstrated to substantially improve water quality at the point of use, there is inadequate understanding on how to effectively manage an HWT programme to increase practices. Unless HWT are practised consistently and correctly by at-risk populations, health benefits and well-being that can be potentially derived from HWT cannot be fully realised.

This study contributes to the current knowledge by challenging the conventional wisdom of seeking uniform policy prescriptions that can be applied across a majority of countries or programmes (Edwards, 1999; UNDP, 2010). Instead, the best strategy is dependent on context, echoing the argument by Lantagne et al. (2009) that there is no universally considered best HWTS technology, but the most effective option for any particular situation must be chosen in consideration of local consumer preference, economic situation, cultural practices and water quality. Consequently, it can be argued that the diversity of the context from which hundreds of millions of people without safe water cannot be easily addressed by only a few large programmes or strategies, but will necessitate a variety of smaller, niche organisations implementing unique, context-specific, and locally appropriate technologies and strategies.

The study demonstrated that small NGOs can dramatically increase their programme outcomes without necessarily increasing their organisational size or operational budget, as argued by Uvin et al. (2000), so the collective efforts of many effective small NGOs can be substantial.

In addition to clarifying the conditions under which each of the implementation strategies can be effective for the DHAN-BSF programme and possibly other HWTS programmes, the study also demonstrated the complexity of programme management. For example, model results showed that the best strategies to increase adoption and sustained use of BSF over the short term are often different from those for the longer term, thus creating tension as to what strategies should be followed by a programme manager. A reason for this tension is that some strategies have a long lead time before the beneficial outcomes are realised. In certain scenarios, distributing highly subsidised filters in new villages to generate household interests does not lead to higher sales for quite some time, until the number of filters sold is sufficiently high to reach critical mass, after which sales accelerate rapidly. Therefore, programme managers are challenged on how to justify implementing a seemingly ineffective strategy that does not provide optimal short-term outcomes, but is highly effective over the long term (i.e. a worse-before-better strategy). This is particularly challenging in an international development environment in which short-term outcomes are more highly valued by donors than longer-term impacts.

Another challenge of programme management is counter-intuitive results. For example, under certain scenarios, allocation of extra subsidy funds resulted in a few filters sold. In other scenarios, expanding market size resulted in lower sales. Often such unexpected behaviour is due to the structure of the system – there are multiple mechanisms at work. Allocation of extra funds towards subsidy can lead to a short-term boost in filter sales, but over the long term due to diversion of funds away from more important activities such as users' training and monitoring visits, households become dissatisfied, and non-adopters are thus unconvinced, resulting in overall lower sales than if the extra funds had not been allocated toward subsidy. Therefore, programme managers must look beyond the obvious and must balance short- and long-term dynamics.

This work is limited to strategies within the control of NGOs, rather than investigating how different stakeholders should coordinate their strategies to accelerate HWTS practices. This was a deliberate choice intended to enrich the depth and usefulness of the policy analysis relevant to NGOs, the intended audience of this work.

A major assumption of this study is the authors' belief that the BSF is desirable when implemented properly in regions where the pre-existing drinking water quality is poor. This work does not set out to test whether the BSF is effective in reducing water-borne contaminants, or to test whether adoption and sustained use constitute a prerequisite to health and achieves sustained outcomes in other areas such as education, employment and household finance.

Another limitation of this single case study is the *generalisability* of the finding to other types of agencies (e.g. UN-agencies, governments, private sector) implementing other types of HWTS (e.g. SODIS, chlorine) in other countries or settings (e.g. urban). While some of the study findings are likely to be applicable widely (e.g. the importance of user education and follow-up monitoring, the unintended consequences of lowering prices, the surprisingly negative results of technology improvements, and the challenges of a single-technology focused programme); some findings are likely case-specific (e.g. offering filters at 30% subsidy for the first two years, spending 5% of budget on staff training).

A major limitation of SD is that models typically represent complex systems at a rather abstract level, and tend to omit many finer details. Moreover, many social phenomena may not be easily reduced to mechanistic mathematical equations necessary to build the model. Often, approximation based on logic and common sense is used. Nevertheless, all models are simplified representations of reality, and usefulness of a model lies in the fact that they simplify the reality into a form that is comprehensible (Sterman, 2002). Furthermore, the overall model behaviour and relative performance of different strategies are often surprisingly resilient to a large range of uncertainty in parameter values (Meadows et al., 2005). Therefore, while the numerical values are considered only approximately, the overall broad brushes on system behaviours and trends are often adequate to contribute to, or to complement other methods for sound policy analysis.

While SD was a helpful tool for this particular study in understanding how feedback structure produces adoption behaviour, and in revealing some key project programme management challenges, including the trade-off between optimising short- or long-term gains, and counter-intuitive results other methods such as agent-based modelling, regression analysis, control trials, and ethnographic study could be more suitable to deal with other aspects of the HWTS implementation challenge. Thus, both the analyst and the clients should understand the applicability and limitations of SD before embarking on this analytical technique. SD technique is effort-intensive and difficult to master. Building SD models to analyse programme strategies is more suitable to researchers and consultants, but probably not for NGO programme managers. However, once a model is built, it can be used in training simulations to effectively teach NGO staff the complexity and consequences of field decisions.

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REFERENCES

Ajzen, I. 1991. The theory of planned behaviour. *Organizational Behaviour and Human Decision Process* 50(2): 179-211.

Andreasen, A.R. 1995. *Marketing social change: Changing behaviour to promote health, social development, and the environment*. San Francisco, USA: Jossey-Bass Publishers.

Barlas, Y. 1996. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review* 12(3): 183-210.

Bass, F.M. 1969. A new product growth for model consumer durables. *Management Science* 16(8): 215-227.

Bossel, J. 2007. *Systems and models: Complexity, dynamics, evolution, sustainability*. Norderstedt, Germany: Books on Demand GmbH.

Brooks, R.J. and Tobias, A.M. 1996. Choosing the best model: Level of detail, complexity, and model performance. *Mathematical and Computer Modelling* 24(4): 1-14.

Brown, L.A. 1981. *Innovation diffusion: A new perspective*. New York, USA: Methuen.

CAWST (Centre for Affordable Water and Sanitation Technology). 2013. What is a Biosand Filter? www.cawst.org/en/resources/biosand-filter (accessed 12 July 2013)

Clasen, T. 2009. *Scaling up household water treatment among low-income populations*. Public health and environment: Water, sanitation, hygiene and health. (WHO/HSE/WSH/09.02) Geneva, Switzerland: World Health Organization.

Christensen, C.M. 1997. *The innovator's dilemma: When new technologies cause great firms to fail*. Boston, USA: Harvard Business School Press.

Creswell, J.W. 2003. *Research design: Qualitative, quantitative, and mixed methods approaches*. 2nd edition. Thousand Oaks, USA: Sage.

De Graff, M. 1987. Context, constraint or control? Zimbabwean NGOs and their environment. *Development Policy Review* 5(3): 277-301.

Devine, J. 2009. *Introducing SaniFOAM: A framework to analyse sanitation behaviours to design effective sanitation programs*. Washington, DC, USA: The World Bank.

DHAN Foundation. 2011. Annual report 2011. Madurai, India: DHAN.

Edwards, M. 1999. NGO performance – What breeds success? New evidence from South Asia. *World Development* 27(2): 361-374.

Enger, K.S.; Nelson, K.L.; Clasen, T.; Rose, J.B. and Eisenberg, J.N.S. 2012. Linking quantitative microbial risk assessment and epidemiological data: Informing safe drinking water trials in developing countries. *Environmental Science and Technology* 46(9): 5160 – 5167.

Fisher D.K.; Norvell, J.; Sonka, S. and Nelson, M.J. 2000. Understanding technology adoption through system dynamics modelling: Implication for agribusiness management. *International Food and Agribusiness Management Review* 3: 281-296.

Fowler, A. 1997. *Striking a balance: A guide to enhancing the effectiveness of NGOs in international development.* London: Earthscan.

Gladwell, M. 2000. *The tipping point: How little things can make a big difference*. New York: Back Bay Books.

Graf, J.; Zebaze Togouet, S.; Kemka, N.; Niyitegeka, D.; Meierhofer, R. and Gangoue Pieboji, J. 2010. Health gain form solar water disinfection: Evaluation of a water quality intervention in Yaounde, Cameroon. *Journal of Water and Health* 8(4): 779-796.

Heierli, U. 2008. *Marketing safe water systems: Why it is so hard to get safe water to the poor – and so profitable to sell it to the rich*. Berne, Switzerland: Swiss Agency for Development and Cooperation.

Homer, J.B. 1987. A diffusion model with application to evolving medical technologies. *Technology Forecasting and Social Change* 31(3): 197-218.

IMF (International Monetary Fund). 2012. World economic outlook database, October 2012. Washington, DC, USA: International Monetary Fund.

Kotler, P.; Roberto, N. and Lee, N. 2002. *Social marketing: Improving the quality of life*. 2nd edition. Thousand Oaks, USA: Sage.

Lantagne, D.S.; Meierhofer, R.; Allgood, G.; McGuigan, K.G. and Quick, R. 2009. Comment on 'point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world'. *Environmental Science and Technology* 43(3): 968-969.

Lewis, D. 2007. *Management of non-governmental development organizations*. 2nd edition. London, UK: Routledge.

Luna-Reyes, L.F. and Andersen, D.L. 2003. Collecting and analyzing qualitative data for system dynamics: methods and models. *System Dynamics Review* 19(4): 271-296.

Mason, K.O. 1997. Explaining fertility transition. *Demography* 34(4): 443-454.

Meadows, D.H.; Randers, J. and Meadows, D.L. 2005. *Limits to growth: The 30-year update*. London: Earthscan.

Meierhofer, R. and Landolt, G. 2009. Factors supporting the sustained use of solar water disinfection: Experiences from a global promotion and dissemination programme. *Desalination* 248(2009): 144-151.

Miller, D. and Garnsey, E. 2000. Entrepreneurs and technology diffusion: How diffusion research can benefit from a greater understanding of entrepreneurship. *Technology in Society* 22(2000): 445-465.

Mowles, C.; Stacey, R. and Griffin, D. 2008. What contribution can insights from the complexity sciences make to the theory and practice of development management? *Journal of International Development* 20(6): 804-820.

Murray-Johnson, L.; Witte, K.; Boulay, M.; Figueroa, M.A.; Storey, D. and Tweedie, I. 2001. Using health education theories to explain behaviour change: A cross-country analysis. *International Quarterly of Community Health Education* 20(4): 323-345.

Myers, D.G. 2005. *Social psychology*. 8th edition. Boston, USA: McGraw-Hill.

Ngai, T.K.K. 2011. How small non-governmental organizations can improve their program implementation strategies to increase the adoption and sustained use of household water treatment systems in the developing world. PhD thesis. University of Cambridge, England.

Null, C.; Kremer, M.; Miguel, E.; Mullainathan, S. and Zwane, A. 2009. How to get safe water: Persuasion, peers, price, promoters, or product? *Amercian Journal of Tropical Medicine and Hygiene* 81(5): 305-306.

Prochaska, J.O. and DiClemente, C.C. 1982. Transtheoretical therapy toward a more integrative model of change. *Psychotherapy: Theory, Research and Practice* 19(3): 276-287.

Rogers, E.M. 2003. *Diffusion of innovations*. New York, USA: Free Press.

Sobsey, M.D.; Stauber, C.E.; Casanova, L.M.; Brown, J.M. and Elliott, M.A. 2008. Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environmental Science and Technology* 42(12): 4261-4267.

Sterman, J. 2000. *Business dynamics: Systems thinking and modelling for a complex world*. Boston, USA: McGraw-Hill.

Sterman, J. 2002. All models are wrong: Reflections on becoming a system scientist. *System Dynamics Review* 18(4): 501-531.

Struben, J. and Sterman, J.D. 2008. Transition challenges for alternative fuel vehicle and transportation systems. *Environment and Planning B: Planning and Design* 35(6): 1070-1097.

Thompson, K.M. and Duintjer-Tebbens, R.J. 2008. Using system dynamics to develop policies that matter: Global management of poliomyelitis and beyond. *System Dynamics Review* 24(4): 433-449.

UNDP (United Nations Development Programme). 2010. *Human development report*. New York, USA: United Nations Development Programme.

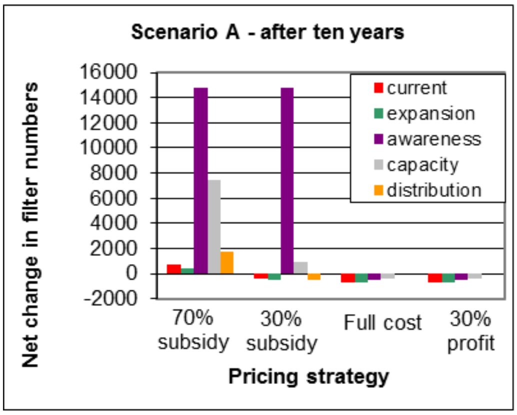
UNICEF (United Nations Children's Fund) and WHO (World Health Organization). 2012. *Progress on drinking water and sanitation 2012 update*. Geneva, Switzerland: United Nations Children's Fund and the World Health Organization.

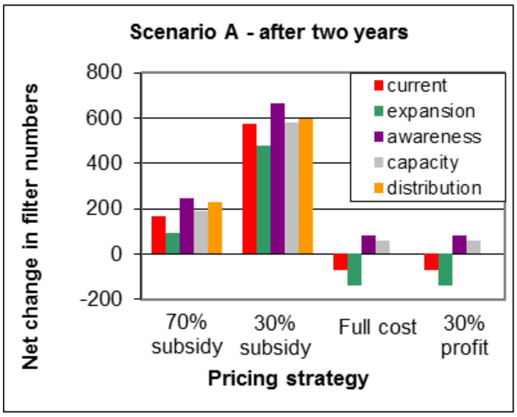
Utterback, J.M. 1996. *Mastering the dynamics of innovation*. Boston: Harvard.

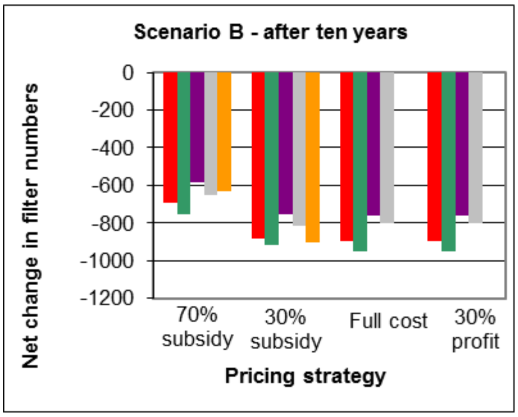
Uvin, P.; Jain, P.S. and Brown, L.D. 2000. Think large and act small: Toward a new paradigm for NGO scaling up. *World Development* 28(9): 1409-1419.

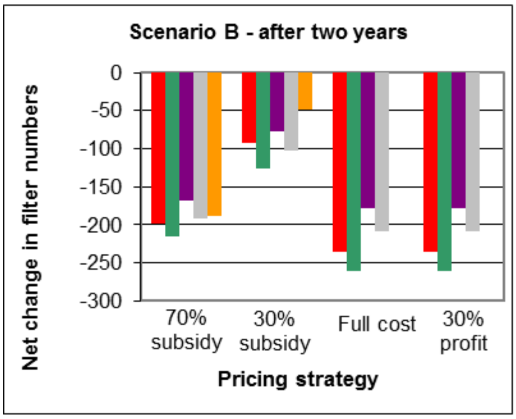
APPENDIX

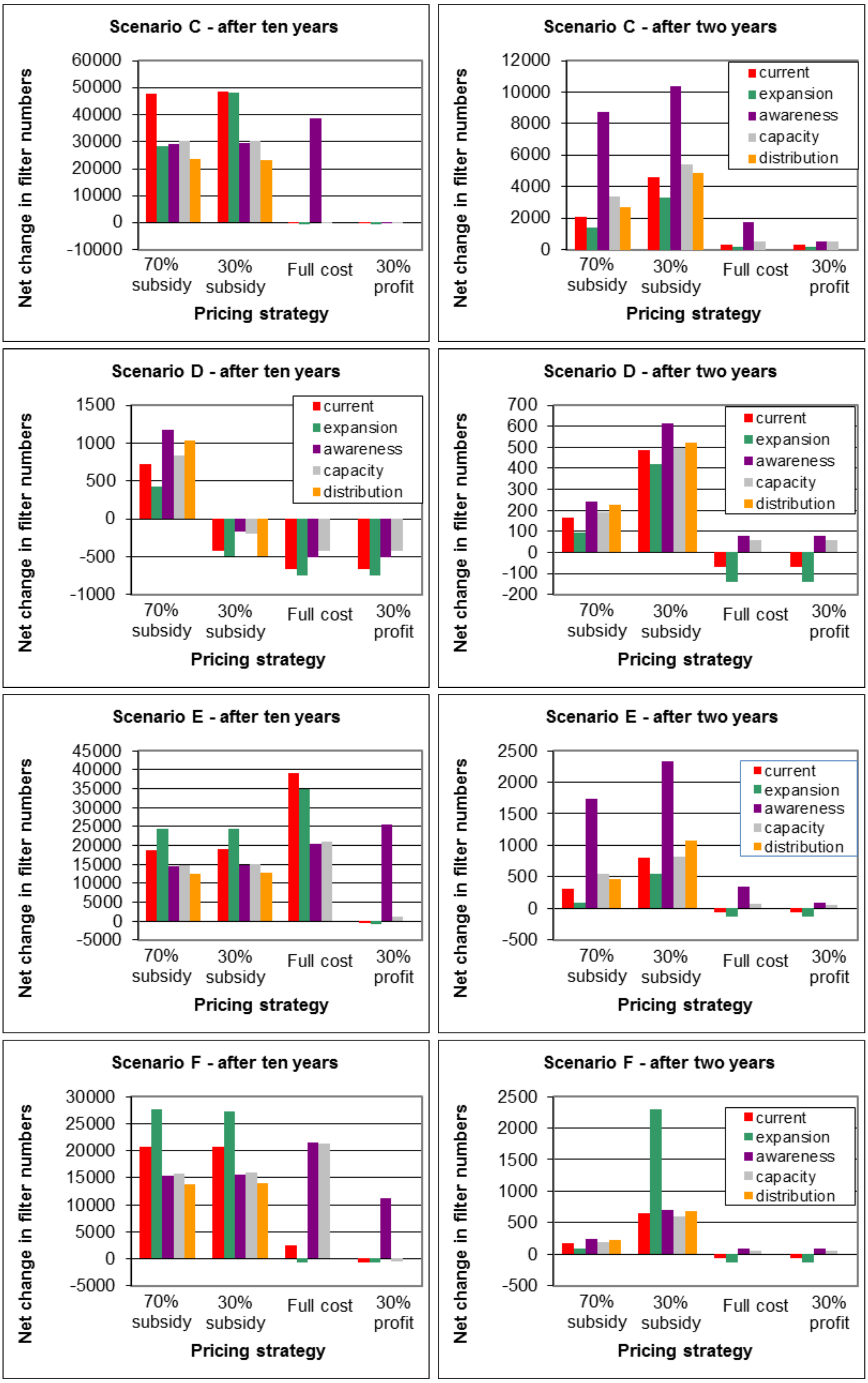
The following bar graphs show the results of the simulation runs. In each graph, the Y axis shows the net change (net increase or net decrease) in the number of filters in operations. Those graphs titled 'after two years' refer to the net change between January 2013 and January 2015. Those titled 'after ten years' refer to the net change between January 2013 and January 2013. There are 18 bars in each of the graphs, representing 18 strategies. These 18 strategies are grouped by pricing for easier comparison. For example, the first bar from the left refers to a current + 70% subsidy strategy, and the second bar from the left refers to an expansion + 70% subsidy strategy.

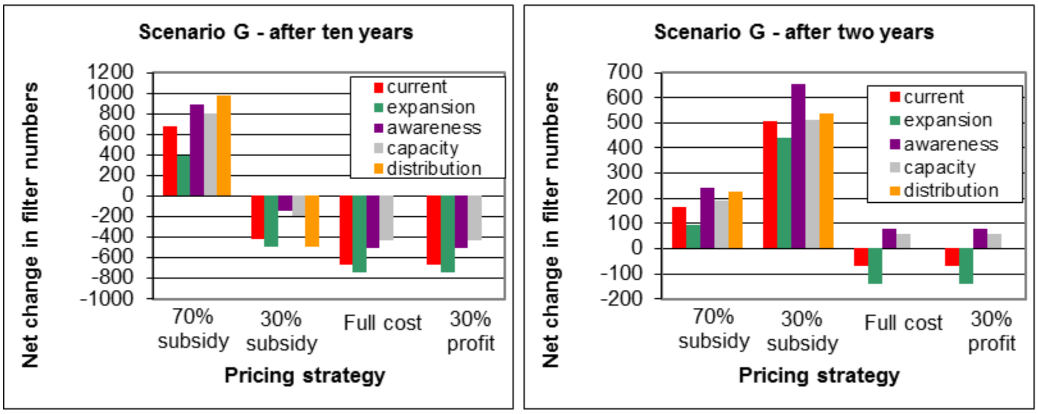









Scenario C - after ten years
Scenario C - after two years
Scenario D - after ten years
Scenario D - after two years
Scenario E - after ten years
Scenario E - after two years
Scenario F - after ten years
Scenario F - after two years
Net change in filter numbers
Pricing strategy
70% subsidy
30% subsidy
Full cost
30% profit
current
expansion
awareness
capacity
distribution


Scenario G - after ten years
Net change in filter numbers
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
current
expansion
awareness
capacity
distribution
70% subsidy
30% subsidy
Full cost
30% profit
Pricing strategy
Scenario G - after two years
Net change in filter numbers
700
600
500
400
300
200
100
0
-100
-200
current
expansion
awareness
capacity
distribution
70% subsidy
30% subsidy
Full cost
30% profit
Pricing strategy